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Juan Antonio Camiñas
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Alboran Sea - Ecosystems and Marine Resources

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Contents

About the Editors

José Carlos Báez is PhD in biology science from the University of Málaga (Spain). From 2017 to present, he has an official research position at the Spanish Institute of Oceanography and is a research affiliate at the University Autónoma de Chile (Chile). His research is focused on the ecology and conservation of marine megafauna, such as sharks, marine mammals, and sea turtles, and tuna fisheries management. He actively participates in monitoring the tuna fisheries operated by the Spanish fleet. He has published more than 122 scientific articles in peer-reviewed journals, of which 63 are scientific journals indexed in Journal Citation Reports by Clarivate Analytics. Many of these published studies are based in the Alboran Sea and its marine ecology. He has been a scientific advisor in reports requested by FAO and the European Union, including the Alboran fisheries and its impact on marine megafauna and the tuna fisheries. Currently, he is member of the International Union for Conservation of Nature's (IUCN-SSC) Marine Turtle Specialist Group, and he is also a member of the board of directors of the Spanish Herpetological Association (AHE), from where he collaborates and advises various national administrations on the conservation of sea turtles. In addition, he is an active member of different working groups of the Regional Fisheries Management Organizations (RFMOs), such as ICCAT and IOTC. He participated as scientific advisor for the British Broadcasting Corporation (BBC) Natural History Unit, during the filming and production of the film *SHARKS*.

Juan-Tomás Vázquez is PhD in geological sciences from the Complutense University of Madrid (Spain) with the thesis "Structure of the Northern Margin of the Alboran Sea." Between 1986 and 1993, he was part of the Marine Geology Service of the **Instituto Geológico y Minero de España**. Between 1993 and 2007, he was professor at the **University of Cádiz** (Faculty of Marine and Environmental Sciences). In 2007, he joined the **Instituto Español de Oceanografía** as researcher. His research focuses on active tectonics and other active geological processes and structures: magmatism and fluid emissions, diapirism, submarine geomorphology (seamounts, canyons, and landslides), and tsunami triggering mechanisms in continental margins and ocean basins, developing this activity in marine regions around Iberia, Canary Islands, and the Antarctic. He has participated in 52 projects financed in national or European calls and in 74 **oceanographic expeditions** of national and international character, being in 28 of them scientific chief or co-chief. He has published more than 167 scientific articles in peer-reviewed journals, of which 63 are scientific journals indexed in Journal Citation Reports, 7 books, and 90 book chapters. He has been member of 8 UNESCO, 2 INQUA, 3 European, and 3 Spanish working groups. He was appointed by the Ministry of Foreign Affairs and Cooperation in 2003 to the advisory commission of experts in Marine Geology and Geophysics for the extension of the Continental Shelf of Spain in accordance with Article 76, paragraph 8 of the United Nations Convention on the Law of the Sea 1982. In addition, since 2008 he is the representative of the IEO in the Technical Scientific Working Group for the preparation of this study and has been a member of the delegations of Spain to the UN (CLCS) for the presentation of proposals for the Extension of the Limits of the Continental Shelf of Spain in the areas of Galicia and the Canary Islands.

Juan Antonio Camiñas PhD in biology from the Complutense University, is a retired scientist from the Spanish Institute of Oceanography (IEO). After more than 30 years at IEO, he became a FAO officer in February 2008 working at the organization until March 2015. During that period, he was the coordinator of two FAO Projects: CopeMed II (*Co-ordination to Support Fisheries Management in the Western and Central Mediterranean - CopeMed Phase II*) and ArtFiMed (*Sustainable development of the artisanal fisheries in Morocco and Tunisia*) aiming at fisheries sustainability in the central and western Mediterranean region. Director of the FAO CopeMed II headquarters in Malaga from 2008, he was member of the Fisheries and Aquaculture Department of the FAO.

Director of the IEO Malaga Marine Laboratory from July 1989 until 2008, he has been working as scientific advisor of the Spanish and the European Commission administrations on fisheries and fish biology issues; his main expertise is in the Mediterranean artisanal fisheries and the interactions of fishing gears with marine turtles and other species. As Spanish representative in the General Fisheries Commissions for the Mediterranean (GFCM) from the early eighties of the twentieth century, he was an animator for the transformation of the GFCM and elected the first Chairperson of the Scientific Advisory Committee (SAC) from 1994 to 2004. He was also a Spanish representative and member of the European Commission STECF (Scientific, Technical and Economic Committee of Fisheries).

Currently, he is member of the Board of Directors of the Academy of Sciences of Malaga and the Chairperson of the Spanish Herpetological Association AHE, both from 2016. He has been coordinating and participating in international marine research projects with the EU, working as consultant with IUCN and to FAO in northern Africa and as marine turtle's expert. He was one of the first Spanish members of the Species Survival Commission-IUCN's Marine Turtles Specialists Group (Mediterranean Region) and is a member and co-founder of the Spanish Network of Marine Turtle Experts in 2018, and he is currently participating in different projects aiming at improving the marine turtles knowledge and international management in collaboration with national and international organizations such as ACCOBAMS, AHE, GFCM, RAC-SPA, MAVA, and IUCN, ministries, and NGOs.

Author or co-author of nine books and author of chapters in 15 more, he has published numerous articles in national and international scientific journals concerning fisheries, marine biology and ecology, marine turtles interaction with fisheries, and awareness articles on his expertise.

Mohammed Malouli Idrissi is PhD in environmental economics and science and an expert on economics fishery aspects, especially on the Mediterranean side. Presently, he is the head of the National Institute of Fishery Research (INRH) in Tangier and a manager officer of the marine scientific program in the Moroccan Mediterranean. He has managed several scientific projects and programs in the Mediterranean, mainly on themes related to small-scale fisheries, Marine Protected Areas, the blue economy, and others.

Between 2014 and 2018, he was a head of the Marine Resources Department at INRH, and during this period, he actively contributed to the implementation of several Moroccan fisheries management plans, which aimed at preserving the main Moroccan fishery resources.

He also had professional experience within FAO between 2008 and 2011, as coordinator of a project on the development of artisanal fisheries.

At the regional level, he is a scientific delegate from Morocco in the Scientific Advisory Committee at the GFCM.

Malouli has published and contributed to the publication of several scientific articles.

Chapter 1
Introduction: Thinking the Future from Now

José Carlos Báez, Juan Antonio Camiñas, Juan-Tomás Vázquez, and Mohammed Malouli Idrissi

1.1 Why a Book on the Alboran Sea?

The Alboran Sea is a region that connects the Atlantic Ocean and the Mediterranean Sea, and is a natural border between Europe and Africa. But it is also a historical compendium of different cultures that extend their influence to the present. Thus, the name "Alboran" seems to come from the Tunisian pirate Al-Borany (Quirosa-Cheyrouze 2007), who used the island of Alboran as a base for his pirate fleet (Gutiérrez-Castillo 2003). Moreover, this region have a remarkable mythological burden that is due to having been considered in historical times as the limit of the known world, and find in it the mythical and legendary columns of Hercules that closed the knowledge Mediterranean during Phoenician, Greek, and Roman periods and called *Fretum Herculem* and *Fretum Gaditanum* by the Roman, meaning the Strait of Hercules and Strait of Cadiz. The Arabic literature from ancient times named Bab al-Zakak, the door of the alley. Today, all ancient significant names have been replaced by a geographical one, the Strait of Gibraltar. The two columns of Hercules could correspond with two elevations, one in the north, the Gibraltar rock, and one in the south, probably the Hacho mount in Ceuta. The two columns of Hercules remain in the official coat of arms of Spain.

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According to Bernal Casasola (2009) referring to the fishing activity in Alboran, which in the waters of the *Fretum Gaditanum* were carried out ostriculture and the elaboration of fishmeal and other by-products, all during the Late Antiquity. This author also underlines that Opiano in his Haliéutica, explains with many details the capture of cetaceans in this region meaning an explicit reference to the presence of whales in western waters of the Mediterranean. Opiano refers to this fishing as a collective action, which is compared to the attack on a city (V, 115–120).

The limits Alboran Sea depend of the geological, geomorphological, hydrological, or biogeographical criteria used (Talamo and Riera 2019), so do not correspond to each other, when using different criteria. According to the International Hydrographic Organization (1953), the limit of the Alboran Sea on the West is a line joining from the tip (Europa Point) of Cap Gibraltar in Europe to the tip of the Península de Almina of Ceuta in Africa (35°54′N 5°18′W), and limit of the East is a line joining from Cabo de Gata (South of Iberian Peninsula, Europe) to Cap Fegalo, near Oran, in Algeria, Africa (35°36′N 1°12′W). However, in a broad sense from a biogeographical point of view the Alboran Sea could include the entire channel of the Strait of Gibraltar to the south of Cabo de Palos in the East (details in Chaps. 2, 6, and 11).

This sea and the related sedimentary basins have been developed by extensional processes in the inner part of an arcuated orogeny, the Betics-Rif ranges, extended both in southern Spain and northern Morrocco in relation to the tectonic movements between the African and Eurasian plates. The current tectonic activity is evidenced by the high number of seismic events (Galindo Zaldivar et al. 2018). Seismotectonics and related processes as submarine slides and potential tsunami waves should therefore be considered as several important geohazard factors in this region (Álvarez-Gómez et al. 2011; Macías et al. 2015). Tectonics has generated a complex physiography (Vázquez et al. 2015), which has influenced the circulation of the water masses and the development of an important depositional contouritic system (Ercilla et al. 2016), an example worldwide given the character of this sea as a connection area between different water mass systems.

In a macroecological context, the Alboran Sea is a marine bridge that connects the Mediterranean and Atlantic populations, from microscopic plankton to the big marine mammals. The geological history has determined the presence of several endemisms. Currently, a unique mix of Mediterranean endemisms, boreal, and tropical organisms inhabits this transition zone. The main circulation of the Surface Atlantic Water in the Alboran Sea, characterized by two mesoscale anticyclonic gyres, represents an important hydrodynamic obstacle between its north and south shores. While this oceanographic pattern favors downstream connectivity, i.e., in the west-to-east direction, it constrains the cross-basin shore-to-shore connection. The surface circulation, however, shows frequent instabilities, involving the shedding of submesoscale eddies and filaments, which have realistic chances to cross the sea north to south, transporting biological material from one shore to the other, acting then as a conveyor band. In this context, the Alboran Sea shows rich biodiversity and productivity and, for many decades has been considered as a miniature ocean to study and understand marine structures, processes, and threats. The Alboran Sea shelters a great variety of natural resources and human activities including fishing, wildlife, research, transport, tourism that historically have been exploited by different countries, mainly by the coastal states. The Alboran Sea represents a regional Mediterranean space where North and South worlds merge, creating a geopolitical region where marine resources and maritime activities should be managed from both national and international perspectives.

1.2 Thinking the Future from Now

It is widely known that currently the planet is suffering a global change affecting the Alboran Sea, its ecosystems and populations. In this context, it is necessary to set a public baseline of the existing knowledge at present to be able to compare and monitor future changes. This book reviews different aspects of the Alboran Sea to help to understand the present situation from its origin. The first and important step to update a paramount vision on this region is to understand the climatic, geologic and oceanographic, including biochemical cycles, process which conform the rich geodiversity, biodiversity, the productivity, and the sustainable use of the marine resources. The fisheries management system should take into account regularly marine environmental variability to achieve biological sustainability of marine resources and consequently economic security to fishery-dependent stakeholders. Well-funded policy-makers' decisions require a sound scientific-based knowledge of the interaction between the marine environment and commercial stocks. This is because the role of marine environment in the evolution of fish stocks is sometimes even more important than the one played by fishers in the commercial exploitation of them. Finally, we should analyze the different aspects of political context that could affect the management of the resources from the Alboran Sea in the context of climate change. For this reason, and given the knowledge accumulated over the years on both shores of this sea and its resources, an updated review of the current state of knowledge is necessary.

The book could be divided into four blocks (1) oceanographic, geological, and ecological contexts (Chaps. 2–7), (2) biodiversity and ecosystems distribution (Chaps. 8–12), (3) fisheries resources and aquaculture (Chaps. 13–20), and (4) conservation, management, and marine policies (Chaps. 21–25).

1.2.1 Oceanographic, Geological, and Ecological Contexts

The first set of chapters corresponds to an introduction to the Alboran Sea from different specialties ranging from aspects related to political geography and legislation, both atmospheric and oceanographic dynamics, and their repercussions on climate, geological evolution, and processes currently dominant in the seabed and ecosystems.

Chapter 2 introduces the different dimensions of this maritime space from a geopolitical and transnational perspective. Legal aspects of geography and the different mentalities of the coastal states are considered in a united context of the North and South worlds, this merged geopolitical thought in the region should be necessary for the correct management of the marine resources and maritime activities.

Chapter 3 offers a general vision of the climatic regional variability in relation to atmospheric processes, which results from the numerous climatic mechanisms affecting the region in the context of north to south and west to east connections, both the large atmospheric circulation in the region and the control by the orography which produces the behavior of the Alboran Sea as a channel for the atmospheric marine boundary layer generating relevant mesoscale disturbances. The oceanographic dynamics is considered in Chap. 4, the Atlantic–Mediterranean waters exchange through the Strait of Gibraltar is the main factor that determines their circulation. The general circulation exhibits a dynamics energy alternating cyclonic and anticyclonic circulation cells. This pattern is forced by tidal dynamics and climatic conditions. Authors demonstrate that these changes affect the temperature and salinity trends of the water masses in the Alboran Sea, both factors to take into account for their impact on climate change at the regional scale and for the management of living resources.

Chapter 5 is devoted to the geodynamic evolution of this region, the dynamics of the Eurasian, African, and Iberian plates from the Upper Jurassic and the opening and closing of related oceanic basins. In this scenario, the westward drift of the Alboran Domain determined the formation of the Betic–Rif–Alboran basin system from the upper Oligocene. The region has been the area of connection between the western (Atlantic) and eastern oceans (initially Tethys and later western Mediterranean Sea) of Iberia. Chapter 6 analyses the seafloor in relation to processes, especially active tectonics, oceanographic and sedimentary dynamics, and their role as geohazards. Tectonic activity is focused between Adra-Cabo de Gata in southern Iberia and Al-Hoceima bay in northern Africa. Two main sedimentary environments are differentiated: shallow and deep margins. The deep environment is characterized by a wide contouritic depositional system and their interaction with turbiditic processes, canyons, landslides, and seamounts.

Finally, Chap. 7 considers the biogeochemical features and dynamics of the Alboran Sea as well as its effects on the marine planktonic community, focusing on the coupling between hydrodynamics, biogeochemistry, and phytoplankton. The Atlantic jet and the upwelling of Mediterranean waters richer in nutrients drive the system, stimulates the growth of phytoplanktons, and enhances the primary production, which makes the Alboran Sea the most productive basin of the Mediterranean Sea.

1.2.2 Biodiversity and Ecosystems Distribution

The second block of chapters addresses biodiversity and endemism in different ecosystems. Chapter 8 reviews the taxonomic, origin, history, and current conservation status of seaweeds and seagrasses populations. Chapter 9 offers a general overview of benthic habitats, as well as their associated biota from the Alboran Sea. Some of these habitats host very complex communities in comparison to similar ones that are located northwards in the Atlantic Ocean or eastwards in the Mediterranean Sea and the current conservation status of those habitats. Chapter 10 reviews the importance of invertebrates as the main components of Alboran Sea biodiversity, also include an analysis of current conservation status. Chapters 8, 9, and 10, together, provide an in-depth review of the status of benthic habitats, as well as of habitat-building species from the Alboran Sea. Chapter 11 analyses the biogeographical aspects (both historical and macroecological) that have favored a high biodiversity of species in the Alboran Sea. Chapter 12 is dedicated to patterns of linkage or isolation, which determine the very development and abundance of certain species within the Alboran Sea. Thus, the oceanographic peculiarities of the Alboran Sea are linked with the biological cycles of some species to explain these patterns.

1.2.3 Fisheries Resources and Aquaculture

Due to the high biodiversity of the region and high productivity, there is an important fishery activity in the area since historical times. The third block of chapters reviews the fisheries in the region.

Chapter 13 analyze the main causes of the decline of small pelagic fishes from the Alboran Sea. Chapters 14 and 15 are dedicated to the artisanal fisheries in Spain, northern Alboran Sea, and Morocco, southern part, analyzing the traditional gears deeply rooted in the region and the main target species, an essential element of coastal communities' activity, revenues, and culture. Currently, landings of sardine and anchovy in northern Alboran are low. Chapter 16 put the focus on the small pelagic fisheries of two species, Sardine and Anchovy, in the Northern Alboran Sea exploited by a Spanish purse seiner fleet based in a long historical series of landings from the 1940s to the present.

Chapter 17 revises main tuna fisheries carried out in Alboran currently by Morocco and Spain, and the effect of climatic oscillation such as the North Atlantic Oscillation on the tuna fisheries.

Demersal resources and their exploitation are reviewed in Chap. 18, based on the high biodiversity of the Alboran Sea, due to the confluence of fauna from the Atlantic and the Mediterranean biogeographic regions.

Blackspot seabream (*Pagellus bogaraveo*), an important commercially exploited fish for the Spanish and Moroccan fleets that operate in the Strait of Gibraltar is analyzed in Chapter 19. Chapter 20 raises the starting and current situation of industrial aquaculture in Morocco and Spain.

1.2.4 Conservation, Management, and Marine Policies

The last set of chapters addresses the aspects of resource management and conservation, as well as other economic, historical, and social aspects. Thus, the Alboran Sea is a relevant hotspot for marine megafauna (i.e., large pelagic sharks, sea turtles, seabirds, and marine mammals), which connected the Atlantic and the Mediterranean Sea. The overlap between various human activities—such as marine traffic or fisheries on the northern and southern coasts—as well as pollution entail the capture or mortality of marine megafauna. Chapter 21 reviews research approaches that could provide suggestions for the effective management of large marine megafauna.

In a framework of Driver-Pressure-State-Impact-Response in fishery management, and considering main driver a need for social and economic development in the region, Chap. 22 aims to analyze the socioeconomics of Alboran Sea fisheries as one of the main pressure over fish stocks and insight on fisheries management of the area in the context of an Ecosystem-Based Management Approach accounting for marine environmental conditions (climate variability and global warming) that influences the Alboran Sea ecosystem and consequently, fisheries.

Chapter 23 provided a historical review of the fishery on the Spanish sea coast since the conquest of the area by the Spanish Catholic Kings, until the twentieth century, and the beginning of marine research.

Chapter 24 reflects on lessons learned, gaps, and needs in marine research and provided with main actions to advance in international collaboration in ocean science, technology, and governance and harness its potential to meet societal needs, address global challenges, and drive sustainable development.

Finally, Chapter 25 reviews the Marine Protected Areas (MPAs), Key Biodiversity Areas (KBAs), and other preserved areas and provides a deep description of the existing habitats and species, and the tools used to the surveillance and mitigation against impacts.

1.3 The Future We Wish: Final Remarks

In bilateral or multilateral frameworks, international cooperation in the Alboran Sea and the Strait of Gibraltar regions aiming the scientific knowledge, conservation, and sustainable development has been constant during the last decades in the region. From the initial marine research activities carried out by Prince Albert I of Monaco and his team at the end of the nineteenth century, latterly followed during the twentieth century by the Spanish scientists from the IEO (Fig. 1.1) commanded by Odón de Buen, the subsequent international interest by different countries in doing

Fig. 1.1 Ancient fishing boat from the 1930s of the twentieth century in the Port of Malaga. Source: Own funds of the Oceanographic Center of Malaga (IEO)

research in the area, in particular the "¿Dónde va? Experiment" during the twentieth century, with the participation of an international team co-directed by the United States and Spain, or the recently Morocco's incorporation into the scientific arena in the region mainly through the creation of a research center in Nador and another in Tangier. This book comes to fill a tremendous gap in the synthesis of more than a century of multilateral research. Nevertheless, a challenge for sustainability science and sustainable development of a region is to promote new perspectives in the interaction between scientists and the other actors involved in the governance process. Science–Policy Interfaces (SPI), as social processes oriented toward the collaboration between scientists, decision makers, and the general public to enrich environmental governance, is revealed as an adequate approach (López Rodríguez 2016). SPI based on shared projects, joint declarations, and shared experiences are a common value in the Alboran region with several examples (Dónde va Group 1984; Kinder et al. 1983), an international consortium that studied the circulation of the western Alboran Sea and the Strait of Gibraltar, the adoption of the Intercontinental Biosphere Reserve of the Mediterranean in Andalusia (Spain)—Morocco (Molina Vázquez and Villa Díaz 2008) to establish a cooperation channel between the two countries, putting common efforts into the promotion of a model toward sustainable development favouring the preservation of the shared ecosystems, the I International Meeting on Conservation and Sustainable Development in the Alboran Sea held in

Malaga in 2007 and ratified in 2009 at the second edition of the meeting, held in the city of Oujda (Morocco) producing the Oujda Declaration (Robles 2010) to promote the creation of the "Alboran Network for Sustainable Development" to support a permanent surveillance system in the form of an Observatory for Conservation and Sustainable Development in the Alboran region, and the subsequent Alboran Poctefex Project (of the Cross-Border Cooperation Program, Spain—External Borders of the European Union).

Other scientific and management experiences involve other countries connected to the Alboran area with similar problems and solutions. Currently, new international programs, governance organizations, and other operators are putting their attention into the Alboran Sea region, an area that is not only a favorable region for cooperation but sometimes used as an example, although a realistic approach shows us the difficulties for the participation of some stakeholders in some participative process (Twomey and O'Mahony 2019).

As an example of where we go, the approach, cooperation, stakeholder's involvement, sharing knowledge, and improving capacities, the FAO regional project COPEMED (Coordination to Support Fisheries Management in the Western and Central Mediterranean) implemented in 1986, currently in its second phase, could be useful. COPEMED aims to strengthen technical and scientific capacities for fisheries assessment and management in the central and western Mediterranean, taking into account environmental, biological, economical, social, and institutional considerations. To this end, it promotes scientific cooperation among the coastal nations through common methodologies, standardized data-gathering as well as joint multidisciplinary analyses. Countries involved in COPEMED are EU and non-EU and three countries, Algeria, Morocco, and Spain, sharing the Alboran Sea are members of the project. The current phase of COPEMED started in 2008 aiming to build on the achievements of the first phase of the project (1996–2005) while strengthening an established framework of international cooperation, which fosters subregional approaches in fisheries research and management. The Project aims to maintain the sustainability of marine fisheries in the central and western Mediterranean Sea, taking into consideration environmental, biological, economical, and social issues, and aims to promote scientific cooperation among the coastal nations through coordinated scientific investigations and data gathering as well as joint multidisciplinary analyses. The Project will support national and regional fisheries management processes and take advantage of the scientific multidisciplinary knowledge that was developed during the first phase. The Project is reducing the differences in fisheries management between northern and southern countries of the region and tries to encourage a subregional approach in fisheries research and management.

The fishery research institutions of the region and the national management bodies benefit from the work of the Project. They will be in a better position to formulate fishery management and development strategies based on sound multidisciplinary knowledge of the sector. The national fisheries departments will be able to perform multidisciplinary data collections and analyses that will be used to formulate fisheries policies. There are mutual benefits for all concerned because of the strong cooperation among nations and with the General Fisheries Commission for the Mediterranean (GFCM) that will result. The ultimate beneficiary is the fishery sector—from resource users to the various stakeholders—which will rely on responsible and sustainable fisheries development and management.

Until the present, COPEMED has made progress in encouraging collaboration among national and regional scientific and fisheries management institutions, and has had a positive effect in the subregion and beyond.

To improve regional cooperation, recently the General Fisheries Commission for the Mediterranean (FAO-GFCM) adopted subregional structures to improve the management of fishery exploited resources. To such a new approach, a new office was created in Málaga (Spain) for the purposes of the Subregional Committee for the Western Mediterranean (SRC-WM).

Other examples of international cooperation (projects carried out by GFCM, FAO or UICN-Med does in Alboran Sea), can serve as regional incentives and to show the way forward. It is the joint effort, respect to the others, collaboration, and international cooperation that will allow us to create the necessary synergies for a common future.

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Chapter 2
Regional Context and Maritime Governance

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2.1 Introduction

The Alboran Sea's physical and geopolitical characteristics are what make this marine area generate governance structures that are both part of, and articulate, interests and demands on scales ranging from the international-global to the local levels, combining, as it does, immediate economic survival interests with conflicts of global complexity. Despite the fact that the surface area of this sub-basin only amounts to 3% of the Mediterranean Sea, the nature and complexity of the scenario make it stand out as far as both multilateral and bilateral international relations are concerned. A simple glance shows a combination of long-standing historical questions, such as territorial disputes on both shores and the extreme importance of maritime trade, and some conspicuous peculiarities, including the presence of some straits of great global importance, the convergence of vast economic disparities, and (the consequent) emigration. Despite the most defining features of this sub-basin (semi-confined waters, proximity of the two shores—and, at the same time, great socio-economic inequalities—and the intensity of some high impact uses) also being drivers of multilateral cooperation for the sake of more effective governance, the immensity of the differences and disagreements is a powerful obstacle to coordinated and acutely complex actions.

Although the Mediterranean Sea as a whole already has a long tradition of generating international cooperation instruments in maritime matters—the Mediterranean Action Plan was the first that was promoted under the United Nations

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Environment Plan (UNEP) regional seas programme—effective compliance with multilateral actions has been hindered by member States' economic, technological, and administrative limitations, which explains why many of the situations of environmental vulnerability that exist throughout the basin have worsened, including those in the Alboran region. Another factor that may have contributed to this process of deterioration is the fact that a large part of the Alboran's waters have remained outside national jurisdiction over recent decades (during which its coastal States' have experienced strong economic and population growth) as a result of exclusive rights not being declared in the application of the United Nations Convention on the Law of the Sea (UNCLOS). The only change to this has come in the last few years, with the area under the high seas regime being reduced to a third of the basin's total area.

In parallel with this, there has been a second, ongoing political and institutional process which, in contrast, has enabled the strengthening of coastal States' ability to govern the area due to the expansion of the EU. With the joining of new member-States throughout the whole basin, EU States now control some 35% of jurisdictional waters (57% in the Alboran), implying that the EU has a notable ability to implement its policies, including those of a military or environmental nature.

This chapter is divided into three main sections to analyse these aspects: the first addresses the region's geopolitical framework and identifies the extant political actors and political and socio-economic relations in the region. The second section examines the basin's legal regime in the context of the United Nations Convention on the Law of the Sea. Lastly, the third section focuses on examining maritime governance in the region, and on the policy instruments and practices involved in the administration of maritime sectors and the management of the disputes that exist both among coastal States and with third States.

2.2 Political Geography of the Region

In this chapter, the area covered by the Alboran Sea is taken as the eco-region defined in Spalding et al. (2007). Stretching from the Strait of Gibraltar to Cabo de Palos-Le Portet (Fig. 2.1), this region has a surface area of about 79,000 km^2, equivalent to 3% of the Mediterranean basin. The area is somewhat complex in jurisdictional terms, due both to its territorial make-up and the structure of the maritime spaces over which sovereignty and jurisdictional rights are exercised. Although all the States around its shores have declared EEZs, there are also some high sea waters due to Spanish law considering that the EEZ extends from Cabo de Gata, even though the seafloor and subsoil that underlie the water column form part of the Spanish continental shelf.

The largest jurisdiction corresponds to EEZ (41%), followed by territorial sea (32%) and High Seas (22%). In national terms, Spain is the State that presides over the greatest jurisdiction (Tables 2.1 and 2.2).

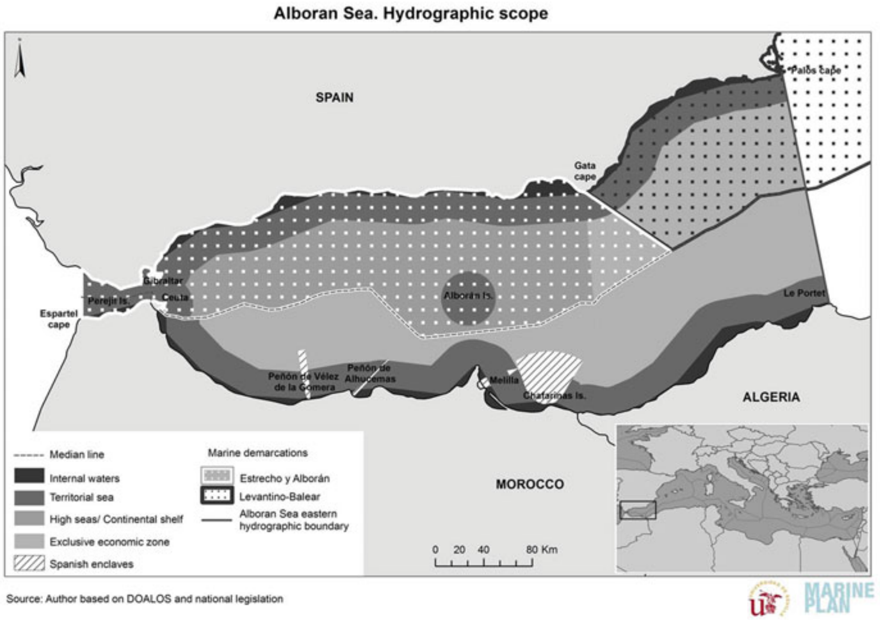

Fig. 2.1 Alboran Sea. Study area

Table 2.1 Alboran Sea. Jurisdictions by country

Country	Jurisdictions	Surface (sq. km)	Total surface (sq. km)
Algeria	Exclusive economic zone	11,133	16,591
	Inland waters	935	
	Territorial sea	4523	
Morocco	Exclusive economic zone	9552	17,642
	Inland waters	1245	
	Territorial sea	6845	
Spanish enclaves	Exclusive economic zone-Contiguous zone	793	44,814
	Inland waters-Territorial sea	97	
	Territorial sea-Contiguous zone	90	
	Territorial sea-Territorial sea	629	
Spain	High seas/Continental shelf	17,140	
	Exclusive economic zone	10,757	
	Inland waters	2069	
	Territorial sea	13,239	
	Total	79,047	79,047

Source: Author

Table 2.2 Alboran Sea. Surface by jurisdictional areas

Total jurisdictions	Surface (sq. km)	%
Inland waters	4346	5
Territorial sea	25,326	32
High seas/Continental shelf	17,140	22
Exclusive economic zone	32,235	41
Total	79,047	100

Source: Author

The Alboran Sea is a sub-basin of the western Mediterranean that lies between the Spanish and the North African coasts, and between the Algero-Provençal Basin and the rest of the western Mediterranean in the east, and the Strait of Gibraltar in the west. It is a clearly identifiable marine area due to a series of defining features (physical, geopolitical, economic etc.) and some conflicts and legal disputes over the multiple and heterogeneous use of a relatively small space for the coexistence of three States (Spain, Morocco, and Algeria), a colonial territory (Gibraltar) and a number of bases under Spanish sovereignty along the Moroccan coast.

The Alboran Sea's morphology (semi-enclosed sea), size (approx. 79,000 km^2: 3% of the surface area of the Mediterranean) and bathymetry accord it some very distinctive features, and its position in the westernmost sector of the Mediterranean enables it to communicate with the Atlantic Ocean through the Strait of Gibraltar.

Situated as it is between the coasts of Spain and the Moroccan and Algerian Maghreb, the Alboran Sea is 490 km (approx. 272 nm) long from east to west and 160 km (approx. 89 nm) wide from north to south.

2.2.1 *The Regional Context*

The Alboran sub-basin is framed in the westernmost part of the Mediterranean region as a whole, whereby it shares this wider region's geographical and physical features and also its human character. The entire Mediterranean is a semi-enclosed sea (as is the Alboran) and it is this particular morphological configuration which, on many occasions, exacerbates the various environmental (pollution, eroding coastal areas etc.) and human problems (conflicts and legal disputes between coastal States and with third States, border issues, and threats to regional security) (Naïr 1995, 1998; Bethemont 2000; Sanguin 2000) that are produced in its waters and on its shores. Notwithstanding, its size and morphology compel the States around its shores to strive for mutual understanding and regional cooperation, as geological features such as its enclosed morphology and the short distance between its shores are not only the cause of friction, but also give rise to the need to coexist and share the common space (Khader 1995; Aubarell 1999; Morillas and Blázquez 2009; López García and Hernando de Larramendi 2010; Beneyto 2010; Florensa 2017).

From the geopolitical and socio-economic viewpoints, the Alboran is basically an area where different and occasionally opposed socio-economic, cultural and strategic models collide. However, it is no less true that, apart from the problems found here [latent north/south tension and a broad and varied range of issues and complexities (unequal north/south development, political and cultural differences, frequently diverging geopolitical and strategic points-of-view, problems with sovereignty, migratory flows, competition for the various marine resources, and environmental issues]), the area also possesses a common historical legacy (Luciani 1984), which makes this space a bridge between Europe, the Maghreb and Sub-Saharan Africa.

A growing network of inter-State relationships has helped to usher in an interesting period of political dialogue between European countries (the former European Economic Community (EEC) and Arab countries (especially in the Maghreb) since the 1970s. Progress in this process of Euro-Mediterranean rapprochement has been embodied in the so-called Euro-Arab Dialogue and the EEC's Mediterranean Global Policy, both of which were unfortunately stalled, or at least put on hold, by the Gulf War (Amin 1994). Nevertheless, a parallel Euro-Mediterranean cooperation process has developed in the areas of the environment and science from the 1970s on: the MEDSPA programme, a range of scientific projects, the Environmental Programme for the Mediterranean, Euro-Mediterranean environmental and fisheries cooperation (the 1990 Nicosia Charter, the 1992 Cairo Declaration, the 1994 Heraklion Declaration) and, of course, the Mediterranean Action Plan and the Barcelona Convention, both of which were extended in 1995. This, what could be referred to as a 'maritime-environmental' foundation stone, took its place alongside the economic and political foundations represented by the Euro-Mediterranean Association, the Union for the Mediterranean and other political dialogues (dialogues initiated by NATO (the North Atlantic Treaty Organisation), the Western European Union (WEU) and the Organisation for Security and Cooperation in Europe (OSCE) with non-Mediterranean countries) (Khader 1995; Aubarell 1999; Núñez Villaverde 2005; Florensa 2017). Both these lines of multilateral action provided a degree of hope during turbulent historical times.

Despite many experts currently talking of the failure of the most ambitious Euro-Mediterranean initiatives, the possibility still exists of committing to instruments which, even though they seem to be more modest and limited to specific topics (science, the environment, fisheries etc.), are no less useful for that. The key to cooperation in the Mediterranean may lie in the search for common areas for the management of spaces and resources of natural and economic value (Grasa and Ulied 2000) rather than getting mired in interminable arguments about civilisation, culture and beliefs.

2.2.2 Countries and Territories: Geopolitical and Socio-economic Information

The waters of the Alboran Sea bathe the coasts of three States, one European (Spain) and two North African (Morocco and Algeria), as well as those of a number of ‘micro-territories’: one British colonial territory (Gibraltar) and several locations under Spanish sovereignty (major garrisons—Ceuta and Melilla—and some minor outposts—Peñón de Vélez de la Gomera, Peñón de Alhucemas, the Chafarinas Islands, Perejil (or Parsley) Island and Alboran Island) (Blake 1987).

The inequality and heterogeneity that exists in the Alboran region is further slightly complicated by the different focuses of Spain, on the one hand, and the Maghreb countries, on the other, in affairs of foreign policy, relations with other States, and membership of regional organisations. Spain forms part of the web of western organisations (EU, WEU, NATO), whereas the two States in the Maghreb belong to the Arab League and the Arab Maghreb Union, the latter an organisation which, despite its ambitious name and goals, has not achieved to date any real political and economic integration of the countries in the area (Morocco, Algeria, Tunisia, Libya and Mauritania).

The Alboran is also a clear example of Mediterranean asymmetries in wealth, development and well-being. Despite the economic and social difficulties triggered by the crisis, according to the World Bank, GDP *per capita* stood at US$28,157 in the European State (Spain) in 2017 and the country had a human development score of 0.891 out of 1 according to the United Nations Development Programme (2018), while the two Maghreb States had lower levels of wealth per inhabitant—US$3007 in Morocco and US$4123 in Algeria—and lower levels of development—0.754 in Algeria and 0.667 in Morocco. These socio-economic inequalities add to the different demographic behaviours on the two shores of the Alboran Sea, an especially serious matter for the Maghreb countries, where high fertility rates have resulted in high birth rates and a high percentage of young people. The latter translates into growing spending needs for infants and the young (education and health) and imbalances between the number of people reaching working age and the number of jobs that the economic system can offer. All this obviously generates unease among the Maghrebi people and tensions in their countries, as well as migratory flows towards the north. As some authors (Naïr 1995; Guerraoui 2000; Suárez de Vivero 2009) state, these socio-economic factors are at the root of the lack of stability in the region and may have major consequences in the field of inter-State relationships.

2.2.3 The Alboran Sea and the Maritime Economy

The Alboran is not only an area on the border between the North and the South, but also a zone of transit, exchange and circulation. This is the reason why its maritime economy rests on two major pillars: one, the extraction of living marine resources; and the other formed by maritime transport and traffic.

Fishing is a traditional activity in the area and makes a contribution to the economy that, while rather small in terms of the national economy, provides worth for the local communities that are dependent upon it. It has become so important that it has triggered several disputes between Spain and the Maghreb countries over the use of certain waters and has impacted EU-third country treaties (with Morocco, especially) and even the trade relationships between them. On numerous occasions, the living resources, which are scarce and highly coveted by all the coastal States, are a basis for sparking frequent North-South disputes (legal disputes, biological rest periods, defense of fishing grounds regarded as belonging to one county or another, a lack of agreements in affairs relating to fisheries management and exploitation etc.). However, this is an even more serious matter in other Mediterranean sub-regions, and it would seem that a certain climate of cooperation and agreement has been achieved in the Alboran Sea.

Regarding the use of the Alboran Sea as an area for sea traffic, it must be said that it is a privileged space with great importance in the world as far as maritime communications are concerned. A large part of the traffic between the Middle East and Asia and the Western world makes use of this area and the Strait of Gibraltar as a key transit route. An additional function needs to be added, one that is secondary but that has a major impact on the regional level: it connects the basin's northern (Europe) and southern areas (the Maghreb and the rest of Africa). So, along with the traditional maritime traffic routes, there are other connections, in this case north-south, which augur greater cooperation in the future and the generation of shared economic interests. This is the fixed link project in the Strait, with electric power lines across the Strait of Gibraltar and the current Maghreb-Europe gas pipelines. One of these pipelines originates in the HassiR'mel gas fields in Algeria, goes through Morocco and crosses the Strait (Martínez Díaz 1993), while the other, which originates in the same fields, connect with Beni Saf (on the Algerian coast) and from there crosses the seabed to Almeria (ERM Iberia, S.A. 2005).

It is clear that a space simultaneously overused by such a great variety of, in many cases, incompatible activities is bound to be a flashpoint for a multitude of conflicts, both between the different public and private users and between the various uses and the marine environment. On top of the economic, environmental and spatial consequences produced by these marine uses on the local and basin levels, there is also a more general feature: the existence of an economic 'equator' that splits the region into two very distinct and contrasting areas from the point-of-view of their levels of development. The responses to such circumstances can be, on some occasions, the choice of economic nationalism and the preservation of spaces and resources that are considered to be one's own, and, on others, commitment to multilateral cooperation and regional integration.

2.3 Alboran Sea: Law of the Sea and Jurisdictional Issues

The Alboran Sea connects two continents and links States that share, in addition to their history and their concerns, territorial conflicts. In this chapter, we first try to place this maritime space in its legal context and, subsequently, present the States that share a border and the sea's national maritime legislation. Finally, we address the maritime borders and current conflicts. In this section, the scope of analysis is the one already described previously.

Although all the States present in the sea have declared an EEZ, there are also high seas waters due to the particularity of Spanish legislation, which sets Spain's EEZ from Cabo de Gata, although the bed and subsoil of the overlying water column are part of the Spanish continental shelf.

The most extensive jurisdiction corresponds to EEZ (41%), followed by territorial sea (32%) and high seas (22%). At the national level, Spain is the State with the greatest jurisdictional presence (Tables 2.1 and 2.2).

2.3.1 The Alboran Sea in the Context of UNCLOS

By sea, we mean a surface that is differentiated by having its own identity: basic level, hydrographical and hydrological characteristics. However, in reality, a well-defined surface area of any particular sea might bear a name of its own. In the case of the Mediterranean Sea, there are several such areas (or sub-basins), some of which have long histories, while others are simply recognized by the names of the coastal States that are part of their littoral, or even the names of some submerged islands under the surface. The Alboran Sea, which is the object of study of this work, is no exception and owes its name to Alboran Island. Consequently, in short, as has already been indicated above, the Alboran Sea is simply one part of the Mediterranean Sea.

Now, it is a fair question to ask about its legal regime. How might it be defined in accordance with the United Nations Convention on the Law of the Sea (UNCLOS)? Before answering, it would be appropriate to present the definitions attributed to the various legal regimes for seas.

In Part IX and, more specifically, in Article 122, UNCLOS lays down definitions for two categories of the sea: closed and semi-enclosed. The convention recognises the first as a sea surrounded by several States that communicates with another sea or ocean through a narrow passage.

The most common example given for this is the Mediterranean Sea. As for the second, this refers to any sea constituted wholly or mainly by the Territorial Seas and Exclusive Economic Zones of several States. One example of this is the Caspian Sea.

According to this illustration, if the Mediterranean Sea is a semi-enclosed sea and the Alboran Sea is a part thereof, ipso facto it, too, is a semi-enclosed sea. Moreover, it is a perfect example of this regime, as it is connected with the ocean via a narrow passage, none other than the Strait of Gibraltar, and is surrounded by three States, i.e., Spain, Algeria and Morocco.

2.3.2 States and Their Maritime Jurisdictions

Now, it must be stated that in addition to fully or partially concerning the coastlines of three States, the Alboran Sea is also bordered on by the colony of a fourth State.

Although it encompasses the entire Mediterranean seaboard of Morocco and much of that of Spain, it only covers a small part of the Algerian coast. Meanwhile, the eastern coast of the colony of Gibraltar descends into the Alboran Sea. It should be pointed out that the western end of the Mediterranean, like the eastern end, is an area where almost all the international legislation governing the sea and its inherent activities is applied, including that established in the regional framework and the national legislation of the Mediterranean States, as well as that of the autonomous community of Andalusia.

Regarding UNCLOS, both Morocco and Algeria signed the convention on 10th December 1982 and ratified it on 31st May, 2007 and 11th June, 1996, respectively. Spain signed the convention on 4th December 1984 and ratified it on 15th January 1997. The United Kingdom endorsed the convention on 25th July 1997, and expressly extended it to include Gibraltar.

2.3.2.1 Moroccan Legislation

With regard to the national maritime legislation of these actor in the Alboran Sea, in 1973 Morocco passed Act 1.73.211 (which will be amended and supplemented by draft legislation 37-17). This sets the limits of the country's territorial sea at 12 nm and an exclusive Moroccan fishing zone at 70 nm from the baselines. Article 2 of the mentioned Moroccan legislation adopts the equidistance method (Gutiérrez Castillo 2009) to delimit its territorial sea from its opposing and adjoining neighbours. Two years and 4 months elapsed before a decree was passed (which will be amended and supplemented by draft decree 2-17-349) that determined the basic closing lines on the coast and the geographical coordinates of the limits of the territorial waters and the Moroccan exclusive fishing zone that later became an Exclusive Economic Zone (EEZ). The EEZ was extended to 200 nm by Act 1-81 (which will be amended and supplemented by draft legislation 38-17), which also created the Contiguous Zone (CZ) adjacent to the territorial sea, the width of which is 24 nm as the sea's breadth does not allow the EEZ to extend beyond the median line. We, therefore, assume that under no circumstances should it exceed 43 nm in the west and 95 nm in the east (the coordinates of the delimitation of the EEZ have not been published to date). Regarding Morocco's continental shelf (CS), this was essentially defined in the *Dahir* (decree emitted by the King) concerning the code for the exploration and exploitation of hydrocarbon deposits and subsumed by the above-mentioned Law

1-81. Article 11 of the Moroccan legislation establishes two methods for delimitation with neighbouring opposing or adjoining States: the median line for the delimitation of its EEZ and equity in the case of its CS.

It should be noted that the Moroccan legislation was drawn up before the conclusion of UNCLOS and that the last Law on the matter dates from 1981. However, it took its inspiration from the latter and sought to adapt to its provisions (Ihrai 2007).

2.3.2.2 Spanish Legislation

Spain's coastline is 7905 km long. The country passed its first law delimiting the fishing zone under its jurisdiction in 1967. However, it was not until 1977 that legislation was passed to accurately define the maritime domains under its jurisdiction, their width and the competencies to be exercised by the State. In that year, Spain enacted Law 10/1977 of 4th January, which set a width of 12 nm beyond the country's straight baselines as the area under Spanish sovereignty.

It must also be stated that the same Law referred to the equidistance method for the delimitation of the country's territorial sea with neighbouring States.

The points of the baseline from which the outer limits of the territorial sea are measured were soon determined. The coordinates of the baselines were published only 7 months later, in Royal Decree 2410/1977. However, no exclusive economic zone was declared in the Alboran Sea until Royal Decree 236/2013. Notwithstanding, prior to 2013 Spain possessed a protected fishing zone in the Mediterranean which was calculated from Punta Negra-Cap de Gata (36°43′ N and 02°9′ W). This has been replaced de facto by the EEZ that, according to the law, is also measured from the same location. It must be highlighted that the seabed and subsoil of the water column in the Alboran Sea outside Spanish territorial sea form part of the Spanish continental shelf.

2.3.2.3 Algerian Legislation

Algeria was the first actor in the area to extend its territorial sea to 12 nm. Article 1 of Decree 63-403 of 12th October 1963 stipulated that the width of the Algerian territorial waters was 12 nautical miles. Twenty-one years were to pass between the extension of the territorial sea to 12 nm and the publication of the geographical coordinates of the line that delimited the country's jurisdictional waters. In fact, it was Decree 84-181 of 4th August 1963 that defined the straight baselines from which the width of the maritime areas under Algerian national jurisdiction is measured.

In 2004, Algerian Presidential Decree No. 04-344 of 6th November 2004 established a contiguous zone adjacent to the territorial sea that extends 24 nm from the baseline of the territorial sea.

The last Presidential Decree, No. 18-96 of 20th March 2018, establishes an EEZ along the country's coastline. There had previously been a fishing zone beyond the territorial waters with a width of 32 nm from the western border at Ras Tenes and 52 nm from Ras Tenes at the eastern border. It is assumed to have been subsumed by the EEZ, since Decree 18-96 takes into consideration the decree that created this zone. Its width has not been explicitly stated but its coordinates were published in the Decree's annex. According to the SHOM (the French Naval Hydrographic and Oceanographic Service) map projection, the outer boundary of the EEZ is much wider in the direction of the Balearic Islands, and Sardinia. There is no reference to the continental shelf in the Algerian legislation, perhaps due to its narrowness and the little importance that it has. This said, Algeria enjoys full rights according to what is stipulated in UNCLOS.

It is useful to point out that the Algerian legislator has not revealed the method by which it delimited its TS and EEZ with neighbouring States, except that in the case of the latter, it published the fact that it had been created and gave its geographical coordinates.

It should be highlighted that, as in the case of Morocco, the term 'territorial waters' is used to refer to the territorial sea. The latter term only appears in the Presidential Decree of 2004.

2.3.2.4 Gibraltar Legislation

The last State to be presented in this part is none other than the United Kingdom, which is involved in the Alboran Sea by way of its colony of Gibraltar. The only legislative document that has invoked the territorial sea is the Law of the Protection of Nature (Act 1991-11). It should be pointed out that what is being referred to here is not an article or a paragraph or even a fragment of this Law, but the definition of an abbreviation in Article 2, entitled interpretation and application, in which the legislator provides definitions of the terms used in the Law. This reads: 'BGTW' means British Gibraltar Territorial Waters, which is the area of sea, the sea bed and subsoil within the seaward limits of the territorial sea adjacent to Gibraltar under British sovereignty and which, in accordance with the United Nations Convention on the Law of the Sea 1982, currently extends to 3 nautical miles and to the median line in the Bay of Gibraltar. The part concerned by the Alboran Sea has a territorial sea of 3 nm width.

2.3.3 Maritime Borders and Disputes

Addressing borders and the conflicts inherent in them entails the involvement of three States in a historical conflict. The only State that is not involved in the Alboran dispute is Algeria, which has no agreement with Morocco as to a delimitation of the maritime boundary between the two countries, and there has not even been any sporadic dialogue on the subject (as mentioned by Morad Medelci in 2013).

Spain, on the other hand, is the dominant State on the majority of the borders and has also been the dominant force in the resulting conflicts. Its borders lie in both the northern side and the southern part of Alboran Sea.

The northern side of Alboran Sea is the place of delimitation between Gibraltar's (UK) and Spain's territorial seas, with the latter upholding the doctrine of the dry coast, i.e. Gibraltar has no rights to any territorial sea according to what is stipulated by Article X of the 1713 Treaty of Utrecht (MRabet Temsamani 2018). As seen previously, as long as the United Kingdom claims a territorial sea with a width of 3 nm around the rock, Gibraltar has a de facto 3 nm of territorial sea around the rock itself and 1.5 nm inside the bay of Algeciras, although Spain does not recognise any rights to these. The first final provision of the Law of the Territorial Sea makes a clear reference to this so as to avoid any interpretation that might suggest implicit recognition of sovereignty for discussion. It should not be forgotten that one of the outcomes of this conflict is that two superimposed zones in the area have been declared Sites of Community Importance (SCI) (Council Directive 92/43/EEC). The first SCI, declared by the United Kingdom and concerning the Southern Waters of Gibraltar, was approved by the Commission on 19th July 2006 while the second, declared by Spain and approved by the Commission on 12th December 2008, fully envelops the Gibraltarian SCI.

The historical Spanish–Moroccan dispute on the southern side of the Alboran Sea is much more complex due to its location. The existence of cities, islands and islets over which sovereignty is claimed by Morocco makes delimitation doubly difficult, firstly, because of the claim itself, and secondly, because of the presence of islands and rocks that make maritime delimitation a challenging affair.

To give a clear picture of the situation, we are talking of the towns of Ceuta, which was occupied by the Portuguese in 1415, and Melilla, which was seized by the Spanish in 1497, the Chafarinas Islands, the Al-Hoceima Islands (which came under Spanish control in 1559 and became Spanish in 1673) and the Peñón de Vélez de la Gomera, or Badis, as it is called in Morocco (occupied in 1508, taken over by the Moroccans in 1522 and reoccupied in 1564) (MRabet Temsamani 2018).

From the Spanish point-of-view, these are places under Spanish sovereignty: the two towns that were founded are Spanish enclaves with an undisputable right in international law to territorial sea, a contiguous zone, an exclusive economic zone and, naturally, all the rights that pertain to the continental shelf. However, the fact that Spain has not established an EEZ in the Alboran Sea also means that only territorial sea and a CS have been delimited in these towns' maritime space.

With respect to the islands and rocks, as the Al-Hoceima Islands and the rock of Vélez de la Gomera are uninhabited, in accordance with Article 121.3 they are only entitled to a territorial sea and a contiguous zone.

However, the case is different for the Chafarinas Islands as they are occupied by a military detachment (Gutiérrez Castillo 2010), entitling Spain to also delimit an exclusive economic zone and a continental shelf.

If we consider the conflict from the point-of-view of the Moroccan government, (MRabet Temsamani 2018), Ceuta and Melilla are Moroccan towns and the islands and the rock are part of Moroccan territory. During its ratification of UNCLOS, Morocco declared its intention to reiterate its claim ‘eternally’.

This territorial conflict becomes apparent with the plotting on the surface of the baselines and the bays’ closing lines along the coastline and when plotting the outer boundaries of the territorial sea, the contiguous zone and the exclusive economic zone. The straight baselines in question are as follows: Almina Point—Black Cape; Farallones—Restinga Tofiño; Restinga Tofiño—the Northernmost Point of Congress island, and the Northernmost Point of King’s Island—the Algerian-Moroccan border.

This means that the two towns under Spanish sovereignty belong to Morocco according to Moroccan internal law, and the same is even truer for the closed bay of Al-Hoceima, which encloses in its internal waters the island of Vélez de Gomera/Badis, which is also under Spanish sovereignty.

In addition, a glance at a maritime chart of the ports of Melilla and Bani Ansar leads us to believe that this is a single port, as part of the port of Bani Ansar is clearly inside the internal waters of the port of Melilla, especially in the region of the former’s dike. However, it was not possible to protest against this overlap on the part of Spain at either local or central level.

As can be observed, no delimitation is forthcoming, since the lack of an agreement on the subject between the two States means that no delimitation will be recognised or respected in the Alboran Sea. In the meantime, Spain continues to strive to avoid any procedures or decisions that might impact its diplomatic relationship with Morocco.

Alboran Island and Las Nubes Islet are located 57 km from the coast of Morocco and 87 km from the Spanish shore. There is no conflict between the two States in this case as no claim has been made. Their current status and legal regime are governed by Article 121, para. 3, which provides for them to possess a territorial sea and a contiguous zone, but gives them no rights to an exclusive economic zone or a continental shelf (Gutiérrez Castillo 2006).

2.4 Maritime Governance and Cross-Border Cooperation

The Mediterranean Sea is an area where a substantial number of multilateral action initiatives can be found in the maritime affairs domain. Some of these are of a strictly political and legal nature (§ 2), including the supranational structure of the European Union. All the coastal States belong to such political–legal structures, although not all to all of them.

This characteristic is a strength for the general governance of the basin, in so far as its execution and development individually depend on each State as a main political actor. However, the inadequacies and shortcomings of a large number of States and the wide breach that separates the two shores in economic, political and social terms, hamper and erode the effectiveness of the regional institutions, including the European Union itself and its various policies in some cases.

Despite the existence of some specific cooperation initiatives on the sub-regional scale, the most representative example of which is, perhaps, the Adriatic Sea/Ionian Sea macro-region, for which the EU launched a Strategy in 2014, this is not the case in the Alboran Sea, which lacks the institutions required to apply any such initiative on the sub-basin level.

2.4.1 Background

There is a history of cooperative actions on the regional level going back to at least the beginning of the twentieth century. The regional marine concept arose early with the International Commission for the Scientific Exploration of the Mediterranean Sea (CIESM) being set up in 1908. Other regional initiatives include the Treaty of Montreux (1936), the Nyon Arrangement (1937) on the freedom and security of navigation, and the General Fisheries Council for the Mediterranean (1948 and called the General Fisheries Commission for the Mediterranean since the end of the 1990s onwards) set up by FAO. In more recent times was the so-called 1975 Mediterranean Action Plan (MAP) although there had been a number of interesting endeavours in the field of environmental protection in the Mediterranean, such as the so-called Euro-Mediterranean Charter (1973) and the Inter-parliamentary Conference of Coastal States on the Control of Pollution in the Mediterranean Sea, the Mediterranean Action Plan (1975) was undoubtedly the first major milestone among all the regional actions for protecting the sea. The Mediterranean Action Plan laid down a complex network of policies, arrangements, programmes, institutions and activities for the protection of the marine environment, and which aims in the long term to achieve the necessary understanding that could serve as a basis for broader cooperation agreements (Chircop 1989). Apart from its legal and technical apparatus, MAP also includes research and pollution monitoring—the MEDPOL programme—and other integrated planning- and development-linked aspects—set out in the Blue Plan.

This Action Plan has evolved (Table 2.3), having been reviewed and given a change of direction in the 1990s (MAP-Phase II). The new Action Plan and the new Barcelona Convention lay more emphasis on sustainable development, integrated management and regional cooperation as key elements (Pavasovic 1996). The 2008 formulation of a protocol on integrated coastal management (in force since March 2011) was one of the most recent milestones in the evolution of Mediterranean marine governance.

Table 2.3 Evolution of Mediterranean Action Plan

Period	Most relevant facts	Strategies and focuses
1970s (initial phase)	- Intergovernmental meeting for protection of Mediterranean: MAP adopted (1975) - Conference of Plenipotentiaries (1976): Barcelona Convention, Protocols on waste, Emergency Protocol - Split Conference (1978): Blue Plan and Priority Action Plan	- Conservationism - Eco-development - Protection of marine environment and combating pollution - Integrated planning of environmental development and protection
1980s (development phase)	- Protocol on Land-based Sources of Pollution (1980) - Development of MEDPOL programme - Protocol concerning Specially Protected Areas (1982) - 4th Ordinary Meeting of the Contracting Parties (1985): Genoa Declaration	- Protection extended to coastal areas - Definition of major environmental protection strategies
Beginning of 1990s (maturity phase)	- 6th Ordinary Meeting of the Contracting Parties (1989): Adoption of UNEP Directorate General report - Nicosia Charter[a] (1990) - Coastal Zone Management Programme (1990)	- Change in direction of MAP towards integrated coastal management - Reconciliation of environment and sustainable development
1990–1995 (maturity and adaption to UNCED postulations)	- Preparation of MAP report for presentation at UNCED (1991) - 8th Ordinary Meeting in Antalya (1993): change of MAP direction - Tunis Conference (1994): Declaration on Sustainable Development in the Mediterranean; Med Agenda 21 - 9th Ordinary Meeting in Barcelona (1995): New MAP and New Convention, Amendments to Protocols	- Sustainable development - Change in direction of legal protection instruments - Application of Agenda 21
1995–present (recent modifications to the system)	- Establishment of the Mediterranean Commission on Sustainable Development (MCSD) (2005) - Conference of Plenipotentiaries (2008): signature of Protocol on Integrated Coastal Zone Management in the Mediterranean (2008); in force in 2011 - 17th Ordinary Meeting in Paris (2012): adoption of the Action Plan for the implementation of the ICZM Protocol	- Sustainability - Participation and governance (states, local authorities, business community, NGOs) - Promotion of the integrated coastal zone management

Source: Author

[a] Charter on Euro-Mediterranean Cooperation concerning the Environment in the Mediterranean Basin

Table 2.4 Legal–institutional marine governance forms in the Mediterranean

International initiatives	- UNCLOS - Conservation agreements - Fishing treaties - Agreements on dumping of waste and pollutants - UNEP-Regional Seas Programme
Regional initiatives	- Mediterranean Action Plan: Barcelona Convention and protocols; Blue Plan; MEDPOL Programme - General Fisheries Council for the Mediterranean - EU initiatives - Other initiatives: METAP (World Bank); NGOs (IUCN); sub-regional initiatives (Declaration on the Conservation and Sustainable Development of the Alboran Sea, Pelagos Sanctuary, RAMOGE Agreement etc.)
National initiatives	- Transposition of international law - General environmental legislation (natural spaces, pollution prevention, coastal protection and coastal and marine environment protection etc.) - Legislation on marine aspects (fishing, protected marine areas, navigation, exploitation of non-living resources etc.)

Source: Prepared by the author

2.4.2 Legal–Institutional Framework

In recent years, several phenomena in the marine environment scenario have been subject to such rapid change that management instruments have not always been able to respond in the most suitable fashion. This has been due above all to the fact that these instruments are usually created by international organisations and their action mechanisms require broad consensus among countries. This is difficult to achieve in a region like the Mediterranean, where there are still sharp economic, demographic, and political contrasts. However, if the action that comes from international organisations does not seem to be very effective, the unilateral action taken by some states is even less so, especially that taken by the weakest in economic and technological terms. Be that as it may, in the Mediterranean international/regional institutions and legislation coexist alongside the various coastal states' own legal frameworks, with regional cooperation instruments seemingly sometimes predominating while at other times national instruments prevail. When the latter occurs, the inequality between countries' capacities and the varying degree of interest that they show in Mediterranean affairs could lead to lack of unanimity over issues that affect them collectively.

Mediterranean marine governance should be unfailingly multilateral and concerted, both because of the basin's peculiar geographical constraints and the nature and size of the problems shared by those along its coasts. However, it is also evident that each of the dimensions of Mediterranean marine governance is framed in a variety of regulations, legislation and institutions. Legal issues, maritime borders and the navigation regime are regulated by UNCLOS—and binding only for the states that have endorsed it. Meanwhile, environmental protection issues are, as is obvious, regulated by the states themselves, UNCLOS and also by an intricate regional web that revolves around the Mediterranean Action Plan, all complemented with other (EU, World Bank, NGOs' etc.) institutions and actions.

There is a therefore a wide variety of concerted actions in this region (navigation, piracy, exploitation of resources, migrations etc.), although the greatest efforts are made in the area of environmental protection (Table 2.4). Unlike in the field of the environment, where over time a regional spirit of cooperation has taken hold, more purely economic and, especially, geopolitical actions remain the domain of state sovereignty. Nevertheless, being aware of how complex and intertwined the problems that afflict the region are, the Mediterranean states have put a number of regional cooperation strategies in place both in the field of the environment (Barcelona Convention) and other areas (the Euro-Mediterranean Association, Conference for Security and Cooperation in the Mediterranean (CSCM), economic cooperation agreements, the European Neighbourhood Policy and the Union for the Mediterranean), seeking the most suitable solution through dialogue and consensus, regional integration, agreements and the participation of multiple actors (states, international organisations, all types of NGOs, economic associations, clusters etc.).

To recapitulate, it can be said that there are some favourable aspects to the framework of action in the Mediterranean Sea, especially in the field of the environment, but it is also true that there are some partial or incomplete aspects that have been at the root of most of the problems that continue to exist (or are worsening). Among the strong points of the protection system we can highlight: (a) the wide range of actions (national, regional, international) due to deep concern and recognition of the environmental issue; (b) the environmental instruments that have traditionally been the most important means for intervening in the regions have acted as drivers of international cooperation and dialogue and of other political and economic actions; (c) the presence at the core of the system of the Action Plan, which has been the catalyst of other complementary actions to its benefit and, especially, for attracting institutional and financial support from bodies such as the World Bank and the European Investment Bank and the very significant political support of the EU; (d) the shaping within MAP of a suitable set of protocols, rules and measures (legal mechanism) conducive to achieving a better environmental state despite non-compliance with said legislation.

In spite of this, and although it is true that the system organised around the Action Plan is the oldest and probably the most effective way of protecting the Mediterranean marine environment, it also suffers from a number of shortcomings: the instruments of environmental protection are not adequately taken into consideration (and are on occasion simply taken as partial corrections and not interventions in the problems at root level); there is a major shortcoming in that the international protection rules and regulations are not properly accepted and complied with, a problem which is not caused by these instruments, but by a lack of greater awareness; the lack of a defined common state strategy to at last abandon the search for fast economic growth and which proposes balanced development respectful of the environment (which should also involve the rethinking of major Mediterranean and Euro-Mediterranean policies); the little awareness of environmental problems and their consequences could be a major motive for regional conflict and insecurity;

the decoupling of some international/regional initiatives and each state's own policies as they can only intervene on the basis of their own immediate priorities and without taking into account the more general problems in the region; the unilateral character of certain actions, which means that they are less effective apart from not considering the cross-border nature of marine ecosystems; the financial weakness of the Action Plan; a variety of situations regarding the implementation and effectiveness of the different protection instruments, as some are partial and not coordinated with the others.

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Chapter 3
Alboran Sea Area Climate and Weather

José María Sánchez-Laulhé, Agustí Jansa, and Carlos Jiménez

3.1 The Climate of the Alboran Area

The Alboran Sea is the westernmost sub-basin of the Mediterranean Sea. It extends between Spain and North of Africa, along 35° N, with a zonal morphology: a 350-km long sea in the E–W direction and 140 km wide, that, at west, narrows down to 14-km wide in the Strait of Gibraltar, surrounded by mountains fairly close to the coast with uneven altitude.

The Mediterranean Sea is a marginal and semi-enclosed sea, with morphological characteristics rather unique, located on the western side of a large continental area and surrounded by Europe on the north, Africa on the south, and Asia on the east (Fig. 3.1). From the climatic point of view, the Mediterranean basin is a unique highly coupled system where complex interactions and feedbacks involving different components of the climate system, such as ocean, atmosphere, land, and biogeochemical processes, along with the effects of complex morphological features, play a prominent role in modulating the climate of the region on a range of spatial and temporal scales (Ruti et al. 2016).

The Alboran Sea is part of a wider area located between zones with very different sunshine duration (Fig. 3.2), and with strong albedo differences: the high albedo arid zone of the North African deserts to the south and the low albedo moist temperate zone of midlatitude to the north (Bolle 2003).

The Alboran Sea is included in a transition zone between midlatitudes and tropical meteorological regimes, exposed to some of the most relevant mechanisms acting upon the global climate system (e.g., Corte-Real et al. 1995; Ribera et al.

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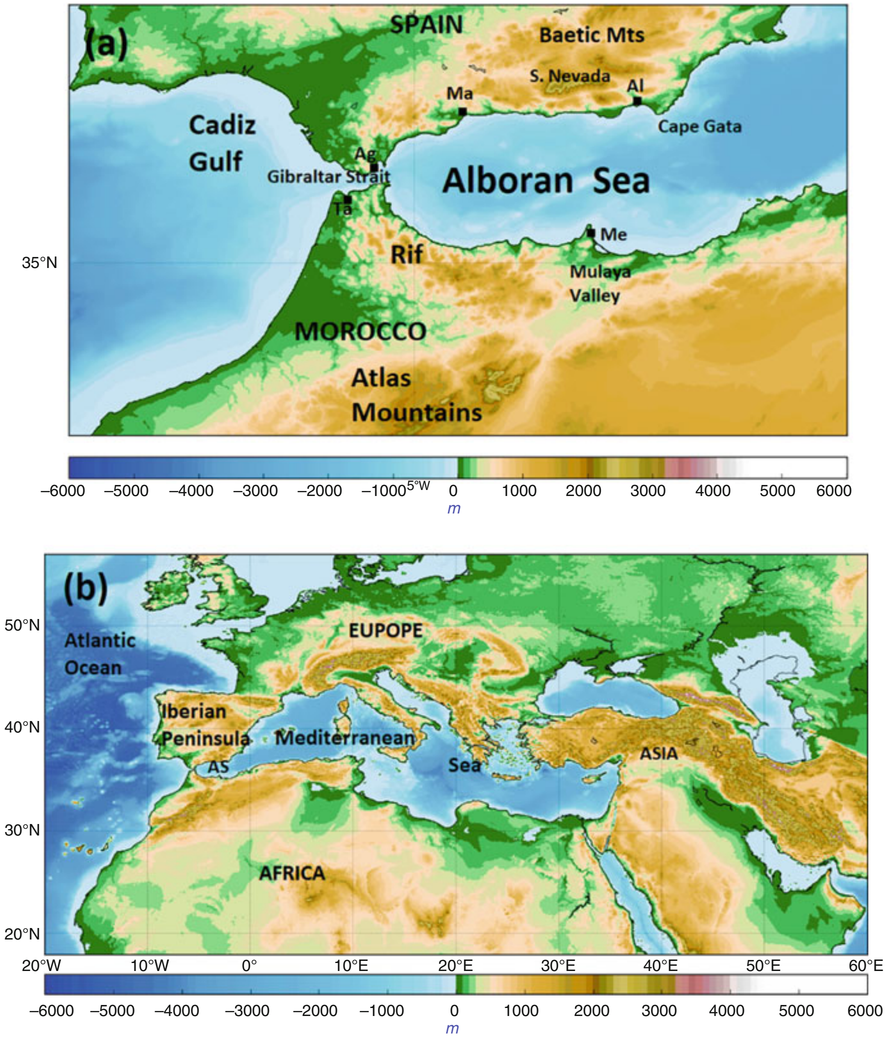

Fig. 3.1 Topographic maps of (**a**) the Alboran sub-basin and Cádiz Gulf, (**b**) Mediterranean basin, and surroundings lands. Ag (Algeciras); Ma (Malaga); Al (Almeria); Me (Melilla); Ta (Tanger). Source: GLOBE database (http://www.ngdc.noaa.gov/mgg/topo/globe.html)

2000; Lionello et al. 2006; Trigo et al. 2006), ranging from the North Atlantic midlatitudes storm track in winter (e.g., Hurrell 1995), to tropical systems such as the Hadley Cell throughout its descending branch along many months of the year, or the African and the remote Asian monsoons in summer (Rodwell and Hoskins 2001). Therefore, the climate of the Alboran area is mostly characterized by mild wet “winters” (from October to April); warm to hot and very dry summers (from June to August), liable to heat waves and forest fires, and overall semiarid conditions

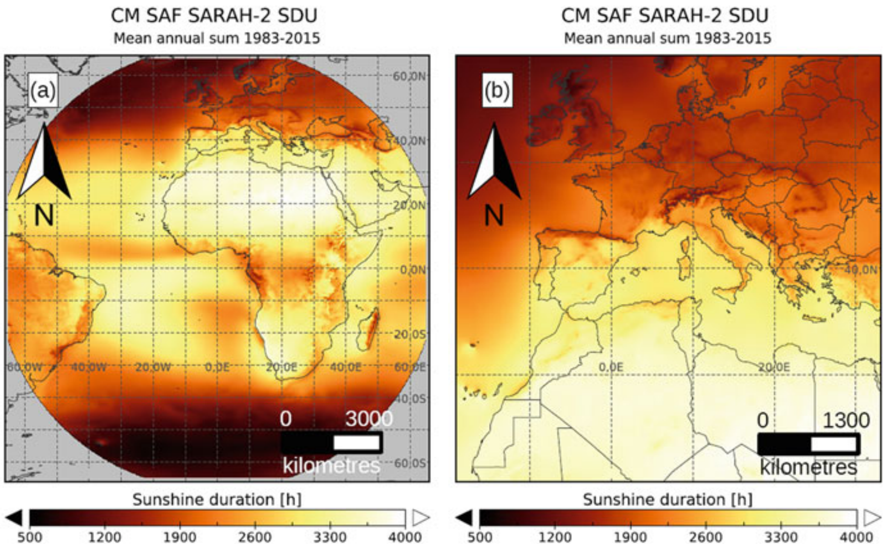

Fig. 3.2 Mean annual sum (h) of sunshine duration (SDU) for the time period 1983–2015 obtained from CM SAF data (Schulz et al. 2009): (**a**) for the Meteosat disk; (**b**) for Europe and North Africa (Kothe et al. 2017)

(Figs. 3.3, 3.4, and 3.5). It is a Mediterranean-type climate, which is loosely defined as a subtropical to midlatitude climate; *Csa* climate in the Köppen-Geiger Classification System updated by Peel et al. (2007). However, on the easternmost side, there are small areas with *BSh* (hot steppe) and *BWh* (hot desert) climates (AEMET-IM 2011). The strong summer–winter rainfall contrast that characterizes the Mediterranean climate is associated with pronounced seasonal cycles in most climatic variables.

3.1.1 *Precipitation*

The periods of precipitation occurrence are associated with the passage of synoptic midlatitude cyclonic systems: extratropical baroclinic cyclones and high-level cyclonic systems, stretched toward subtropics troughs and cut-off lows, both generated by Rossby waves breaking. The distribution of precipitation (Algeciras: 991.8; Malaga: 533.7; Almeria 199.9; Melilla 388.8 mm year^{-1} during the period 1981–2010) shows large westward longitudinal precipitation gradients along both coasts, mainly in winter (Figs. 3.4, 3.5, and 3.6), being *shadowed* by mountain ranges. The most common explanation for this pattern is that precipitation is enhanced as air ascends on the windward side of the mountains and reduced as air descends on the leeward side. The rainfall annual minima occur on the east coast of

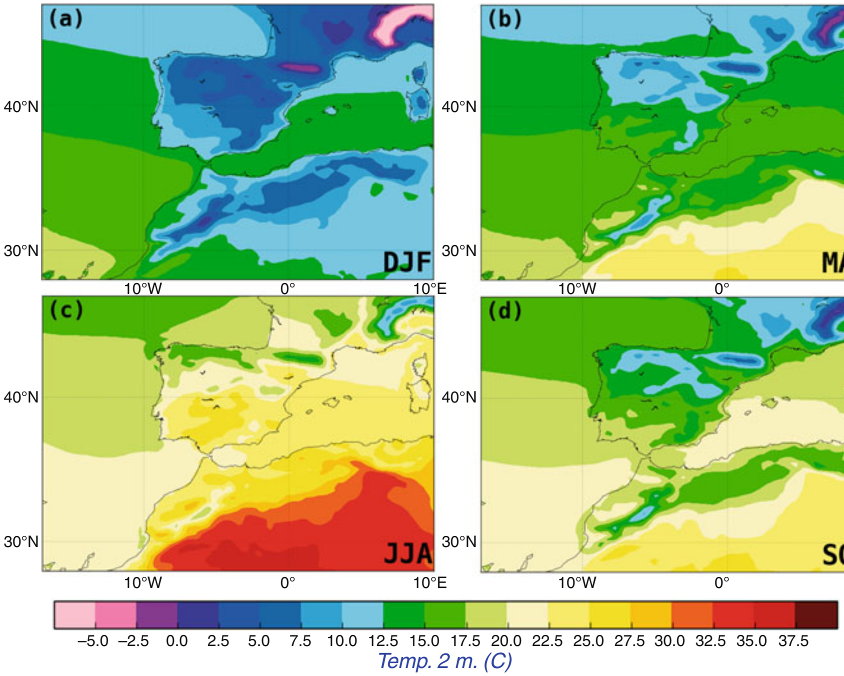

Fig. 3.3 Mean seasonal 2 m temperature for the period (1979–2017) using the ERA5 dataset: (**a**) winter (DJF), (**b**) spring (MAM), (**c**) summer (JJA), (**d**) autumn (SON)

Alboran (eastern side of Sierra Nevada) and on the Muleya Valley (east of the Rif mountain ranges).

Water resource is a critical issue. Freshwater is unevenly distributed in time and space with few short-duration heavy precipitation events and long drought periods. The region is prone to high-impact events such as Heavy Precipitation Event (HPE) and flash floods mainly taking place in Fall (Ducrocq et al. 2014). During this season, the Alboran Sea is still relatively warm (Fig. 3.16), and the slowly moving cut off lows, interacting with the coastal mountain ranges, are able to organize quasi-stationary low-level warm and moist marine flows that can produce heavy rainfalls. HPEs occur also during winter in the seacoast (Polvorinos et al. 1999; Sánchez-Laulhé 2006).

HPEs are typically associated with back-building quasi-stationary mesoscale convective systems—MCSs—(Bluestein and Jain 1985) (Fig. 3.7). MCSs become nearly stationary when the new convective cells occur upstream of the existing convection, facing a conditionally unstable low-level marine flow. Successive triggering of convective cells over the same region is essential for accumulating high rainfall totals in a short time; orographic lifting has been widely proposed as the causative mechanism to trigger the deep convection in the same place (e.g., Rotunno and Ferretti 2001; Bousquet and Smull 2006). But also the establishment of a cold pool induced by the MCS itself can force the uplift of the incoming flows and

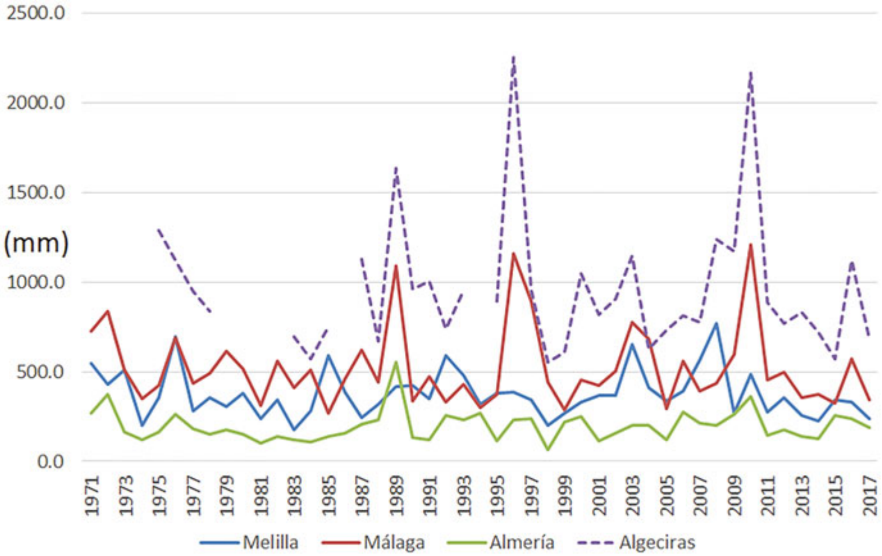

Fig. 3.4 Precipitation annual series (1971–2017) from the AEMET meteorological stations of Melilla, Malaga, Almeria, and Algeciras. See Fig. 3.1 for their geographical localizations

maintain these convective systems far away from a mountain barrier (Ducrocq et al. 2008).

Lightning frequency over the Alboran Sea presents a maximum in autumn as shown in Fig. 3.8, although it is one of the Mediterranean sub-basins with lower lightning density. Lightning occurrence over land surrounding the Alboran Sea is low all the year around, except in the Atlas Mountains where there exists high activity from April to September (Anderson and Klugmann 2014).

Duffourg and Ducrocq (2013) estimated that evaporation in the Mediterranean is the origin of 40–60% of the advected water vapor feeding northwestern Mediterranean convective systems whereas the remaining moisture would come from the subtropical Atlantic Ocean (Winschall et al. 2014) or North Africa (Turato et al. 2004). More recently, Ciric et al. (2018) analyzed the average percentage of Mediterranean contribution to extreme rainfall for all months and the entire Mediterranean area, and estimated that the contribution in autumn was approximately 40% for the eastern facade of the Iberian Peninsula. However, for the Alboran Sea, the influence of Mediterranean moisture on HPE was rapidly reduced to the west. Its contribution would not reach 10% in the vicinity of the Strait.

In winter, matching with precipitation, insolation presents a minimum in the Strait of Gibraltar, whereas it presents a maximum east of Melilla in the south coast of the Alboran Sea. In summer, the minimum of insolation in Alboran is located along the south coast, caused by low clouds originated by easterly wind (Fig. 3.9).

Over the Mediterranean Sea itself precipitation minus evaporation, P–E, is negative throughout the year (e.g., Mariotti et al. 2002; Seager et al. 2014)

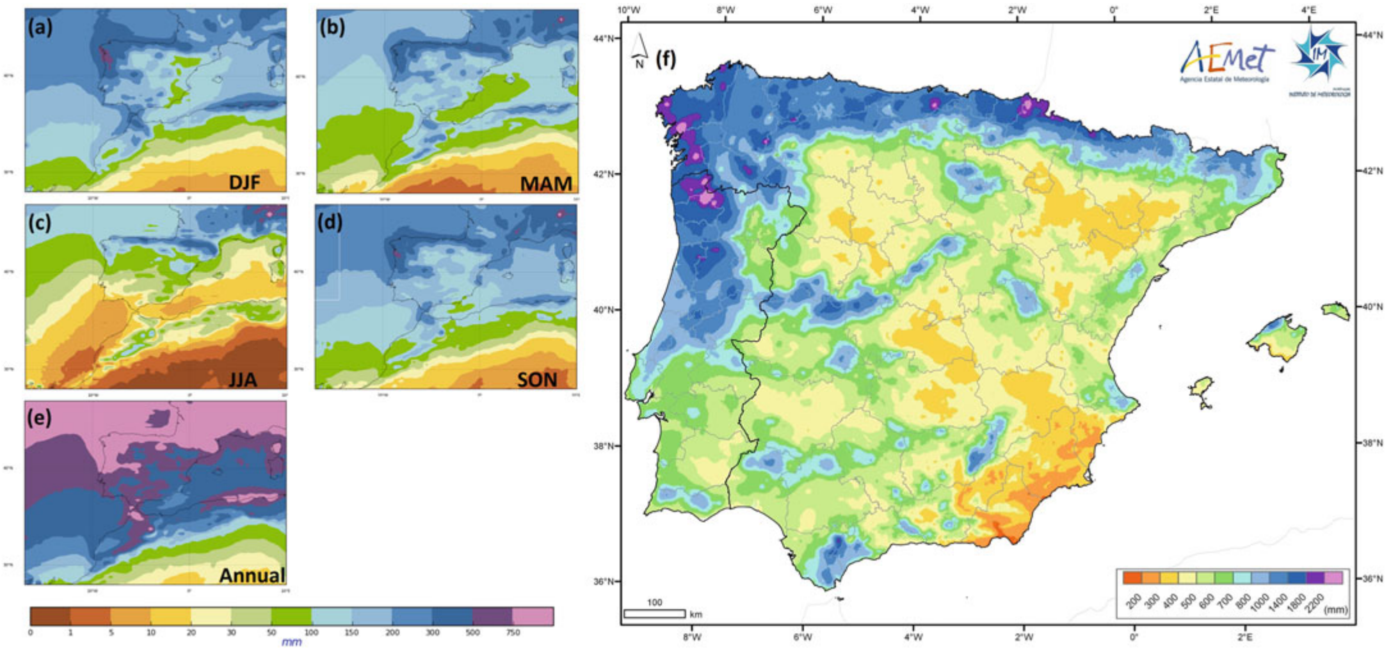

Fig. 3.5 Mean rainfall (mm) distribution over the period 1979–2017 (using ERA5 reanalysis) for: (**a**) winter (DJF), (**b**) spring (MAM), (**c**) summer (JJA), (**d**) autumn (SON), (**e**) annual, (**f**) Annual average rainfall in the Iberian Peninsula, 1971–2000 (AEMET-IM 2011). The bottom scale is for (**a**)–(**e**) graphics

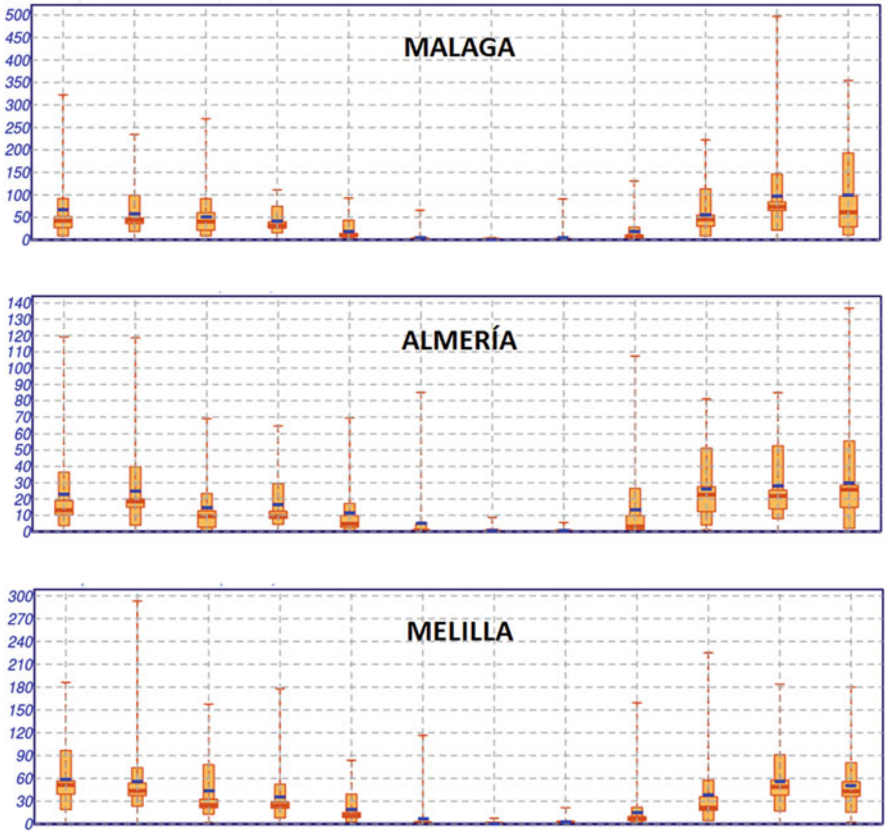

Fig. 3.6 Box and whiskers diagrams for monthly precipitation (mm) recorded in Málaga, Almería, and Melilla stations. The minimum and maximum values are denoted with a horizontal dash in the upper and lower limits of whiskers, the edges of the boxes of box correspond to 10th, 25th, 75th, and 90th percentiles of the data distributions, and the central bold reddish and blue bars denote the median and the mean, respectively. Source: AEMET

(Fig. 3.9). Water loss to the atmosphere and riverine inputs combined lead to an estimated Mediterranean freshwater deficit of about 500 mm year^{-1}, consistent with most oceanographically based estimates for water flux from the Atlantic Ocean at the Gibraltar Strait. The annual mean resulting tendency to increased salinity is balanced by river discharge of freshwater and salt export to the Atlantic through the Strait of Gibraltar (Mariotti et al. 2002). Over the Alboran Sea mean P–E is also negative throughout all seasons (Fig. 3.10), being the annual mean values (in the 1979–2014 period) for P, E and P–E, obtained from ERA-Interim (Dee et al. 2011) along 36° N, 531 mm year^{-1}, 1051 mm year^{-1}, and -520 mm year^{-1}, respectively.

Precipitation variability presents a strong seasonal cycle modulated by inter-annual to multidecadal variability patterns. The annual variation coefficient is very high in the western Alboran, with values over 30% in the Strait of Gibraltar. There

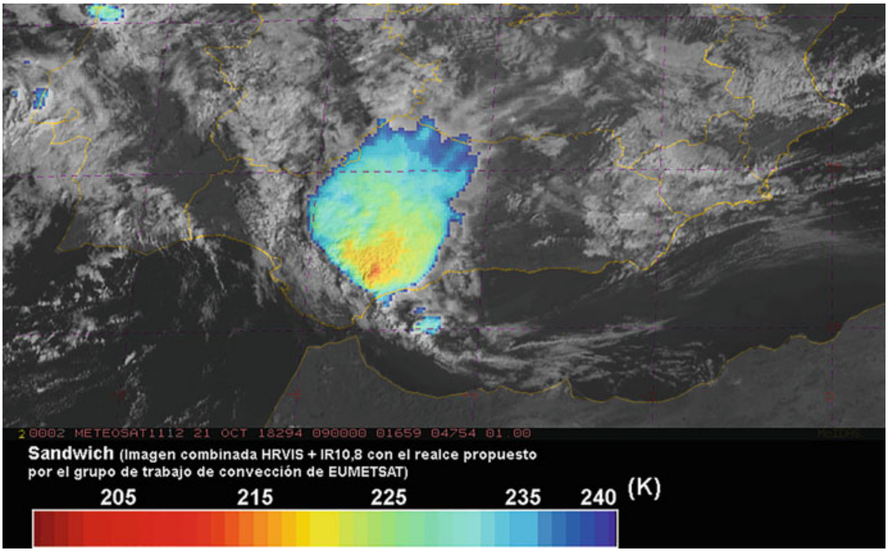

Fig. 3.7 Mesoscale convective system associated with an intense precipitation event causing significant flash floods in the south of the Iberian Peninsula on October 21, 2018. Sandwich image product, obtained blending the HRV and IR10.8 Meteosat imagery (Setvák et al. 2012). Source: AEMET

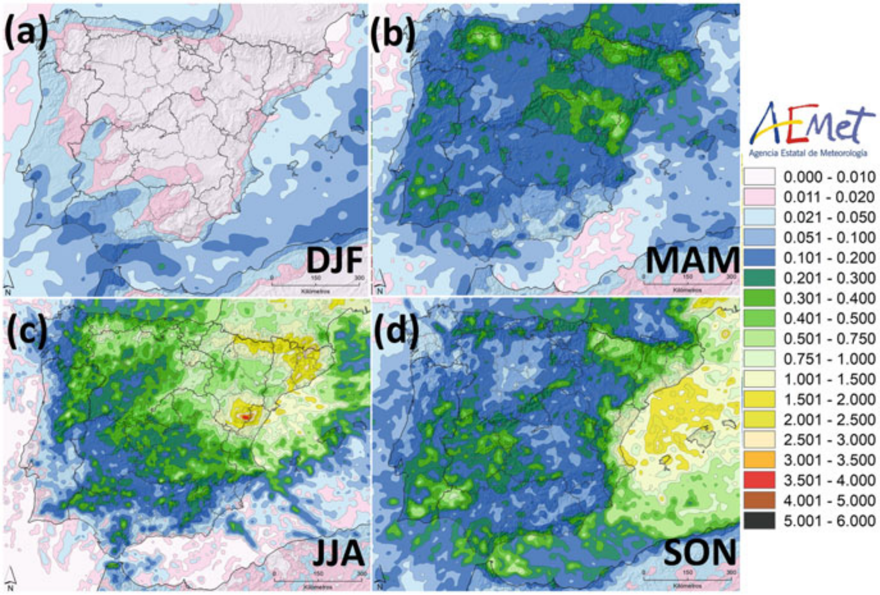

Fig. 3.8 Seasonal average (2007–2016) of detected flash density lightning (flashes per km^2) for: (**a**) winter, (**b**) spring, (**c**) summer, (**d**) autumn. Data from the AEMET electric discharges network (Nuñez et al. 2019)

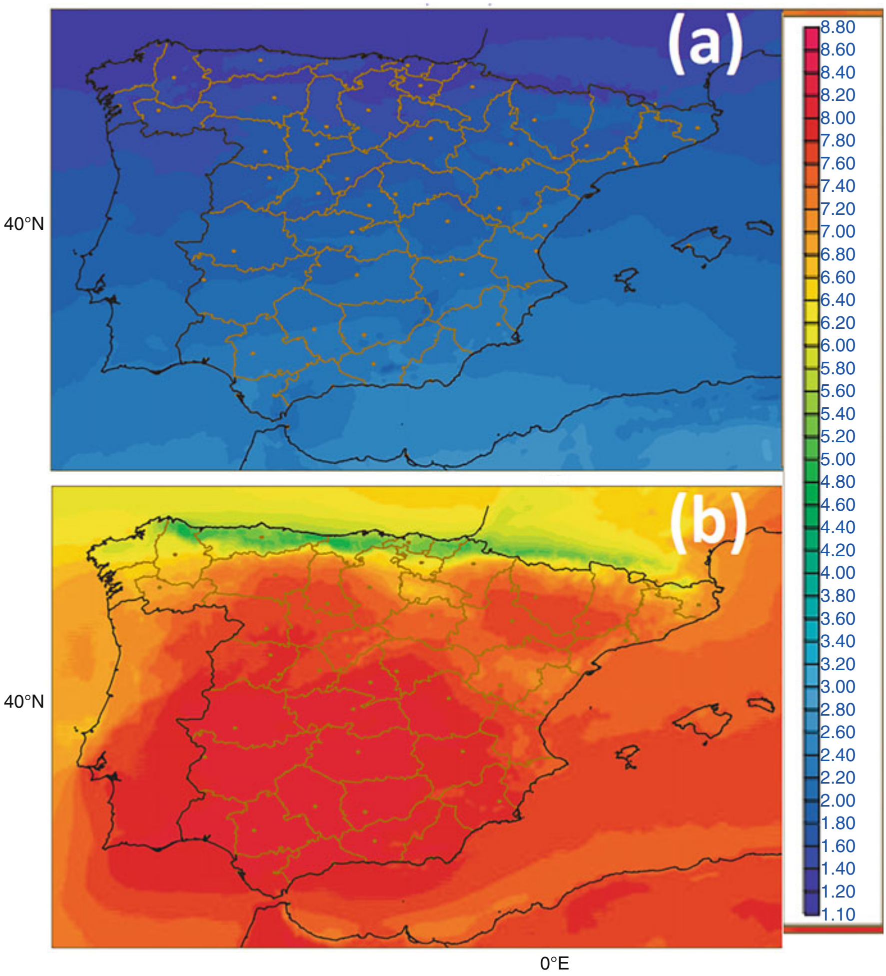

Fig. 3.9 Mean surface incoming shortwave (SIS) radiation for the time period 1983–2005 of (**a**) December and (**b**) July. Obtained from CM SAF datasets by Sancho et al. (2012)

exists a significant correlation coefficient between annual series of recorded precipitation and NAO index (correlation coefficient using Hurrell NAO index is −0.42 for Malaga and −0.39 for Algeciras). This variability decreases, and accordingly correlation with NAO becomes no significant toward the east of the sub-basin. The rainfall multidecadal variability is clearly visible in Malaga station data records. It experienced a slightly dry 1940–1950s period, followed by a wetter period until the 1970s, and by another pronounced dry period until the end of 1980s (Fig. 3.11). The Iberian Peninsula, Morocco, and Algeria underwent similar changes (e.g., Goodess and Jones 2002; Chbouki et al. 1995; Adjez 2000). The multidecadal NAO change has been linked to surface sea temperature (SST) variations in the Tropics (e.g.,

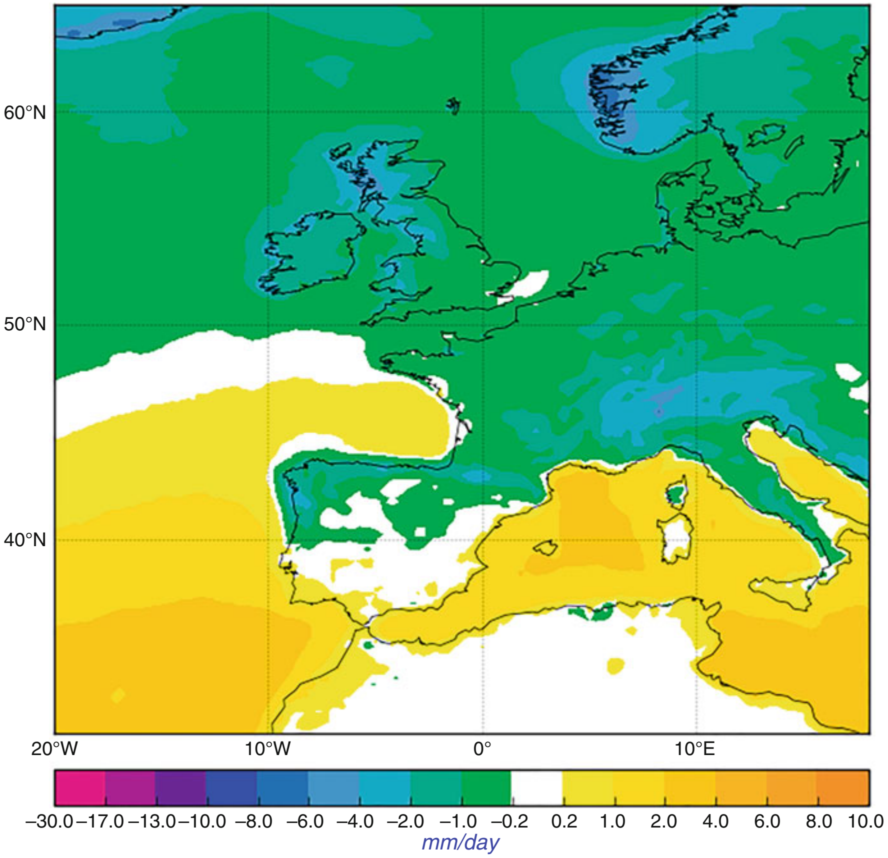

Fig. 3.10 Mean annual evapotranspiration minus precipitation (E−P) for the period 1979–2017, obtained from the ECMWF ERA5 reanalysis dataset

Hoerling et al. 2001). The influences of El Niño Southern Oscillation (ENSO) (e.g., Brönnimann 2007), and the dust intrusions from the Sahara (e.g., Evan et al. 2016) should not be neglected.

3.1.2 *Winds*

The presence of strong synoptic-scale pressure gradients in the mountainous area surrounding the Alboran Sea, originates regional windstorms that are accompanied by a number of distinctive local phenomena on smaller scales, including gap winds, mountain waves, local downslope winds, wake turbulence, blocking of low altitude winds, rotor clouds, hydraulic jumps, etc. (Wallace and Hobbs 2006). When an extratropical cyclone propagates eastward across the Iberian Peninsula, and the cold

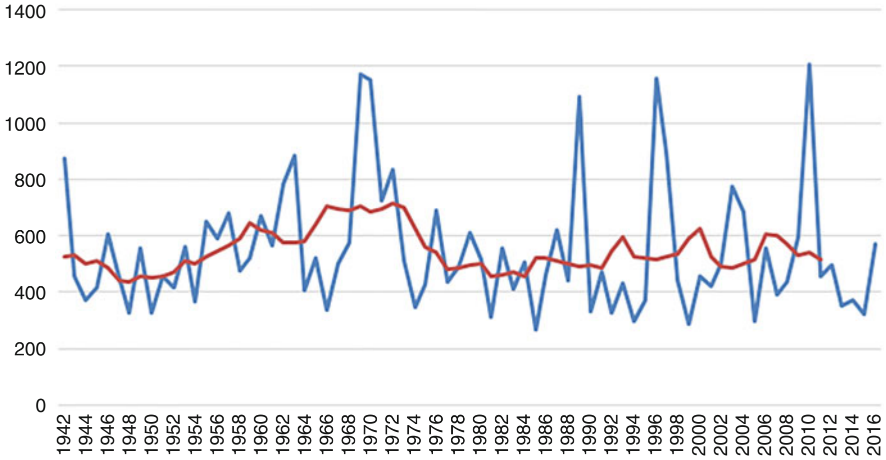

Fig. 3.11 Annual precipitation (mm) recorded at AEMET Malaga station (blue line) and 9-years running precipitation mean (red line). Source: AEMET

low altitude northern winds in the rear of the cyclone result blocked upstream of the Alboran coastal mountain ranges, strong pressure gradients develop across the ranges and the air flows southward through the gaps in the ranges producing northwesterly high winds over the Alboran Sea, locally called *terral winds*. As the elevation of the land surface is higher on the windward side than on the leeward side, *terral* winds will be warm because of adiabatic warming, and their relative humidity when it completes its descent may be very low. The airflow off the north coast of Alboran tends to be complex with gusty winds inside and downstream from the canyons and lighter winds elsewhere, but the extreme warmth and dryness of the downstream air masses are pervasive.

Easterly high winds, denominated *levanter winds*, occur very frequently in the Strait of Gibraltar. Levanters can be synoptic or mesoscale events. Synoptic levanters are regional winds that extend far beyond the Strait, from the Mediterranean into the Atlantic covering the Alboran Sea and part of Iberia and reaching upward into the upper troposphere. Isobars present east–west orientation. The interaction of the easterly flow with the mountains that close the Alboran Sea to the west, and even the flow interaction with the further south Atlas Mountains, make that wind in the Strait and over the Gulf of Cadiz acquire characteristics of regional downslope windstorm. A low-pressure center locates offshore the Atlantic coasts of Morocco, which sometimes is observed as a low cloud vortex in satellite images (Fig. 3.12).

Mesoscale levanters occur only over immediate Strait and usually below 1000 m (Dorman et al. 1995). Winds increase to the west, so that highest velocities take place near Tangier, and isobars are aligned at right angles to the Strait. A mesoscale surface low appears centered west of the narrowest part of the Strait near Tangier, so that winds are ageostrophic. Mesoscale levanters are a consequence of the cold air

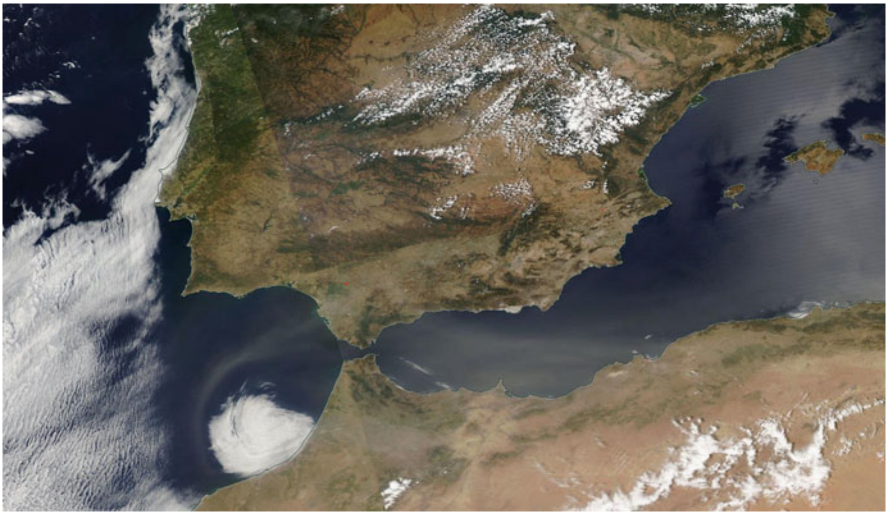

Fig. 3.12 Satellite image of a synoptic levanter windstorm event; clear sky and dust contrails leeward the Gibraltar Strait and a low cloud vortex off the northwest coast of Morocco. Satellite Terra, July 10, 2016, 11:05 UTC Source: NASA Worldview

damming in the Mediterranean basin. Frequent surges of cold air from the North Atlantic cross Western Europe and fill the western Mediterranean with subsiding air, being often these air masses shallow enough to be blocked by coastal mountain ranges. In these circumstances, the cool air filling the Alboran Sea escapes through the Strait of Gibraltar toward the Atlantic Ocean like water through a broken dam (Scorer 1986).

High-speed levanter winds (18–24 ms^{-1}) occur at about the same frequency in summer and winter, but frequency of these wind synoptic events strongly increases in the summer just following an El Niño event (Sanchez-Laulhe 2018).

In the Western Mediterranean, cold air associated to extratropical cyclones enters most frequently through northern mountain gaps, principally Rhone and Ebro Valleys. This cold air mass can expand first southward along the coastal mountain ranges at the eastern of the Iberian Peninsula, and then westward, along the north coast of the Alboran Sea. This expansion is associated to the displacement along the coast of a trough or a sea level pressure low, generated by downslope flow to the south of an extratropical cyclone. Sometimes, the easterly "cold" Mediterranean airstream converges over the Alboran Sea with the warm *terral* winds creating strong temperature, humidity, and density gradients. These gradients create imbalances on the north coast resulting in the advance westward of the cold air as a density stream along the coast (Sánchez-Laulhé and Polvorinos 1999).

Because of damming, very often, the Alboran sub-basin behaves as a channel for the atmospheric marine boundary layer, as reflected in the climatological wind roses shown in Fig. 3.13a, b (Guijarro et al. 2015).

Other phenomena related to wind blocking in the marine boundary layer (MBL) are the formation of hydraulic features along the coast when flows are transcritical

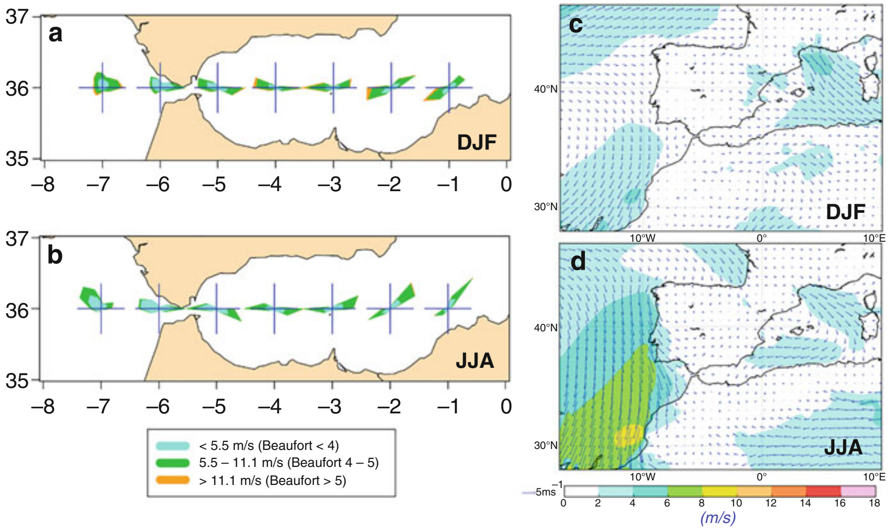

Fig. 3.13 (**a**) and (**b**) Climatological wind roses in winter (DJF) and summer (JJA) adapted from Guijarro et al. (2015); (**c**) and (**d**) 10 m vector wind (ms^{-1}) with isotachs (ms^{-1}) averaged for winter and summer, respectively, over the ERA-5 period 1971–2017 information [2017]

(Froude number (ratio of flow speed to phase speed of internal waves) is between 0.5 and 1) or supercritical (Sánchez-Laulhé 2001). Expansion fans form at convex bends in the coastline, such as Cape Gata, where the flow in the MBL diverges, the MBL thins, and wind speed increases. Compression bulges form at concave bends in the coastline where the flow in the MBL converges, deepens, and wind speed decreases, developing a blocking high in sea level pressure field, as it occurs in mesoscale levanter events windward the Strait of Gibraltar. The alongshore wind stress on the sea surface close to the coast induces offshore Ekman transport of the upper ocean layer and induces coastal upwelling of the cooler water from below.

Waterspouts and non-mesocyclone tornadoes (landspouts) (Lee and Wilhelmson 1997) are frequents in winter along the Spanish Mediterranean seacoasts, as can be seen in Fig. 3.14, where a maximum of events in the Alboran west coast can be observed. Mostly they are primarily F0 or F1 in the Fujita scale of tornado intensity, although F2 have also occurred, and there is a historical reference of F3 tornado in the Cádiz Gulf (Sánchez-Laulhé 2005). Waterspouts of a more intense kind than F1 are generated in convective storms. The most intense waterspouts form immediately after the presence of a strong cold outflow directed from land to sea at surface, associated with mature convective cells. It is hypothesized that this cold outflow would surround an existing misocyclone, enhancing the convergence within, that in turn would develop new deep convection causing the misocyclone to become a tornado (Lee and Wilhelmson 1997). Another hypothesis is that the tornado would be formed by tilting of horizontal vorticity in a hydraulic jump generated as a result

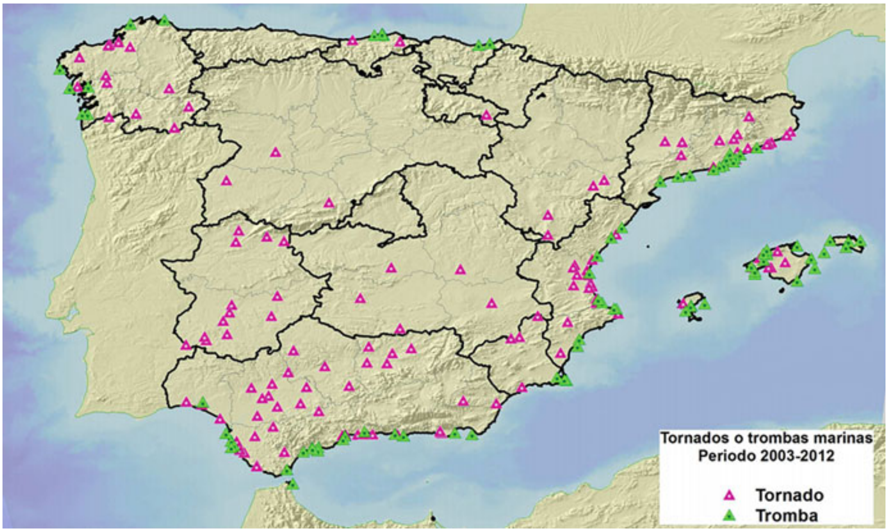

Fig. 3.14 Waterspouts and tornadoes observed in the period 2003–2012 (Riesco et al. 2015)

of the interaction of the cold outflow with the marine boundary layer (Sánchez-Laulhé et al. 2017).

3.1.3 *Aerosols*

The Mediterranean region is affected by large aerosol loads from anthropogenic and natural sources forcing the regional climate. These aerosols include sea-salt aerosols from the Mediterranean Sea and the Atlantic Ocean, pollution aerosols from Europe, dust from the Sahara Desert, and biomass burning aerosols. The largest and most active dust source worldwide is the Sahara Desert. Saharan dust outbreaks can carry large amounts of particulate material over the Mediterranean region and the Atlantic Ocean. Figure 3.15 shows the global dust aerosol optical depth (AOD) averaged over the period 2003–2012, with data taken from the ECMWF MACC reanalysis dataset (Inness et al. 2013). Dust peaks in summer over the western Mediterranean (not shown).

Dust affects climate modifying not only the radiative budget through their microphysical and optical properties (e.g., Foltz and McPhaden 2008; Bergamo et al. 2008). Moreover, Saharan dust deposition triggers marine phytoplankton growth in both the North Atlantic (Ravelo-Pérez et al. 2016) and the Mediterranean Sea (Gallisai et al. 2014), playing a key subsequent role in controlling the chemical composition of sea water and hence in the carbon cycle (Conway and John 2014).

African dust emission and transport exhibit a high variability from diurnal (Cuesta et al. 2009) to multi-decadal time scales (Wang et al. 2015; Evan et al.

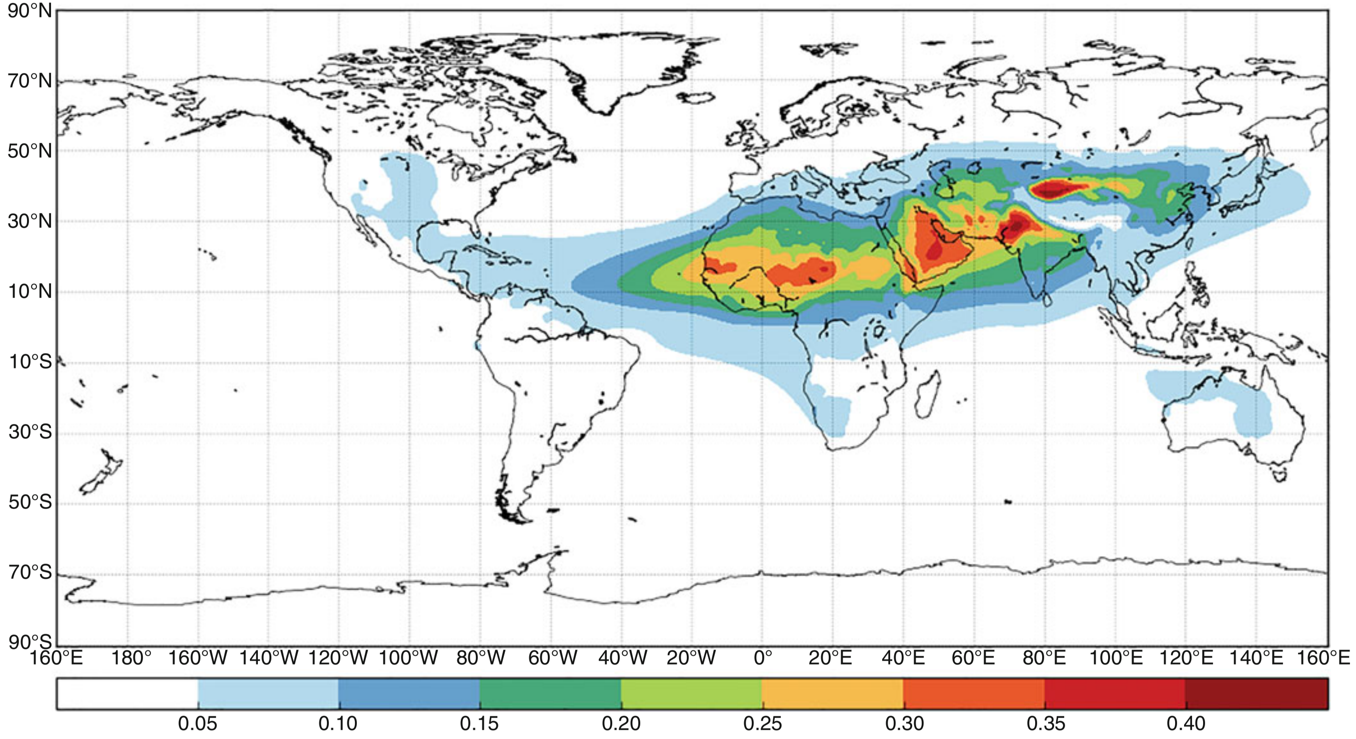

Fig. 3.15 Dust aerosol optical depth averaged over the period 2003–2012. AOD data are taken from the ECMWF MACC reanalysis dataset

2016). The seasonal variation of Saharan dust outflows has been reasonably well studied in affected regions (Barnaba and Gobbi 2004; Israelevich et al. 2012; Prospero et al. 2014). Inter-annual dust outflow variations are relatively well-known in winter period (Nakamae and Shiotani 2013), mostly associated with the NAO (Chiapello et al. 2005; Ginoux et al. 2004). However, only in recent years research on inter-annual variations of Saharan dust outflows during summer period has been carried out (i.e., Ben-Ami et al. 2009; Rodríguez et al. 2015). In this season, Saharan dust mobilization shows its peak (Engelstaedter and Washington 2007). On subseasonal and synoptic timescales, the Sahara Heat Low migrate around its location, shown in Figs. 3.20 and 3.21, and pulsates in strength as it interacts with midlatitude weather systems (Thorncroft and Flocas 1997; Chauvin et al. 2010; Roehring et al. 2011; Cuevas et al. 2017).

Air pollution emissions by industries and large urban areas around the Mediterranean and in central Europe can further affect regional air quality, surface energy, and water budgets (Lelieveld et al. 2002). Biomass burning and forest fires constitute another important source of carbonaceous aerosols in summer (Sciare et al. 2008).

The decrease of anthropogenic aerosols over Europe resulting from air pollution policies (Turnock et al. 2016) has been pointed out as an important contributor to the enhanced western European summer (Junie-August) warming since the mid-1990s (e.g., Dong et al. 2017).

3.1.4 *Temperature*

Mean seasonal 2m temperatures in the area are shown in Fig. 3.3. The temperature seasonal cycle in the area is affected by the thermoregulatory effect of the sea, and also by orography. In winter, accurate temperature gradients exist between the mountainous high lands and the warmer Alboran Sea. On the contrary, in summer, although there are temperature gradients from the sea toward the warmer lands, it is outstanding the gradient across the Atlas Mountains, which form a barrier to the hot and dry summer Sahara air mass. The SST annual cycle in the Alboran point 36° N 3° W is shown in Fig. 3.16.

In winter (also in spring and fall), extremely cold temperatures are associated with the Atlantic Ridge weather regime (Trigo et al. 2006; Cassou 2009). In summer extreme warm temperatures are associated with blocking conditions, subsidence and stability, and an east–west dipole over the Euro-Atlantic sector (Xoplaki et al. 2003), which corresponds to the Atlantic Low weather regime (Cassou et al. 2005).

Báez et al. (2013) found that variation in both mean annual SST and mean winter SST in Alboran were significantly related to the mean autumn NAO of the previous year, while mean summer SST was related to mean autumn AO of the previous year.

In the north coast of Alboran, extreme maximum temperature occur usually in summer during a downslope wind event. This downslope wind occurs with advection of a warm air mass of tropical origin from the Atlantic Ocean toward the Iberian Peninsula, followed by overheating when the air reaches the coast of Alboran as a *terral* wind. In the south coast, downslope (southerly) winds are rare and its duration

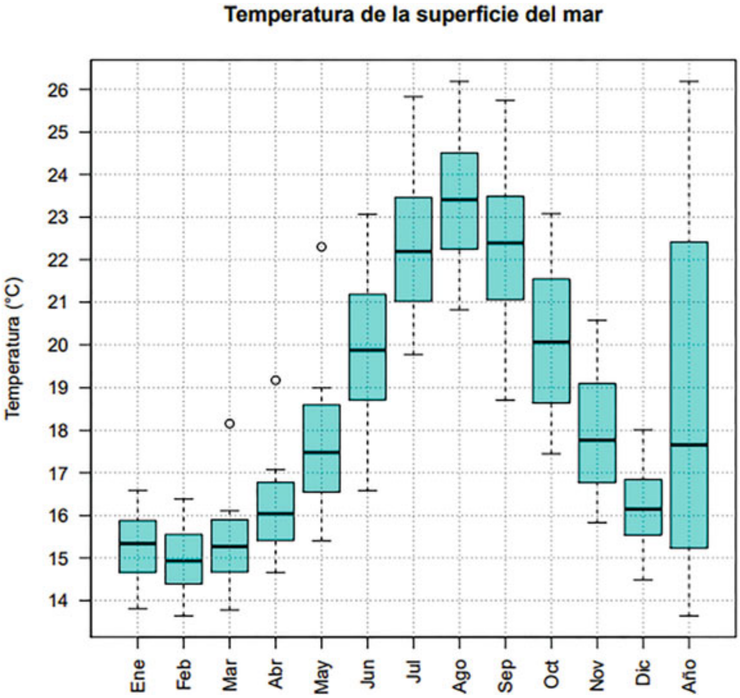

Fig. 3.16 SST annual cycle in the Alboran point 36° N 3° W. The edges of the boxes of box correspond to 25th and 75th percentiles of the data distributions, and the central bold bars denote the mean. The minimum and maximum values are denoted with a horizontal dash in the upper and lower limits of whiskers. Isolated points are data that distance from the box more than 1.5 times the interquartile range (Adapted from Guijarro et al. 2015)

is much lesser, leading to extraordinary temperature oscillations (Sánchez-Laulhé 2004).

3.1.5 Climate Trends and Climate Change

The Mediterranean is often referred to as a climate change "hotspot" since it exhibits larger changes than many other regions of the globe (Giorgi 2006; Giorgi and Lionello 2008).

Precipitation and temperature in the Mediterranean during the twentieth century show significant trends. Gauge-based reconstructions, gauge-satellite merged products, and atmospheric reanalyses have indicated a negative precipitation trend for the Mediterranean in winter in the twentieth century (Giorgi 2002; Mariotti et al. 2002), although high uncertainties affect the observation records in the early part of the century. Besides, the extent to which the anthropogenic climate change has contributed to the observed trend is still unknown due to limited knowledge of the amplitude of internal climate variability on multi-decadal to centennial timescales (Hoerling et al. 2012; Kelley et al. 2012; Mariotti et al. 2015; Zappa et al. 2015).

Giorgi (2002) found a significant warming trend of 0.75° C in 100 years, over the larger Mediterranean land area for the twentieth century. Over most of the western Mediterranean, warming has been mainly registered in two phases: from the mid-1920s to 1950s and from the mid-1970s onwards (e.g., Xoplaki et al. 2003).

Rapid European summer warming has occurred since around 1990 (Bador et al. 2016) at a rate of around 2.5 times the global mean temperature increase (van Oldenborgh et al. 2009). This warming was largest in western and central Europe and in the Mediterranean, with record-breaking heat waves and extreme temperatures.

Using CM-SAF data records (Schulz et al. 2009), Kothe et al. (2017) and Pfeifroth et al. (2018) found a slightly positive linear decadal trend in sunshine duration and in surface sun radiation, respectively, in the Mediterranean, Europe, and North Africa for the time period 1983–2015.

An increasing trend in the occurrence of extreme winter precipitation events (from heavy to torrential) in Spain and Italy has been identified by Toreti et al. (2010).

In a similar way, observations from the last decades reveal a warmer and drier scenario in the Iberian Peninsula in comparison to past decades. In particular, temperatures have shown strong increases since the 1960s, so Brunet et al. (2009) showed that in the period 1973–2005 the average rate of change estimated for average temperature in Spain was 0.48 °C per decade, while Vicente-Serrano et al. (2014) estimated this rate in 1.5 °C in the five decades 1961–2011 in the Iberian Peninsula. Consequently, the annual evaporative demand by the atmosphere increased, estimated at 7.3% by Vicente-Serrano et al. (2014). Meanwhile, the relative humidity has shown a strong decrease with no significant changes in specific humidity (Vicente-Serrano et al. 2014). The tendency toward the decrease of the

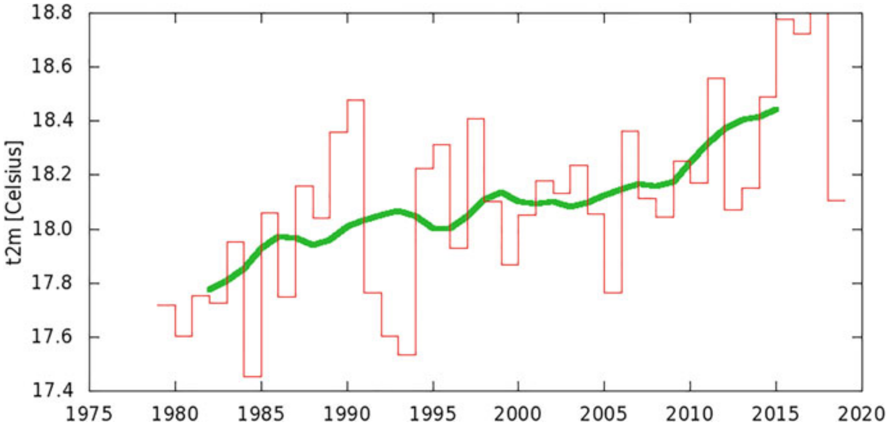

Fig. 3.17 SST annual mean (red line) and 10-years running mean (green line) series in 3° W, 36° N, for the ERA-5 dataset period 1979–2018. Plot obtained using the Climate Explorer tool (https://climexp.knmi.nl)

precipitation accumulations for subtropical latitudes, pointed out by the IPCC, is not easy to verify for the Iberian Peninsula, given the complexity of the precipitation spatial distribution and temporal concentration, which needs the use of a considerable number of long climatic series. Most studies do not show significant precipitation trends for the whole Peninsula, but some of them show a decreasing trend in the south of the Peninsula (Rodrigo et al. 1999; Castro et al. 2005; Caloiero et al. 2018).

Satellite observations from 1985 to 2006 indicate that in the last two decades the temperature in the upper layer of the Mediterranean Sea has been increasing at an average (±SD) rate of $0.03 \pm 0.008\ ^{\circ}\mathrm{C}\ \mathrm{year}^{-1}$ for the western basin (Nykjaer 2009; Fig. 3.17).

Global climate models predict that, under increasing greenhouse gas concentrations, the Alboran area, like the rest of the Mediterranean region, will be affected by large temperature increases and precipitation reduction (Christensen et al. 2013). In addition, it will suffer pronounced circulation changes, which together with the hydroclimate changes, will result in a reduced P-E over the Mediterranean region in the future year-round (Hoerling et al. 2012; Zappa et al. 2013; Seager et al. 2014; Simpson et al. 2014). The IPCC 2013 report indicates that there is medium confidence that droughts will intensify in the twenty-first century in southern Europe and the Mediterranean region due to reduced precipitation or increased evapotranspiration, or both.

Water resource is a critical issue for a large part of the Mediterranean basin. Freshwater is unevenly distributed in time and space with few short-duration heavy precipitation and long drought periods. Such a situation occurs against a background of increasing water demand and aggravates with climate change (HyMeX 2010). In a context of climate change, the Mediterranean region population is confronted with challenging environmental changes, such as short-time extreme events (heavy precipitation, flash floods, etc.) and long-term modifications (change in access to water resources, droughts, etc.) (Drobinski et al. 2014).

3.2 Large Scale and Synoptic Systems in the North Atlantic-European Sector

3.2.1 Large-Scale Circulation

The climate in a region is controlled by the long-term mean atmospheric (and oceanic) circulation, transient eddies of both high and low frequency: baroclinic eddies and weather regimes, respectively. All of them have dependence largely on latitude and latitude, mainly due to the insolation and the planetary waves, respectively, and of other physical and physicogeographical factors like altitude and orography, land–sea interactions (distance from the sea), and smaller scale processes (Xoplaki 2002).

The seasonal mean atmospheric general circulation can be considered as the sum of two components, a zonally symmetric one represented by the zonal mean winds and another zonally asymmetric one formed by standing planetary waves originated by orography and land–sea temperature contrasts (Hoskins and Karoly 1981; Held et al. 2002). The asymmetric component takes the form of persistent highs and lows in low levels, which, for example, shape midlatitudes and subtropical dry zones (Broccoli and Manabe 1992; Rodwell and Hoskins 1996, 2001) and guide extratropical storms.

The main elements of the general circulation can be described by both, the stream function, ψ, and the velocity potential, χ. The atmospheric flow is largely determined by the ψ: winds follow streamlines, leaving ψ higher values to the right, and being their intensities proportional to the separation between streamlines. As for vertical movements, there are ascents in tropospheric regions with relative minimums of χ in upper levels of the troposphere and relative maximums in low levels, and the opposite for descents. The maps in Fig. 3.18 (obtained from the ERA-40 dataset; Kållberg et al. 2007) show ψ and χ at 200 hPa, and 850 hPa for troposphere in winter, December to February, and in summer, June to August. It is perceivable from the streamlines at 200 hPa the presence of planetary (wavelength of the order of the Earth's radius) stationary waves, and a predominance of westerly winds, especially intense for winter of each hemisphere. Zones of intense ψ gradient correspond to the mean position of jet streams. Only in the equatorial zone of the maritime continent and Africa in DJF, and in the most equatorial zone of the boreal hemisphere in JJA, due to the intense anticyclone of the South Asian summer monsoon, the wind is from the East.

In low levels, westerlies are also the predominant winds in middle latitudes (Fig. 3.18b, d), although less intense than at high levels because of the strong west vertical wind shear due to the sharp southward temperature gradient. In the Tropics, however, easterly winds, called trade winds, dominate throughout the year. Between middle and low latitudes, there exists a zonal belt of ψ maximum that corresponds to the subtropical anticyclonic zone.

Subtropical jet streams, in Northern Hemispheric (NH) winter (*SJ* in Fig. 3.19a) at about 30° N, separate two different flow regimes, the mid-high latitudes regime and the tropical regime. The NH stationary waves present, in both extratropical and tropical latitudes, three major troughs and three major ridges/anticyclones at high levels, with an abrupt change in the longitudinal phase across 30° N. Tropical troughs (ridges) and extratropical ridges (troughs) align in north–south direction, with strong subtropical jet streams between major extratropical troughs and major tropical ridges and the storm tracks immediately on the northern flank of the strong subtropical jet over the oceans. In the NAE sector, a strong subtropical jet stream (*ST* in Fig. 3.19a) occurs between the *extratropical North America trough* and the *tropical western North Atlantic ridge* (*T* and *R*, respectively in Fig. 3.19a). The subtropical jet weakens eastward because of the relatively low sea surface temperatures (SSTs) in the equatorial Atlantic Ocean, and it peaks up between the *Central Europe-Mediterranean Sea trough* and the *East Africa ridge*.

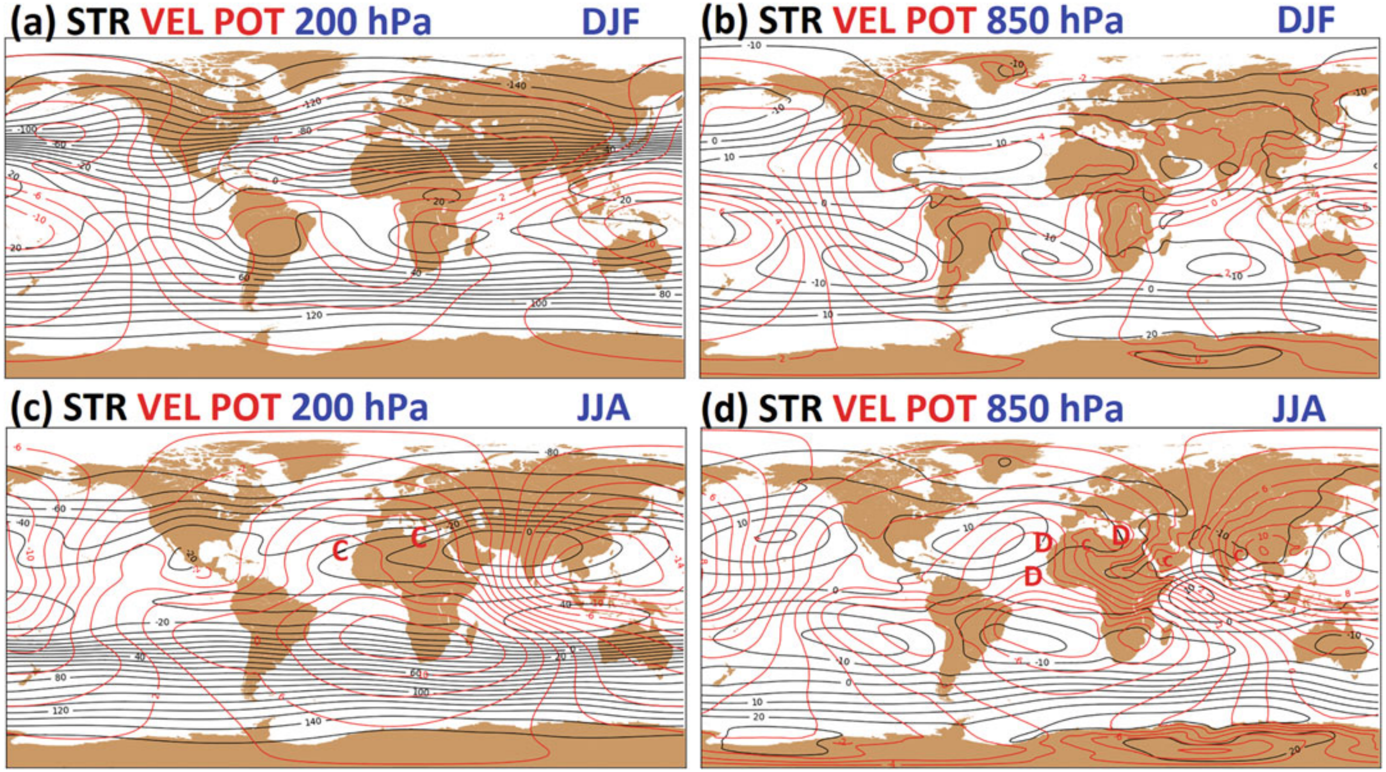

Fig. 3.18 Summer (JJA) and winter (DJF) averaged at 200 hPa and 850 hPa stream function ($10^6\ m^2s^{-1}$; black contours) and velocity potential ($10^6\ m^2s^{-1}$; red contours), for the ERA-40 period 1958–2001

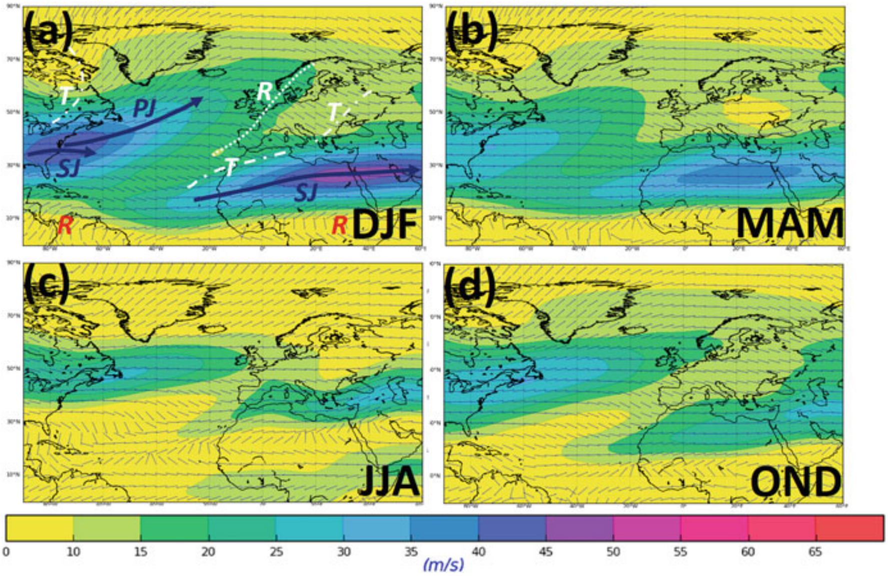

Fig. 3.19 Seasonal averaged 250 hPa winds, for the ERA-40 period 1958–2001. In winter (**a**) location of: *SJ* subtropical jet, *PJ* polar jet, *R* ridge, and *T* trough are marked

The Alboran area is located downstream of the midlatitude *western Europe ridge* and the *subtropical eastern North Atlantic–North Africa trough*. The climatological strong European ridge is the region where global highest mean values of atmospheric blocking are found. The subtropical trough extending from eastern North Atlantic to North Africa marks the cutoff low track resulting from Rossby wave breakings associated to blockings.

The relationship between asymmetric components of low and high levels varies from tropics to extratropics (Chen 2005). In extratropics, where temperature advections are important, Rossby dynamics is predominant. Asymmetries in low levels are advanced one-quarter of wavelength with respect to the corresponding ones in high levels, being descents (ascents) and ridges/anticyclones (low-pressure systems) in lower levels downstream ridges (troughs) in upper levels. In Tropics, effects of temperature advections are one order of magnitude lower than effects of diabatic heating from vertical convection, prevailing Sverdrup dynamics. Asymmetries in low levels are in quadrature with respect to high levels: above a low-level trough (ridge) exists a high-level ridge (trough). In agreement with Sverdrup vorticity balance of the steady flow (Rodwell and Hoskins 2001)

$$\beta v = f\frac{\partial \omega}{\partial p}. \tag{3.1}$$

In Eq. (3.1), v is meridional wind, f is the Coriolis parameter and β its meridional gradient, and ω the vertical velocity in pressure coordinates in the vertical. Low (upper) tropospheric ascents, associated with poleward flows, exist between low-pressure troughs (ridges) at west and anticyclones (lows) at east. Conversely, tropospheric descents, associated with equatorward flows, exist in lower levels between high (low) pressure systems at west and low (high) pressure systems at east.

Consequently, Atlantic *midlatitudes trough in lower levels* (Fig. 3.18b), or alternatively the *Icelandic low in surface* (Fig. 3.19a), stands downstream the upper-level North America trough (Fig. 3.18a), and the *eastern North Atlantic ridge* at 850 hPa is located downstream the upper-level ridge. However, the subtropical Azores high is located under the subtropical North Atlantic trough.

In summer, southwards gradients of ψ, and therefore westerlies, decrease considerably because of the reduction of pole-to-equator temperature gradients (as compared to winter), and amplitudes of extratropical stationary waves reduce accordingly. On the contrary, monsoons cause that asymmetries of the tropical–subtropical zone be more marked, extending the Sverdrup regime up to about 40° N. Thus, low latitude upper levels circulation is characterized by two oceanic troughs and two anticyclones, the Mexican anticyclone, associated to the North American

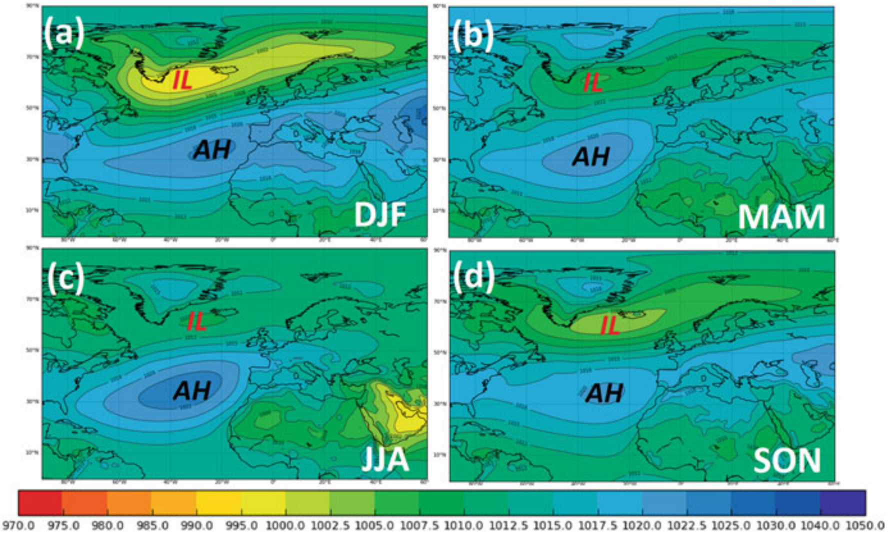

Fig. 3.20 Seasonal averaged mean sea level pressure, obtained for the ERA interim (Berrisford 2011) period 1979–2017 (*AH* Azores high, *IL* Iceland low)

monsoon, and the very prominent Tibetan anticyclone, associated to the Asian monsoon, that extends westward over North Africa.

The western African monsoon is peculiar, of a much smaller size than the other two NH monsoon systems, and situated deep in the Tropics. It is associated, with a lower level Saharan heat trough centered over North Africa, with a Saharan anticyclone in the middle troposphere—under the western side of the Tibetan high- and with a mid-level jet east of the peripheral southern part of the Saharan high. Unlike other monsoons, precipitations of the African monsoon locate in the south flank of the Saharan monsoon high.

The oceanic subtropical anticyclones are outstanding features in seasonal maps of sea mean level pressure. Located at about 30° latitude in both hemispheres, under the average position of the subtropical jet stream, they occupy 40% of the surface of the globe and exist throughout the year. Subtropical anticyclones appear as a maximum of ψ in lower levels (Fig. 3.18), reaching mean pressure maximum values, except in the case of the winter Siberian high (Fig. 3.20). Subtropical anticyclones play a central role in the Earth’s climate system. To a large extent, they connect the tropical and the midlatitude atmospheric regimes, determine tropical cyclones tracks and subtropical deserts location, and drive oceanic subtropical gyres and hence also the warm western boundary currents that carry warm waters to poles.

Extension, position, and intensity of the North Atlantic subtropical anticyclone—the Azores High—varies throughout the year. In the winter, the Azores High is part of a zonal belt of high pressure whose primary forcing is attributed to the strong zonal-mean descent branch of the Hadley global cell in the wintertime Hemisphere. Planetary-scale waves modify the belt of high pressure; so, the eastern North America trough shrinks the west flank of the Azores High while the eastern North Atlantic ridge stretches the east flank. The Mediterranean Sea low-pressure area, which is a prolongation of the Central Europe trough, interrupts the subtropical belt of high pressure. This fact is imputed to the high population of Mediterranean cyclones, partly determined by excursions of the Polar Jet Stream and the European trough in winter, which favors cyclogenesis over the area (Xoplaki 2002). Poleward of the Azores High, intense pressure gradients can be successively observed that are associated to the westerly midlatitude winds and the Iceland subpolar low-pressure zone. The Iceland Low presents a cellular aspect, and is due to both, thermal effects in lower levels of the relatively warm underlying ocean, and its position downstream of the major North America trough at the upper troposphere, where the storm track is located. The Azores High is the only subtropical anticyclone maintaining in the winter season a certain cellular structure, and forming a meridional pressure dipole together with the Iceland Low. The pattern of variability in the intensity of this pressure dipole is known as the North Atlantic Oscillation (NAO), very interrelated to the hemispheric Arctic Oscillation.

The Azores High moves in summer over the Atlantic basin poleward and expands, primarily due to the contraction of the Iceland Low. This contraction is caused by the considerable continental warming from 60° to 90° N and the subsequent decrease in temperature difference with the ocean, with the consequent loss of baroclinicity and reduction of the processes of cyclogenesis. Moreover, in terms of intensity relative to the zonal mean pressure, Azores High reaches its peak. In this season, the Azores High shows a cell-type configuration with a ridgeline following a northeast–southwest orientation, approximately similar to that of the African Atlantic coastline. The western Mediterranean basin is dominated by the expanded subtropical ridge that toward the east is displaced southward by a trough extending northwest from the Arabian Gulf, which is a prolongation of the Indian summer monsoon depression. A tight pressure gradient along the coast appears between the Azores High and the Saharan thermal trough and, to a lesser extent, between the Azores High and the Iberian thermal trough.

On eastern flanks of subtropical anticyclones there exist regions of strong atmospheric descent, notably intense in summer, showing a maximum (minimum) of χ in upper (lower) levels (Fig. 3.18), determining mostly dry weather. Similar summer descent regions of subtropical anticyclones appear on coastal regions of California, Chile, southwest Africa, and Australia, and the Mediterranean basin. The climates of all these regions, including the Alboran sea area, can be classified as “Mediterranean type.” Where skies are not clear, maritime clouds are of low type, mostly stratocumulus developed in the maritime boundary layer (MBL). Above the MBL, there is a relatively shallow layer—either isothermal or containing a subsidence inversion—that acts as a convectively stable interface separating the MBL air from the potentially, or actually, warmer, middle troposphere air. This layer has very low relative humidity, due to the predominant, faint but persistent, large-scale subsidence prevent cloudiness formation or maintenance.

There is no unanimity on the primary forcing mechanism involved in the formation and intensification of subtropical anticyclones in summer. Rodwell and Hoskins (2001) suggested that the Mediterranean-type climates may be induced remotely by the monsoon to the east, attributing as primary forcing for the air adiabatic descent over the eastern North Atlantic, the interaction between the large scale Rossby wave forced by the diabatic warming of the Asian monsoon and the midlatitude westerlies. Below the descent, feedbacks, involving SST and MBL clouds, further enhance descent over these regions. However, other studies (Miyasaka and Nakamura 2005; Nakamura 2012; Wu and Liu 2003) suggested that the formation and variation of Azores High are mainly determined by the spatial distribution and variations of diabatic heating, producing a tight thermal contrast between the heated dry landmasses over the western portion of the North-Western Africa and the relatively cool ocean off the coast.

The summer atmospheric circulation over the Mediterranean basin is characterized by localized intense subsidence and low-level northerlies over the central to eastern portion of the basin, presenting χ another maximum (minimum) of in upper (lower) levels (Fig. 3.18). This subsidence was attributed by Simpson et al. (2015) to the influence of the elevated terrain of the Middle East on the Mediterranean summertime circulation. Between the strong descents and low-level northerlies over both the eastern Atlantic and the central to eastern Mediterranean, there is an area of ascent, that include Alboran, attributed to the interaction between the Atlas Mountains Range and the predominant low-level easterly winds. Descents areas in summer on the Mediterranean and subtropical East Atlantic are marked by “C” (wind convergence) at 200 hPa (Fig. 3.18c) and by "D" (wind divergence) at 850 hPa (Fig. 3.18d).

Wei et al. (2018) showed that dynamical and thermodynamical interactions between the summertime MBL clouds, Azores High circulation, and local SSTs in the subtropical North Atlantic constitute an important aspect of the summer interannual climate variability.

The intensity of subtropical highs over the NH oceans during summer has changed in recent years. However, whether such changes are related to climate warming remains unclear.

The hydrological cycle is linked to the general circulation of the atmosphere by water vapor transport. The symmetric component of the general circulation explains around 40% of the total spatial variance of annual mean net precipitation (precipitation minus evaporation, P–E): precipitation in tropics occurs in the intertropical convergence zone, leading to vertical motion and moisture transport and forming the ascending branch of the Hadley cell. In the subtropics, strong subsidence associated with the descending branch of the Hadley cell leads to a minimum in precipitation and a region of net evaporation. Poleward this dry zone, transient eddies transport water vapor into midlatitudes, where precipitation associated to storm track eddies is high, leading to positive net precipitation. Part of the spatial variance rest of annual mean P–E is due to asymmetric component of the circulation, taking the form of extratropical stationary Rossby waves, dry subtropical lows, monsoons, storm tracks, and Walker circulations (e.g., Wills and Schneider 2015).

Under global warming, model-based studies have diagnosed a weakening and poleward expansion of the Hadley circulation, and poleward expansion of the subtropical dry zone (e.g., Lu et al. 2007); an intensification of summertime highs (Li et al. 2012); and changes in the structure of stationary waves (e.g., Wills and Schneider 2018). These changes in the general circulation could cause an increasing anticyclonic circulation over the Mediterranean area in winter at the end-of-century, as diagnosed in various studies (Giorgi and Lionello 2008; Hoerling et al. 2012). The atmospheric mechanisms involved and its relevance for the climate change response have not been clarified yet. Changes in the North Atlantic SST and storm track (e.g., Woollings et al. 2012) might be important. Increased high pressure over the Mediterranean in winter is related to increase mass divergence that could have large regional impact on the hydrological cycle tending to cause a stronger negative P–E. Such changes have already had implications on the increasing aridification of the Mediterranean region (Seager et al. 2014).

The Arctic is warming more than twice as quickly as the global surface average. This phenomenon is known as "Arctic amplification." It stems predominantly from the rapid loss of sea ice cover in the region that is one of the most striking manifestations of climate change (Kay et al. 2011; Stroeve et al. 2012). Some studies have shown that the Arctic sea ice decline can significantly affect the large-scale atmospheric dynamics at mid-to-high latitudes of the Northern Hemisphere by altering storm tracks, jet stream (position and strength), and planetary waves (Deser et al. 2010; Screen et al. 2013; Peings and Magnusdottir 2014a). Two effects are identified by Francis and Vavrus (2012), which each contributes to a slower eastward progression of Rossby waves in the upper-level flow: (1) weakened zonal winds, and (2) increased wave amplitude. These effects are particularly evident in autumn and winter consistent with sea ice loss, but are also apparent in summer, possibly related to earlier snowmelt on high-latitude land. Slower progression of upper-level waves would cause associated weather patterns in midlatitudes to be more persistent, which may lead to an increased probability of extreme weather events that result from prolonged conditions, such as drought, flooding, cold spells, and heat waves. Grassi et al. (2013) have associated an increase in the occurrence and intensity of extreme cold events, over continental Europe, and extreme precipitation events, over the entire Mediterranean Basin, was with loss of Arctic sea ice. In

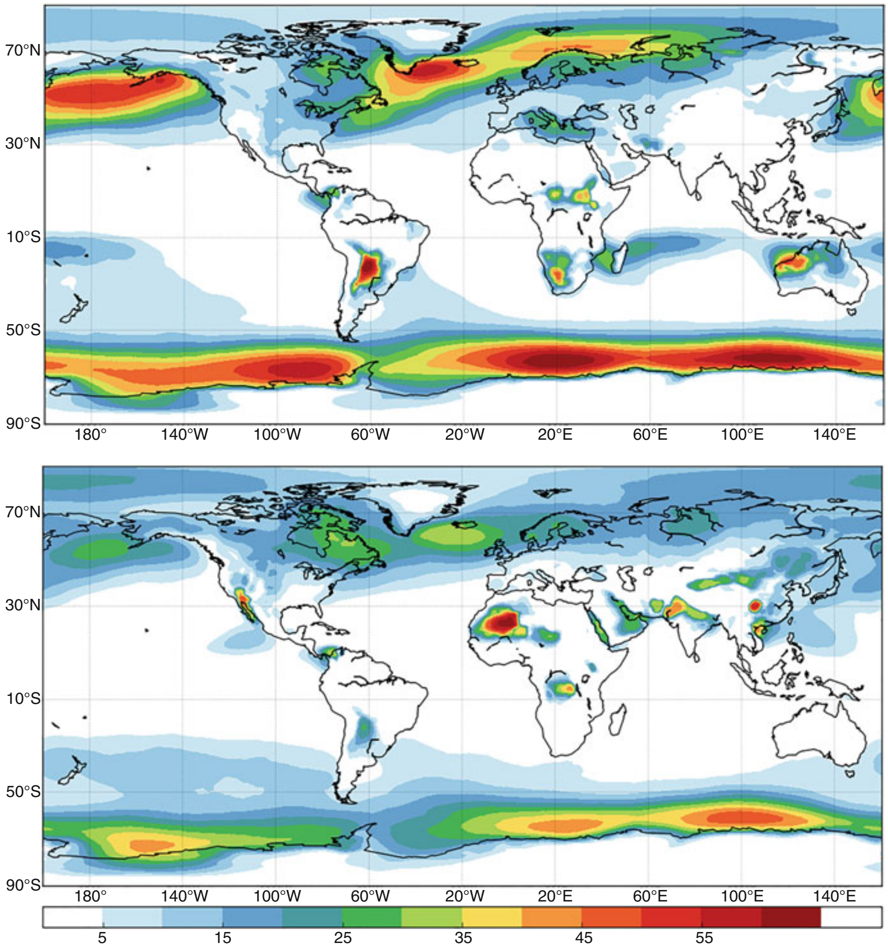

Fig. 3.21 Seasonal mean cyclone frequencies f_c (%), identified from ERA-Interim (1979–2014) interpolated on a longitude–latitude grid with 1° horizontal resolution for (**a**) DJF, and (**b**) JJA. Source: Feature-based ERA-Interim Climatologies (Sprenger et al. 2017)

particular, simulations suggest an increased risk of winter flooding in southern Italy, Greece, and the Iberian Peninsula.

Chemke et al. (2019) found that, under Arctic sea ice loss, ocean heat transport acts by transferring the Arctic signal to the tropics and by contracting the mean Hadley cell.

3.2.2 Synoptic Systems

Weather and climate in the extratropical latitudes are largely controlled by the passage of synoptic systems: baroclinic extratropical cyclones (midlatitude storms), high-level midlatitude troughs stretching toward subtropics, and high-level cut-off lows.

Observational evidence clearly shows that the midlatitude storms typically move eastward across the major oceans along definite paths called storm tracks. Climatological regions of storm tracks have been determined using cyclone tracking algorithms that generally detect minima in mean sea level pressure, or maxima in low-level vorticity, and identify them as cyclones' centers. Figure 3.21 shows the seasonal climatological maps of the Atlantic storm track obtained from the Feature-based ERA-Interim Climatologies (FEIC) datasets (Sprenger et al. 2017), which used an algorithm based on concepts presented in Wernli and Schwierz (2006). Its interpretation is straightforward, since it corresponds at every location to the percentage of time instants, f_c, that the point is located within a cyclone. The Atlantic storm track begins near the east coast of North America, on the immediate northern flank of the strong subtropical jet, coinciding the zone of maximum f_c with the Iceland Low (Fig. 3.20), and tilts slightly northeast across the Atlantic toward northwest Europe, moving away from the weak subtropical jet stream of the Central Atlantic Ocean. Its structure is primarily a consequence of the localization and strength of the North Atlantic subtropical jet. The storm track eddies tend to form in the strongly baroclinic region on the poleward side of the subtropical jet (e.g., Simmons and Hoskins 1978, 1980; Lee and Kim 2003). When the subtropical jet is strong, as it occurs in the eastern coast of North America, the preferred region for eddy activity stands on the immediate northern flank of the subtropical jet. Contrary, when the subtropical jet is weak the preferred region for eddy displaces 20°–30° poleward from the subtropical jet, as it occurs in central and eastern North Atlantic. However, Brayshaw et al. (2008) have shown that the structure of the Atlantic storm track is in an important part due to the characteristics of the North American continent.

All developing cyclones are accompanied by large poleward of both heat fluxes and zonal momentum fluxes. The poleward momentum fluxes do that the subtropical jet stream appears to be shifted poleward over the oceans (Fig. 3.19). Indeed, this displacement does not exist and a new jet stream is formed. Often, it is observed over the oceans at certains longitudes the coexistence of two jet stream systems with different characteristics: one at high latitude, denominated the eddy or polar jet, and another in lower latitudes, the subtropical jet.

The North Atlantic storm track is usually far away from the Alboran Sea, although the behavior of the storm track is highly variable and Gibraltar is one of the gates through which Atlantic cyclones enter the Mediterranean basin. In the Alboran area, the fc field presents a zonal minimum in the NAE sector longitudes, being $f_{\mathrm{c}} < 5\%$ in winter and $f_{\mathrm{c}} = 0$ in the summer, corresponding the f_c relative summer maxima over the Iberian Peninsula to the presence of heat lows.

The pattern of frequency density of Fig. 3.21 compares well with the frequency density (or track density) produced by other studies (e.g., Sinclair 1997; Sickmöller et al. 2000; Hoskins and Hodges 2002; Dacre and Gray 2009).

Besides midlatitude storms, weather in Europe strongly depends on life cycles of Rossby waves that propagate along the slowly varying part of the North Atlantic jet stream (Martius et al. 2010). Early stages of midlatitude storm life cycle are dominated by the one-way influence of the baroclinic zone on the cyclone, but in their late stages, cyclones and anticyclones may strongly modify its environment, causing the jet stream to meander over thousands of kilometers. This wavy pattern also migrates eastward, forming the transient Rossby waves. The strong meridional potential vorticity (PV) gradient associated with the jet stream serves as a waveguide for propagating Rossby waves. Frequently, small disturbances in the jet entrance region over eastern North America grow and evolve into large-amplitude features in the European sector where they often break (e.g., Schwierz et al. 2004). Rossby wave breaking (RWB) leads to the development of upper cold troughs on the equatorward side, associated to elongated tongues of high PV stratospheric air ($\mathrm{PV} > 2$ PVU; $1\ \mathrm{PVU} \equiv 1 \times 10^{-6}\ \mathrm{K\ kg^{-1}\ m^{2}\ s^{-1}}$). These structures with anomalously high PV can exert a profound far-field impact on the flow throughout the troposphere (Hoskins et al. 1985). Frequently, the high PV tongues are further stretched into narrow filaments, PV filamentation, resulting from tropopause folds, so-called PV streamers. PV streamers are widely recognized as upper-tropospheric precursors for Mediterranean cyclogenesis, and as trigger of high impact weather, in particular heavy precipitation and flooding events, when sufficient moisture is available within the lower to mid-troposphere. Several studies have related PV streamer and heavy precipitation over Spain (e.g., Jacobeit 1987; Romero et al. 1999; Nieto et al. 2007; Merino et al. 2016), over the Mediterranean region (Massacand et al. 1998; Martius et al. 2006, 2007; Raveh-Rubin and Wernli 2015), over Alps (e.g., Martius et al. 2006), and over Africa (Knippertz and Martin 2005). RWB events are also important for the large-scale flow itself as they reinforce weather regimes such as blocking ridges (Michel and Rivière 2011; Spensberger and Spengler 2014).

PV streamers eventually break up into distinct upper level cut off low systems (COLs), completely detached from the main westerly current, associated to high-PV cutoff vortices air into the troposphere (e.g., Appenzeller and Davies 1992; Nieto et al. 2008). Along with its slowly southward excursion, a COL usually maintains the characteristics of a high PV anomaly: Most COLs present a weak or moderate cyclonic flow in lower tropospheric layers, whose magnitude decreases toward the earth’s surface, low temperature and reduced static stability in the middle and lower troposphere. Because of their long-term persistence, cold vortices, interacting with

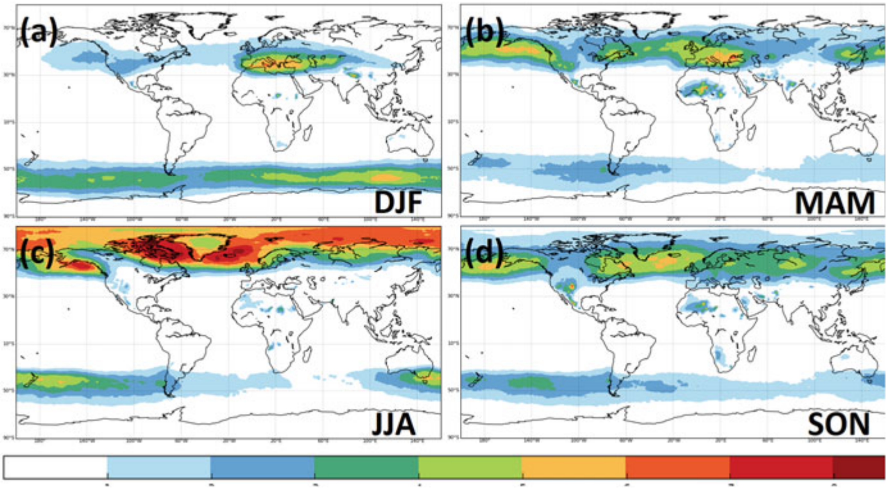

Fig. 3.22 Seasonal mean frequencies, fc (%), of stratospheric cut off on 310 K isentropic surface, period 1958–2001, for the ERA-Interim reanalyses interpolated on a longitude–latitude grid with 1° horizontal resolution for (**a**) DJF, (**b**) MAM, (**c**) JJA, and (**d**) SON. Source: Feature-based ERA-Interim Climatologies

the coastal mountain ranges, are able to organize quasi-stationary low-level warm and moist inflows toward an area of potential ascending motion and potential convective instability, and organize, primary in fall, mesoscale convective systems that can produce heavy rainfalls.

Figure 3.22 presents a seasonal climatology of frequencies, f_c (%), for stratospheric cut off events on 310 K isentropic surface in the Northern Hemisphere, that can be assimilated to a climatology of COLs, obtained from FEIC dataset (Sprenger et al. 2017) identified from ERA-Interim (1979–2014) (Dee et al. 2011) through the Wernli and Sprenger (2007) algorithm. The maps show as favored regions for COLs occurrence those located downstream end of the North Atlantic storm track, standing out the Mediterranean as a region with a particularly high number of COL episodes.

The behavior of the Atlantic storm track, and therefore the intensity and zonality of the polar jet, is affected by major large-scale atmospheric modes of variability. In particular, blocking events, NAO (Hurrell 1995; Rogers 1997; Serreze et al. 1997), ENSO (Trenberth et al. 1998; Zhang et al. 1997), and persistence of the stratospheric polar vortex (e.g., Waugh and Rong 2002; Black et al. 2006). Also, studies have also found very large interannual variability in the occurrence of COLs at the annual and seasonal scales, affected by the same large-scale modes, although without any significant trends (Nieto et al. 2007; Gimeno et al. 2007a, b).

Despite important discrepancies, most studies seem to agree with an increase in deep cyclones and in a poleward shift of the storm tracks during the second half of the twentieth century (e.g., Bengtsson et al. 2006). However, the dynamic mechanisms controlling these shifts are not well established (Mbengue and Schneider 2018).

3.2.3 Mediterranean Cyclones

The Mediterranean region is characterized by high frequency of cyclones. The near subtropical location of the basin suppresses cyclonic activity in summer, whereas it is highly populated by cyclones in winter (Petterssen 1956; HMSO 1962; Reiter 1975; Radinovic 1987; Campins et al. 2000; Nissen et al. 2010). This last fact is synthesized by the presence of a winter stationary Mediterranean trough (Fig. 3.20). In this season, the basin presents all the cyclogenetic factors: high baroclinicity, warmer than its surrounding lands, and positioned at the lee of mountain ridges (e.g., Lionello et al. 2006). The frequency of passage and the intensity of the midlatitudes cyclones play a dominant role in determining local weather and climate, being the prime contributors to precipitation (Trigo et al. 2000), but also in a way important for cloudiness, radiation, temperature, etc. (Radinovic 1987).

Most cyclones affecting the Mediterranean region develop within the basin itself and nearby areas. Although HMSO (1962) found that 42% of the cyclones were formed outside the Basin, Romem et al. (2007) estimated that only 13% of the cyclones were generated outside the Mediterranean Basin, entering the region along three different routes. The largest number of entering cyclones (46%) originated from the Sahara Desert, at the lee of the Atlas Mountains (e.g., Egger et al. 1995). The second area of origin was the Atlantic Ocean (31%), whose cyclones entered the Mediterranean Basin through Gibraltar and Biscay and continued their track eastward, mostly along the Mediterranean northern coast. The third area of origin is Western Europe (23%), mostly through the Gulf of Genoa.

Most Mediterranean cyclones are generated in the basin itself under the influence of a PV streamers, widely recognized as upper-tropospheric precursors (“parent cyclones”), playing a primary role in the development and intensification of these (Emanuel 2005; Fita et al. 2006; Chaboureau and Claud 2006; Chaboureau et al. 2012; Flaounas et al. 2015; Raveh-Rubin and Flaounas 2017). Consequently, the highly variable behavior of the storm tracks, particularly in the eastern North Atlantic, affects the frequency of cyclones having profound impact on the hydroclimate of the Mediterranean region.

Cyclones in the Mediterranean region are conditioned by topography in both their origin and life cycle. They tend to be meridionally confined and hence, have a smaller scale than north Atlantic ones and shorter lifetimes (Trigo et al. 1999). Their horizontal size differs between mesoscale (Alpert et al. 1999) and synoptic-scale (Campins et al. 2000; Trigo et al. 2002) and a number of identification and tracking methods have been developed or specifically adapted for them (e.g., Campins et al. 2011).

Passage of Mediterranean cyclones along the Alboran Sea is very infrequent because, although sometimes they originate over Alboran, they usually propagate eastward along the northern coast of the Mediterranean until reaching the Levant region where they weaken or even dissipate (Kahana et al. 2002; Flocas et al. 2010). Two major branches of cyclones initiate in western Mediterranean: (1) from the northwest Mediterranean descends along the Tyrrhenian and Adriatic Sea, (2) from south of the Atlas mountain ridge enters the central part of the basin from south-west. However, in case of strong European blocking, retrogressive upper-level cut-off lows/PV maxima of high impact can affect Alboran.

In cases of prevailing blocking regime over the European–Atlantic sector, and/or in case of negative NAO, cyclonic activity in the Mediterranean is generally enhanced. The period between 1957 and 1980 was marked by a significant increase in Northern Atlantic moderate-to-deep cyclones frequency. During this period, linked to positive-to-negative shifts of the Atlantic Multidecadal Oscillation (AMO; Knight et al. 2005; Trenberth et al. 2017) between 1957 and 1980 (Varino et al. 2018), polar regions underwent a significant cooling over the whole troposphere that increased and shifted poleward the midlatitude meridional temperature gradient and the baroclinicity.

The high variability of the Atlantic storm track has a profound impact on the Mediterranean hydroclimate (e.g., Corte-Real et al. 1995; Trigo et al. 2000; Dunkeloh and Jacobeit 2003; Xoplaki et al. 2004; Krichak and Alpert 2005).

There are indications of a poleward shift of the Atlantic storm track and a strengthening north of the British Isles, and a weakening of the Mediterranean storm track with the climate change (Bengtsson et al. 2006; Pinto et al. 2007; Zappa et al. 2013). For the period 1961–1999, Ziv et al. (2013) found a late-twentieth-century decrease in the number of Mediterranean cyclones. This was in agreement with Trigo et al. (2000), which attributed the concomitant decline in the Mediterranean rainfall to the weakening of Mediterranean cyclones. However, according to Kelley et al. (2011, 2012) and Hoerling et al. (2012), the late-twentieth-century drying was dominated by natural variability of the NAO, so that it is not necessary to appeal as a cause of this drying to rising greenhouse gases.

3.2.4 Euro-Atlantic Weather Regimes

Although the extratropical planetary-scale wave patterns are geographically anchored, they do change in time, either because the heating patterns in the atmosphere vary or because of internal (chaotic) processes. The results are robust circulations, called weather regimes, which have time scales longer than that associated with developing baroclinic systems but shorter than a season. Weather regimes have a typical 6–10 day nominal persistence and are spatially well defined (typically the width of an oceanic basin) and limited in number. They could be understood as envelopes for daily atmospheric variability. While the day-to-day meteorological fluctuations can be described in terms of temporal transition between regimes, the year-to-year (or longer timescale) climate fluctuations can be interpreted as changes in their frequency of occurrence provided the hypothesis of long-term quasi-stationary climate (Cassou 2009). A consequence of the transient behavior of the atmospheric planetary waves is that anomalies in climate on seasonal time scales typically occur over large geographic regions. Some regions may be cooler or perhaps drier than average, while at the same time thousands of kilometers away,

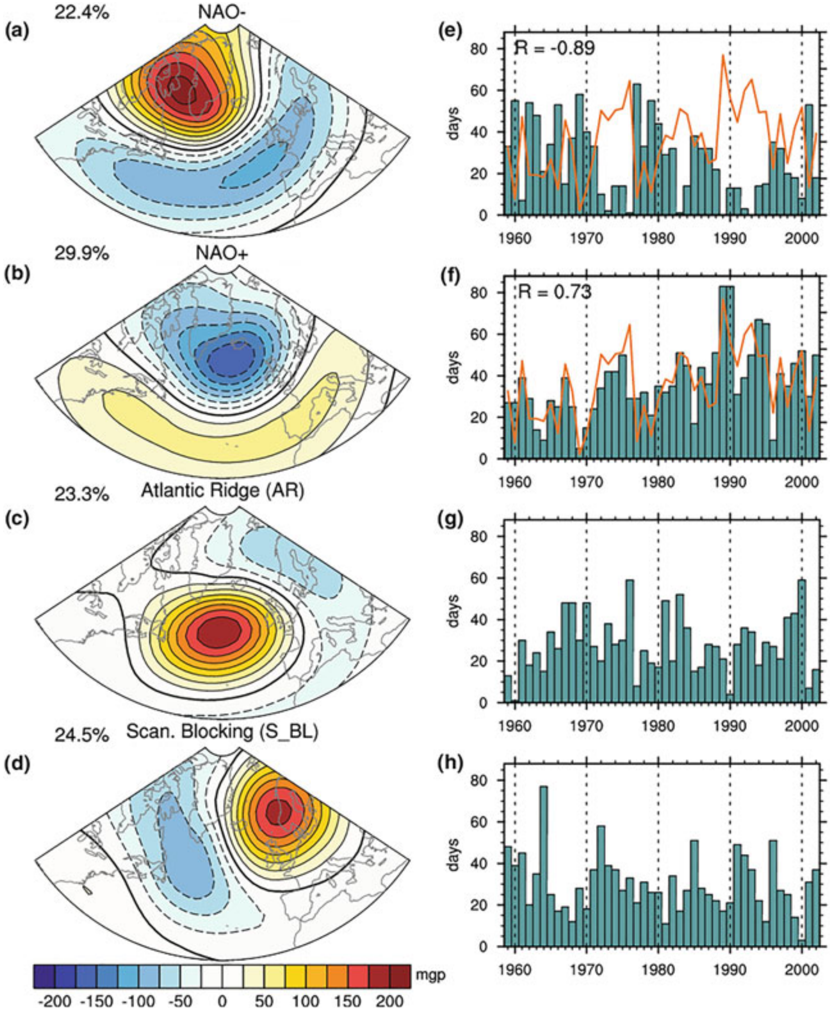

Fig. 3.23 (**a**)–(**d**) Centroids of the four wintertime NAE sector Z500 weather regimes (m). Each percentage represents the mean frequency occurrence of the regime computed over 1958–2002 from 1 December to 31 March. Contour intervals are 25 m. (**e**)–(**h**) Number of days of the occurrence of each regime per winter from 1959 to 2002. The NAO index (orange curve) defined here by the normalized principal component of the leading EOF of averaged DJFM Z500 is superimposed on the upper two panels corresponding to the NAO regimes. Correlation (R) between the NAO index and the frequency of occurrence of the NAO regimes is provided. From Cassou et al. (2010)

warmer and wetter conditions prevail. These simultaneous variations in climate, often of opposite sign, over distant parts of the globe are commonly referred to as "teleconnections" (Wallace and Gutzler 1981; Esbensen 1984; Barnston and Livezey 1987; Kushnir and Wallace 1989; Trenberth et al. 1998). Statistically speaking, weather regimes are classes of seasonal large-scale atmospheric circulation patterns gathered together from a similarity criterion, that are defined by their mean conditions, by their variances, and by their frequency of occurrence.

The weather regimes are characterized by a strong longitudinal dependence with maximum temporal variance over the northern oceans, especially during boreal winter. Different methods can be applied to obtain the weather regimes over a given geographical domain all of them leading to similar patterns (Michelangeli et al. 1995).

Figure 3.23a–d shows the four wintertime (December–March) weather regimes of the NAE sector, obtained by Cassou et al. (2010) through cluster analysis from ERA40 reanalysis 500 hPa geopotential (Z500) anomaly maps over 1958–2002. The first two clusters (Fig. 3.23a, b) capture the negative and the positive phases of the NAO (NAO− and NAO+, respectively). The third cluster (Fig. 3.23c), Anticyclonic Ridge regime, displays a strong anticyclonic ridge off Western Europe almost covering the entire basin, which features the northward extension of the Azores high. The fourth cluster (Fig. 3.23d), the Scandinavian Blocking regime, exhibits a zonal pressure dipole between Greenland and Scandinavia with a clear southeastward extension of low-pressure anomalies toward the Iberian Peninsula. The temporal evolution of the number of days attributed to a given regime over the complete winter season is given in Fig. 3.23e–h. NAE sector weather regimes are a significant driver of the intraseasonal, interannual, and multidecadal variability of the Atlantic Ocean fields.

The Atlantic Ridge (AR) regime is reminiscent of the so-called East Atlantic teleconnection pattern (negative phase, Barnston and Livezey 1987) viewed as a Euro-Atlantic wave train. It displays an anticyclonic ridge (positive Z500 anomalies) over the Central-North Atlantic Ocean, and cyclonic conditions over Central Europe and the Mediterranean (negative Z500 anomalies, Fig. 3.23c). In the winter, temperature variability in the Mediterranean region is to a large extent explained by the AR pattern (Sáenz et al. 2001). During AR regime, the localization of the Azores High shifts northwards, increasing significantly the probability of cold extremes occurrence over the Iberian Peninsula. Concerning Mediterranean precipitation variability, the AR influence is less distinct, but there are some coupled circulation rainfall patterns during winter that are being moderately correlated with it (Dunkeloh and Jacobeit 2003).

The Scandinavian Blocking regime is reminiscent of the Scandinavian teleconnection in its positive phase pattern, characterized by a strong anomalous height anomaly over Northern Europe (Tyrlis and Hoskins 2008) and a mild deeper trough extending south-eastward from the Labrador Sea to the Iberian Peninsula. This regime is especially important for Mediterranean winter rainfall variability. It enhances Mediterranean cyclogenesis and leads to widespread above-average precipitation in the Mediterranean region (Xoplaki 2002), and to events of extreme rainfall in the Spanish Mediterranean coast included Alboran.

The NAO is primarily a north–south dipole characterized by simultaneous out-of-phase zonally elongated sea-level pressure (SLP) anomalies between temperate and high latitudes over the North Atlantic. The NAO, with centers of action near Iceland

and over the subtropical Atlantic from the Azores across the Iberian Peninsula, is the dominant mode of winter climate variability in the North Atlantic region (Hurrell 1995; Hurrell and Van Loon 1997; Cassou et al. 2004). The NAO is strongest in the winter, but it is also evident during the whole year in the Northern Hemisphere (Barnston and Livezey 1987), although it is less dominant and has both smaller amplitude and spatial extent. Accordingly, the associated fluctuations of surface pressure, temperature, and precipitation occur throughout the year [e.g., Folland et al. 2009 discuss the summer NAO]. NAO presents a strong interannual to interdecadal variability that is visible in the temporal evolution of the number of days attributed to NAO+ and NAO− over a complete winter season showed in Fig. 3.23e, f.

The NAO plays an important role in the interannual variability of European and North African climate (e.g., Marshall et al. 2001) and it is the most important mechanism responsible for the strong interannual precipitation variability observed in the western Mediterranean region (e.g., Rodríguez-Puebla et al. 1998; Trigo et al. 2002), particularly during the winter months, in which this pattern is more active (Hurrell et al. 2003).

In the winter, across much of the NH, and specifically across wide regions of the North Atlantic Ocean, Europe, and the Mediterranean, surface air temperatures and SSTs are significantly correlated with NAO variability. In the NAO+ phase, the pressure minimum associated with the Iceland Low is deepened, while the pressure maximum associated with the Azores High is enhanced. This phase leads to reinforced and northward displaced westerly winds favoring warmer than normal temperatures in central (Wibig and Głowicki 2002) and northern Europe, and over the northern part of the Mediterranean region, and cooler conditions over the southern part (Xoplaki 2002; Trigo et al. 2002, 2006), with an inverse pattern for the NAO−. However, several studies have shown that the NAO influence on European temperatures is not constant over time (Jacobeit et al. 2001; Slonosky et al. 2001; Slonosky and Yiou 2002). Although most studies do not return significant correlations NAO-air temperature in the Alboran area, Báez et al. (2013) have found a significant relation between SST in the Alboran Sea and NAO and AO of previous seasons.

More important is the impact on precipitation variability due to corresponding changes in storm track activity. Changes in the mean circulation patterns over the North Atlantic are accompanied by changes in the intensity and number of storms, and their paths, that are reflected by important changes in transport and convergence of atmospheric moisture and, thus, distribution of evaporation and precipitation. During positive NAO phases, there is a northward shift of the storm track with enhanced activity. This leads, in general, to wet conditions from Iceland to northern Europe, although the greatest variations in the precipitation may occur over the Atlantic, as pointed out by Scaife et al. (2005), and tend to dry conditions from the Azores across the Iberian Peninsula, northwestern Africa, and over large parts of the western and northern Mediterranean (Marshall et al. 2001). The anomalies are reversed for the negative phase (e.g., Ulbrich et al. 1999; Trigo et al. 2004, 2006). NAO− induces above-normal precipitation in southern Europe, particularly over the

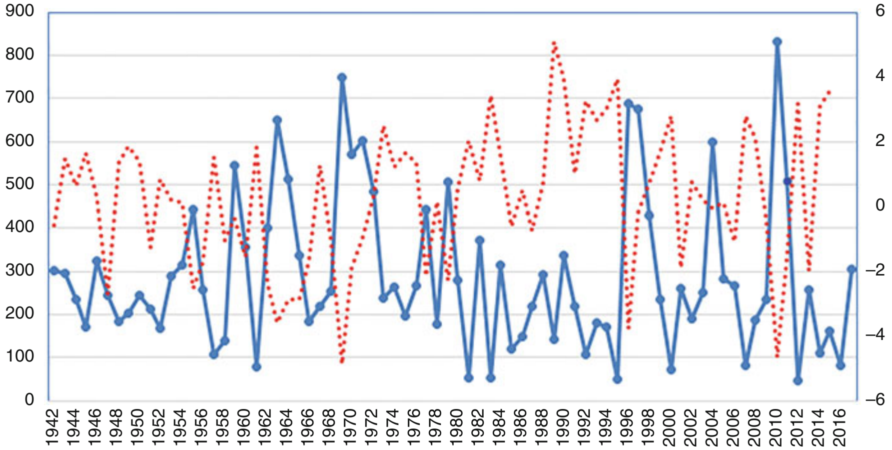

Fig. 3.24 Time series plot of winter (DEFM) precipitation recorded by Malaga station (blue solid line) and Hurrell annual NAO index (red dashed line)

west and southwest sectors of the Iberian Peninsula, including western Alboran Sea (Hurrell and Van Loon 1997; Trigo et al. 2002). This relation can be seen in Fig. 3.24, where winters (DEFM) series of both precipitation at Malaga station and NAO index are shown. During the transitional seasons, NAO influence on the Mediterranean becomes weaker (Dunkeloh and Jacobeit 2003; Türkes and Erlat 2003).

Major sudden stratospheric warmings (SSWs; see Butler et al. 2015) can influence the extratropical tropospheric circulation below for weeks to months (e.g., Mitchell et al. 2013; Kidston et al. 2015). SSWs on average are followed by NAO negative phases. SSW occurs approximately once every other year, originating a sudden warming of the polar stratosphere and the weakening and reverse in direction of the zonal mean westerly wind of the stratospheric polar vortex over a few days. NAO is the major factor governing air–sea interactions over the Atlantic. It affects the ocean through changes in heat content, gyre circulations, mixed layer depth, salinity, high latitude deep water formation, and sea ice cover. SST fluctuations and NAO strength are related. During boreal winter, the leading pattern of SST variability consists of a tripolar configuration, with SST anomalies of one sign in the midlatitudes, extending from the coast of North America into the center of the basin, surrounded by anomalies of the opposite sign in the subpolar North Atlantic and in the band between the equator and 30° N (Cayan 1992; Visbeck et al. 2003). Since NAO is most powerful during winter, the associated SST pattern is strongest in late winter. This configuration suggests that SST anomalies are driven by changes in air–sea heat exchanges and surface wind-induced Ekman currents associated with NAO variations. Thus, indices of the NAO have become widely used to document and understand how this mode of variability alters the structure and functioning of marine ecosystems (Hurrell and Deser 2009).

While internal atmospheric variability exhibits temporal incoherence, the ocean tends to respond to it with marked persistence of heat content anomalies that could feedback to the local atmosphere. Mosedale et al. (2006) have demonstrated that the SST tripole in the Atlantic Ocean can provide a small yet statistically significant feedback on the NAO. The level of retroaction of anomalous extratropical SST upon weather regimes appears to be weak in mid and low latitudes except through specific mechanisms such as the re-emergence of SST anomalies in the North Atlantic from one winter to the next. The impact of re-emergence upon the climate system has been investigated by Cassou et al. (2007), concluding that the atmospheric response to reemerging SST anomalies resembled the atmospheric circulation that created them the previous winter but with reduced amplitude. Re-emergence only occurs after an NAO− winter with a strongly negative NAO index (Buchan et al. 2014; Buchan 2017). The re-emergence effects can be observed in the years following a winter NAO index lower than −3 (1969/1970, 1996/1997, 2009/2010) in the Malaga station winter (DEFM) precipitation series (Fig. 3.24).

The origin of low-frequency variability and NAO potential predictability is still under discussion. As it occurs with long-lived atmospheric anomalies in middle and high latitudes, a large amount of the interannual NAO variance may be attributed to internal atmospheric dynamical processes (e.g., Hurrell and van Loon 1997; Kug et al. 2010; García-Serrano et al. 2008, 2011; Jung et al. 2011; Li and Lau 2012) as, for instance, stratosphere–troposphere coupling (Scaife et al. 2005) and Rossby wave–breaking events (Woollings et al. 2008). Feldstein (2003) found that positive NAO phase developed after anomalous wave train propagation across the North Pacific to the North American east coast, while the negative NAO phase appeared to develop in situ. Other results indicate that tropical forcing mechanisms may also play a role, (e.g., ENSO; e.g., Greatbatch and Jung 2007). Yu and Lin (2016) have shown that NAO correlates significantly with heating anomalies associated with precipitation in the tropical Indian Ocean and tropical American–Atlantic region, but not with the underlying SST anomalies.

While on interannual time scale the North Atlantic SST anomalies are mainly forced by the atmosphere, on longer time scales the NAO could be influenced by low-frequency SST variations in the North Atlantic, implying a possible predictable oceanic influence on the NAO (e.g., Rodwell et al. 1999; Kushnir et al. 2002; Kushnir and Held 1996; Seager et al. 2000; Watanabe and Kimoto 2000; Czaja and Frankignoul 1999; Wang et al. 2004; Frankignoul et al. 2011; Scaife et al. 2011).

The NAO decadal behavior, influencing climate in Europe, Asia, and northern Africa, might be associated with the underlying low-frequency SST forcing. The SST anomalies could arise from modulations of the oceanic gyre circulation (e.g., Grötzner et al. 1998) or feedback processes related to the thermohaline overturning at high latitudes (e.g., Timmermann et al. 1998), and they are likely connected to both tropical and extratropical lower frequency SST in the Indo-Pacific and Atlantic regions (Wanner et al. 2001).

Both the Pacific Decadal Oscillation (PDO; e.g., Deser et al. 2016) and the AMO seem to be closely related to the NAO on frequency variations lower than decadal timescale (Wang et al. 2010). These suggest that the longer-term variations of the

NAO may be related to or forced by the lower-frequency SST in the Pacific and Atlantic.

In particular, the linkage between the NAO and the AMO (Peings and Magnusdottir 2014b; Omrani et al. 2014) has been widely explored, since the AMO has been recognized as an important driver of Northern Hemisphere climate variability (e.g., Kerr 2000; Enfield et al. 2001; Zhang et al. 2007; Sun et al. 2012, 2015). A warm AMO phase usually accompanies the occurrence of more frequent negative NAO events (e.g., Ting et al. 2011; Kavvada et al. 2013; Peings and Magnusdottir 2014b).

Arctic sea ice exhibits multi-decadal variability that is likely related to the AMO at least for the Arctic sea-ice variations in the Atlantic sector. Arctic sea-ice decline during the satellite era is likely a consequence of both multi-decadal variation and anthropogenic forcing. Most of the studies addressing its climatic impacts focus on the reduction of autumn and winter Arctic sea ice. A negative feedback between the Arctic sea ice and the AO/NAO has been suggested (Deser et al. 2010; Honda et al. 2009), but there are also modelling studies that did not show negative AO/NAO response to the reduction in autumn Arctic sea ice.

Because the AO/NAM is a dominant mode of the internal variation of the NH atmosphere, the sea-ice reduction does not always induce the negative phase of AO/NAM. However, because the preferred waveguide of the winter climatological jet stream is located near the anomalous turbulent heat flux around the Barents Sea these dynamical processes often occur in association with the sea-ice reduction. As a result, the probability of a negative phase of the AO/NAM tends to increase (Nakamura et al. 2015).

NAO may be seen as an Atlantic–European manifestation of the hemispheric Arctic Oscillation (AO) or Northern Annular Mode (NAM) (e.g., Thompson and Wallace 1998). The AO has a similar structure to the NAO, but is zonally more symmetric. Many studies have been performed to distinguish the two mode patterns. Kodera and Kuroda (2004) showed that NAO and AO represent two independent teleconnection patterns for sea level pressure: one is an SLP seesaw between the Azores and Iceland and the other one between the Polar and Mediterranean regions. Wang et al. (2005) have further shown that AO affects interannual variability of winter surface air temperature over the Euro-Asian and African continents, whereas NAO is more regional, with the major effect on the surface air temperature in the western North Africa. This discrepancy can be reflected in other atmospheric variables such as sea level pressure and geopotential height fields as well. Christiansen (2002) and Wang et al. (2005) demonstrated that the AO-related signal could penetrate deeply into the stratosphere while the NAO one is largely a tropospheric phenomenon. Wang and Ikeda (2000) identified the leading Sea-Ice Area (SIA) mode as AO related and the second SIA mode as NAO-related, which served to differentiate AO and NAO by their atmosphere–ice interaction mechanism.

Over the NAE sector, a robust SLP response to ENSO appears largest in wintertime. The response to El Niño events appears as a projection onto a negative phase of the NAO (Mann et al. 2000; Brönnimann et al. 2007). The signal manifests as a dipole over Europe with anomalously high SLP over northern Europe, with a colder and drier than normal climate, and low SLP over southern Europe and the Mediterranean where a wetter and warmer than normal climate tend to prevail (e.g., Brönnimann et al. 2007). The anomalies associated with the responses to La Niña events are approximately opposite in sign to those of El Niño. In Europe, this signal tends to maximize in late winter (January–March), lagging the central Pacific SST maximum anomalies by a few months (Moron and Gouirand 2003). Several mechanisms to connect the signal between the Pacific and Atlantic basins have been proposed, involving: the atmosphere over the North Pacific (e.g., Graf and Zanchettin 2012; Zhang et al. 2015), the stratosphere (e.g., Bell et al. 2009), or the effects over the North Atlantic atmospheric circulation of the delayed tropical Atlantic SST anomalies following the ENSO maximum (e.g., Li et al. 2007; Davini et al. 2015).

Mariotti et al. (2002), Knippertz et al. (2003) explored the nonstationary relation between ENSO variability in boreal winter and the large-scale circulation and weather conditions over Europe–northwest Africa in spring, considering precipitation, SLP anomalies, and NAO indices and confirmed that the relation between Euro-Mediterranean rainfall and ENSO had been changing in the course of the last century. They find that spring rainfall is significantly anti-correlated at the beginning and the end of the last century and that there was no such link between the 1930s and 1960s. The variability of ENSO–rainfall correlations over the last century could be consistent with the fact that the relation of ENSO and SLP anomalies over Europe was not constant over this period (van Loon and Madden 1981), which can be seen as a high uncertainty in the relationship between ENSO and NAO.

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Chapter 4
The Oceanographic and Climatic Context

Manuel Vargas-Yáñez, M. Carmen García-Martínez, Francina Moya, Rosa Balbín, and José Luis López-Jurado

4.1 Introduction

The Alboran Sea is the westernmost sub-basin of the Western Mediterranean (WMED), being connected with the Atlantic Ocean through the Strait of Gibraltar. Therefore, it is the first region of the Mediterranean Sea receiving the Atlantic Water (AW) flowing through the Strait, from the nearby Gulf of Cadiz, and the last basin that the Mediterranean waters cross before exiting to the Atlantic Ocean. As a consequence of its location, the Alboran Sea is filled by a large number of water masses. On one hand, two Atlantic water masses, Surface Atlantic Water (SAW) and North Atlantic Central Water (NACW), can be distinguished, at least in the westernmost sector of the Alboran Sea (Naranjo et al. 2015). On the other hand, all the Mediterranean waters, both those formed in the WMED and in the Eastern Mediterranean (EMED), must eventually outflow (Millot 2009). Therefore, all these water masses should be present in the Alboran Sea. In fact, these water masses formed in the WMED can be clearly identified and their presence in the Alboran Sea has been described in the scientific literature. On the contrary, some of the water masses formed in the EMED can be distinguished in the Alboran Sea, whereas others have lost their signature.

The formations of the Mediterranean waters and their circulation are the result of the climatic conditions within the Mediterranean Sea, which is characterized by a freshwater deficit and a net heat loss through its surface. These conditions produce a thermohaline circulation that can be summarized in a very simple way as AW

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flowing eastwards at the surface layer, and Mediterranean waters flowing westwards at the intermediate and deep layers to finally outflow through the Strait of Gibraltar, being these currents modulated by the Coriolis force (Millot and Taupier-Letage 2005). This general circulation pattern is ultimately responsible for the circulation of the Alboran Sea, which has a very energetic dynamics at its upper layer, showing intense currents (Perkins et al. 1990), frontal areas, and mesoscale structures (Troupin et al. 2018; Olita et al. 2017; García-Lafuente et al. 1998; Tintoré et al. 1988).

The heat and water budget of the Mediterranean Sea can change on a large range of time scales, producing changes in the exchange through the Strait of Gibraltar and consequently on the properties of the water masses and their circulation patterns within the Mediterranean Sea and the Alboran Sea itself. Such time scales go from seasonal (Vargas-Yáñez et al. 2002), to inter-annual (Mihanovic et al. 2018; Renault et al. 2012), decadal and secular (Vargas-Yáñez et al. 2010a, b). The latter time scale is presumably linked to the current global warming process.

Besides this variability associated to the Mediterranean thermohaline circulation, the Alboran Sea circulation is influenced by changes in the wind and pressure fields that could alter its circulation at shorter (sub-inertial, several days to weeks) time scales. Finally, some of the shortest time scales affecting the circulation of the Alboran Sea are those associated to tidal phenomena, although these latter processes are of minor importance within the Mediterranean Sea. This circulation feature is mainly barotropic, affecting the whole water column, as internal tides, which have a large magnitude in the Strait of Gibraltar (Naranjo et al. 2014; Sánchez-Román et al. 2009) are of minor importance within the Alboran Sea (Vargas-Yáñez 1998; García-Lafuente et al. 1999).

In order to provide a brief description of the physical processes that determine the properties of different water masses and their circulation within the Alboran Sea and their time and spatial variability, this chapter is organized as follows. First, the climatic forcing, the formation of the different water masses and the thermohaline circulation of the Mediterranean Sea are described from a general perspective establishing the climatic and oceanographic context of the Alboran Sea. Then a more specific description of the water masses and their properties in the Alboran Sea are presented. Once the water masses that occupy the Alboran Sea have been described, their circulation is addressed. The first section is devoted to a brief description of the tidal currents which constitute a source of variability at short time scales. Then, the circulation of the different layers that form the Alboran Sea are analyzed. This analysis is decomposed into the upper layer, on one hand, and the intermediate and deep layers on the other. Although these two sections have been established according to the different depth levels considered, and not to the different time scales, it can be established that the time scales that affect the main traits of the Alboran Sea circulation, mainly in the upper layer, extend from the sub-inertial to the inter-annual, passing through the seasonal one. The last section is specifically devoted to long-term changes that affect the properties of the main water masses in the Alboran Sea and are very likely associated to climate change. This chapter ends with a summary and conclusions section.

Therefore the index of this chapter is as follows:

- Climate forcing, water mass formation processes and thermohaline circulation in the Mediterranean Sea.
- Water masses in the Alboran Sea.
- Currents and circulation in the Alboran Sea.
  – Tidal currents.
  – The upper layer circulation.
  – Intermediate and deep water circulation.
- Long-term variability.
- Summary and conclusions.

4.2 Climatic Forcing, Water Mass Formation Processes and Thermohaline Circulation in the Mediterranean Sea

The Mediterranean Sea is a concentration basin. When averaging over the whole basin and for a long period of time, the evaporation exceeds the freshwater supplies. Different works (Skliris et al. 2018; Jordà et al. 2017; Criado-Aldeanueva et al. 2012; Schroeder et al. 2012; Sánchez-Gómez et al. 2011; Ludwig et al. 2009; Struglia et al. 2004; Boukthir and Barnier 2000) have attempted to estimate the terms involved in the freshwater budget of the Mediterranean Sea: Evaporation (E), Precipitation (P) and river runoff (R). Although there is a large dispersion between the different estimations (Jordà et al. 2017), for the purposes of the present review it could be stated that, if the Mediterranean was not connected to the Atlantic Ocean, the freshwater deficit would produce a decrease in the Mediterranean Sea level of between 0.5 and 1 m/year.

If the heat fluxes between the sea surface and the atmosphere are averaged for the whole Mediterranean surface, the result is a net heat flux from the Mediterranean to the atmosphere. In other words, the Mediterranean Sea losses heat through its surface. Once again it is not an easy task to estimate the average fluxes (Jordà et al. 2017; Criado-Aldeanueva et al. 2012; Ruiz et al. 2008; Bunker et al. 1982) but they can be reasonably considered to be between 5 and 7 W/m^2.

The Mediterranean water deficit and the net heat loss through its surface are compensated by the entrance of AW through the Strait of Gibraltar. The AW compensates for the net evaporation and it also produces a salt flux into the Mediterranean Sea. This is compensated by an Outflow of Mediterranean Water (MOW) as a deep current below the AW. The AW inflow is larger than the MOW to compensate for the net evaporation. At the same time, the net salt transport through Gibraltar must be zero in a theoretical equilibrium state. This balance is usually described by means of the Knudsen equations:

$$V_{\mathrm{i}} = V_{\mathrm{o}} + E \qquad V_{\mathrm{i}} S_{\mathrm{a}} = V_{\mathrm{o}} S_{\mathrm{m}}$$

V_i is the annual volume of the inflow, V_o the outflow volume, S_a the salinity of the inflow of AW, and S_m the salinity of the MOW.

Finally, the AW temperature is higher than the temperature of the MOW and therefore the exchange through the Strait of Gibraltar produces a net heat flux that compensates for the losses through the sea surface.

As the AW progresses into the WMED through the surface, it becomes saltier because of the intense evaporation and mixing with resident waters. Part of it continues to flow into the EMED through the Sicily Channel. In summer, the AW which occupies the sea surface in the Levantine Basin, to the south of the Island of Rhodes and in front of the Israel and Syria coasts can reach salinity values close to 39.2 (Hecht et al. 1988). The effect on density of the salinity increase is compensated by the high summer temperatures. In winter, however, cold and dry continental winds produce the cooling of these salty waters which increase their density. A water column of 150 or 200 m is homogenized with temperature and salinity values of 15 °C and 39.1 (Lacombe and Tchernia 1972) and sinks to its equilibrium depth. After restratification of the upper water column, this water mass receives the name of Levantine Intermediate Water (LIW).

Part of the AW in the Levantine basin flows into the Aegean Sea where intermediate convection also occurs in winter. The result is an intermediate water, warmer and saltier than the LIW which is characterized by a salty and warm peak above the LIW on the θS diagrams. Although this water mass can be confused with the result of mixing between the LIW and the AW above, it is a distinctive water mass that receives the name of Cretan Intermediate Water (CIW, Millot 2013). Both LIW and CIW flow westwards decreasing their salinity and temperature by mixing with water masses above and below it. Although CIW has occasionally been distinguished at the Sicily Channel (Gasparini et al. 2005), once in the WMED the mixing of these intermediate waters originated in the EMED are simply considered in the literature as LIW (Millot 2013) and so will be done hereafter. When the LIW crosses the Sicily Channel towards the WMED, its temperature and salinity values are around 14 °C and 38.7 (Sammari et al. 1999). LIW describes a cyclonic circuit around the WMED. As it circulates within the WMED, the LIW continues reducing its temperature and salinity. When finally it gets into the Alboran Sea, these values are close to 13.1–13.2 °C and 38.5 (Vargas-Yáñez et al. 2017). Figure 4.1 shows a scheme of the LIW circulation within the WMED.

As shown in Fig. 4.1, the LIW flows over the continental slope of the northern WMED as part of the Northern Current. The general circulation in the Ligurian Sea and mainly in front of the Gulf of Lions is characterized by its cyclonic character. The cyclonic circulation produces the divergence of surface waters in the centre of such structures and the vertical movement of deep waters towards the surface. Therefore, LIW is closer to the sea surface in the centre of these cyclonic gyres, diminishing the water column stability. In winter, very cold and dry winds from the continent, cool the surface waters and increase their salinity in the Gulf of Lions area

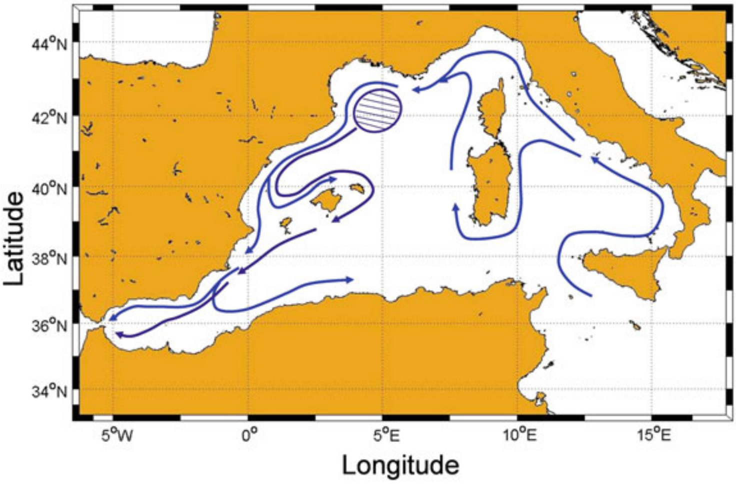


Fig. 4.1 Blue lines show the main pathways of LIW. Dark blue lines show the circulation of WMDW. The shaded area is the typical region of deep water formation in front of the Gulf of Lions

(centred around 42° N/5° E, Mihanovic et al. 2018; Lebeaupin Brossier et al. 2017; Smith et al. 2008; Leamann and Schott 1991; MEDOC Group 1970; Anati and Stommel 1970). The result is the increase in the density of surface waters, which reach the potential density of LIW (~29.05). As a consequence, the water column mixes from the surface down to 500–600 m depth. This process is named pre-conditioning phase. At the end of the winter, the persistence of strong winds and storms are able to further cool and increase the salinity of these waters that get as dense as deep waters (~29.1). A violent mixing of the whole water column from the surface to 2500 m occurs (violent mixing phase). The temperature and salinity of the homogenized water column is around 12.8 °C, 38.43 and this water mass is called Western Mediterranean Deep Water (WMDW). When severe winter conditions relax, the newly formed WMDW sinks and spreads around the WMED (spreading phase). Surface waters are replaced by new AW and the stratification of the upper part of the water column is restored. The WMDW follows a cyclonic circuit similar to the one followed by the LIW, but with the restrictions imposed by the WMED bathymetry. A fraction of the WMDW flows into the Tyrrhenian Sea through the Sardinian Channel where it sinks. These waters are mixed with those flowing through the Sicily Channel from the EMED. The eastern water masses taking part in this process are the LIW (Hopkins 1988) and also the Eastern Overflow Water (EOW), a mixture of LIW and the upper part of the Eastern Mediterranean Deep Water (Fuda et al. 2002). The result is the Tyrrhenian Dense Water (TDW). Finally, WMDW, TDW and LIW flow into the Alboran Sea and continue their paths towards the Strait of Gibraltar where they are mixed and outflow into the Atlantic Ocean.

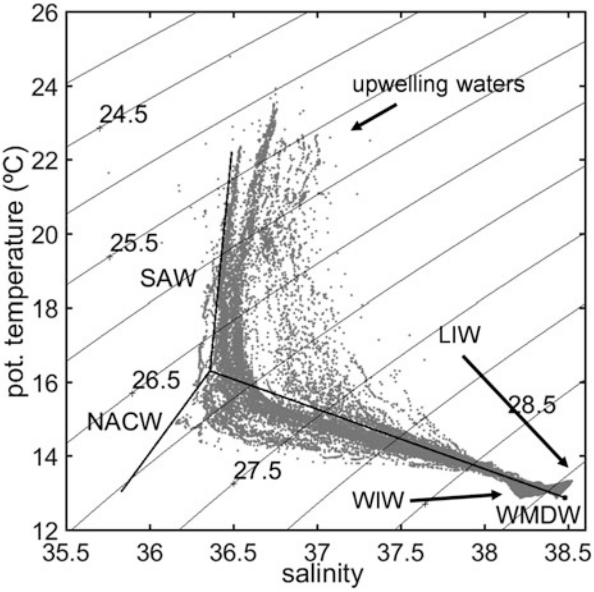
According to the circulation scheme and the water mass formation processes depicted above, the WMED is usually considered a three-layer sea. The upper layer is occupied by the AW, and extends from the surface to 150 m. The intermediate layer extends from 150 to 600 m and is occupied by the LIW. Finally, the deep layer goes from 600 m up to the sea bottom and is occupied by the WMDW and TDW. Nevertheless, the intermediate layer is not only occupied by water masses originated at the EMED, but also by others formed at the WMED. Under the influence of the strong northerly winds, in winter, the waters in the continental shelf of the Gulf of Lions and the continental shelf of the Balearic Sea can reach temperatures below 13 °C, and even close to 11 °C (Vargas-Yáñez et al. 2012a), much lower than those of the LIW and WMDW. As these waters are located over the continental shelf (200 m depth), under the influence of continental waters, and out of the influence of the LIW which flows at depths between 200 and 600 m, these very cold waters reach salinity values lower than those offshore. Therefore, a water mass with a temperature below 13 °C and salinity between 37.7 and 38.3 is formed, receiving the name of Western Intermediate Water (WIW). WIW sinks to its equilibrium depth, between 100 and 400 m, above the LIW (Juza et al. 2019; Vargas-Yáñez et al. 2012a; Pinot and Ganachaud 1999; Pinot et al. 1995; López-Jurado et al. 1995; López-Jurado 1990; Salat and Font 1987). Finally, Napolitano et al. (2019) have recently hypothesized that the Tyrrhenian Sea could also be a site of intermediate convection where Tyrrhenian Intermediate Water (TIW) would be formed. Nevertheless, according to the existent literature, this water mass has not been distinguished in the Alboran Sea.

4.3 Water Masses in the Alboran Sea

The upper layer of the Alboran Sea is filled by the AW that flows from the nearby Gulf of Cadiz through the Strait of Gibraltar. Therefore, the temperature and salinity values of the Alboran Sea upper layer are those of the waters in the Gulf of Cadiz, more or less modified. The degree of modification will depend on the distance to the Strait of Gibraltar and on the dynamics of the different areas within the Alboran Sea.

The Camarinal sill, between Point Paloma in the Spanish coast and Point Altares in Morocco, has a maximum depth of 300 m, imposing a restriction to the entrance of AW into the Alboran Sea. Data from MEDAR/MEDATLAS database (MEDAR Group 2002) have been collected from 1945 to 2000 to obtain the climatological profiles of temperature and salinity in the Gulf of Cadiz (García-Martínez et al. 2018), where the upper 300 m are occupied by the North Atlantic Central Water (NACW), characterized by the decrease of temperature and salinity with depth. In winter, temperature and salinity values at the sea surface are close to 16.3 °C and 36.4. At 300 m these values decrease to 13.1 °C and 35.8 (hereinafter, potential temperature will be written simply as θ for brevity). In summer, surface waters warm up to 22.23 °C with a slight increase of the salinity (36.49). These surface waters are named as Surface Atlantic Water (SAW). Both SAW and NACW can be clearly distinguished in the Western Alboran Sea (Naranjo et al. 2015) and are shown and labelled in Fig. 4.2 as straight black lines. This figure shows the θS values for all oceanographic stations from the FE-92 cruise in September/October 1992 (Data obtained from MEDAR/MEDATLAS database, MEDAR Group 2002). This

Fig. 4.2 θS diagrams for all oceanographic stations in FE-92 cruise covering the Alboran Sea



campaign has been chosen because it covers the whole Alboran Sea, with stations extending from 5.2° W to 0.13° W, and the main features of its circulation were clearly observable during the time of that cruise.

Figure 4.2 shows the different water masses already described in the previous section. Dots lying on the vertical line labelled as SAW correspond to the westernmost sector of the Alboran Sea where AW flows directly from the Strait of Gibraltar without modification. In some cases, dots are aligned around the NACW line, once again indicating no modification of the waters. The line extending from the base of the SAW to the dot labelled as WMDW represents the mixing line between Atlantic and Mediterranean waters. Waters on the left side of the θS diagram, that is, on the Atlantic side, have salinity values around 36.5. The Mediterranean waters at the right side of the diagram (LIW, WMDW and TDW, not shown) have salinity values around 38.5 or less. Therefore, the mid-point between these two values, 37.5, is usually considered as the interface or separation layer between the AW, flowing to the east, and the Mediterranean waters flowing to the west. Those dots extending vertically, parallel to the SAW line, but displaced towards higher salinity values (~37) correspond to surface waters with a higher percentage of Mediterranean water. These are upwelling waters warmed by solar heating and heat fluxes from the atmosphere during summer.

The θS values below the mixing line at the final part of the diagram correspond to the WIW with θS values in the Alboran Sea lower than 13 °C and salinity values between 38.1 and 38.2. This water mass is formed in the Northwestern Mediterranean and in the Balearic Sea and is advected to the south above the LIW and following its same pathway (Pinot and Ganachaud 1999; Pinot et al. 1995;

López-Jurado et al. 1995; López-Jurado 1990). The θS values above the mixing line show an absolute salinity maximum (>38.5) and a relative temperature maximum (>13.25 °C) that correspond to the LIW. WMDW is found below the LIW, filling the Alboran Sea to the sea bottom with θS values that range between 12.78 °C and 12.8 °C and between 38.42 and 38.43. Finally, since TDW is denser than LIW, but lighter than the WMDW it is located between these two water masses, and can thus easily be confused with the mixing line between LIW and WMDW (García-Lafuente et al. 2017).

In summary, AW, WIW, LIW, WMDW and TDW can be observed in the Alboran Sea and even in the Strait of Gibraltar (García-Lafuente et al. 2017; Naranjo et al. 2015; Millot 2009). Their spatial distribution depends on the dynamics and circulation of this basin and will be discussed in the next sections.

4.4 Currents and Circulation in the Alboran Sea

The currents in the Alboran Sea are mainly driven by the Mediterranean thermohaline circulation previously described, which is modulated by the Coriolis force, winds and bathymetry. As a result, there is a fast AW flow, usually referred to in the literature as the Atlantic Jet (AJ), flowing into the Alboran Sea through the Strait of Gibraltar. This AJ and its variability dominate the circulation of the upper 200 m of the Alboran Sea. Because of the freshwater deficit and heat losses in the Mediterranean Sea, there is a deep current that flows to the west below the AW. The position of the interface separating both the inflow and the outflow depends on the geographical location, decreasing from 250 at the western sector of the Strait of Gibraltar, to 75 m at its eastern limit (Bray et al. 1995). Nevertheless, these figures are strongly modulated by the tidal dynamics within the Strait (Naranjo et al. 2014, 2015).

The LIW, WMDW and TDW flow from 200 m depth to the sea bottom within the Alboran Sea to finally outflow to the Atlantic Ocean. The circulation of the intermediate and deep water masses is conditioned by the Coriolis force and bathymetric constrictions.

Besides this two-layer circulation scheme whose time variability is within the sub-inertial range, there are tidal currents with diurnal and semi-diurnal periodicity. Because of the periodic character of these currents they do not constitute an efficient mechanism for the net transport of water, salt, heat or any biochemical tracer in the Alboran Sea and for the rest of the Mediterranean, although a different situation could stand for the Strait of Gibraltar.

The tidal range and the intensity of tidal currents in the Mediterranean Sea are small if compared with the nearby Atlantic Ocean. Next section presents a brief description of their characteristics in the Alboran Sea. Then, the circulation of the upper layer of the Alboran Sea and its variability are addressed.

4.5 Tidal Currents

The tides in the Mediterranean Sea are a consequence of the astronomical forces directly acting on it, and the propagation of energy from the Atlantic Ocean through the Strait of Gibraltar. In a very simple way, it can be said that the tide in the WMED behaves as a standing wave with an amplitude node for sea surface elevation around 0–2° E and maximum amplitudes in the Strait of Gibraltar and at the eastern limit of the Tyrrhenian Sea (Arabelos et al. 2011; Albérola et al. 1995). The Alboran Sea is located to the west of the nodal line and currents have a phase of 90° with respect to the sea surface, being zero for the high tide and increasing eastwards while sea level decreases. A simple explanation for this behaviour by means of a linear analytical model can be seen in García-Lafuente et al. (1994).

In the Alboran Sea, the main constituent is the M2 harmonic. Its amplitude decreases from 30 cm in the Strait of Gibraltar to 10 cm at Cape Gata (Arabelos et al. 2011, Albérola et al. 1995). The tidal currents associated to the M2 harmonic are of the order of 2 cm/s, increasing with depth to 4 cm/s, very likely because of the effect of topography on contracting streamlines (Albérola et al. 1995). More recently, observations of Lagrangian currents from drifters have evidenced energy peaks at the K1 (diurnal) and M2, S2 (semi-diurnal) frequency bands (Poulain et al. 2013).

Although the barotropic tide has a low amplitude in the Mediterranean Sea, it produces large internal tides in the Strait of Gibraltar which enhance mixing between the incoming AW and the outflowing Mediterranean Waters. As a result of these mixing processes, the long-term exchange between the Atlantic Ocean and the Mediterranean Sea is enhanced and the properties of the AW within the Alboran Sea are modified (Naranjo et al. 2014).

4.6 The Upper Layer Circulation

As already described, the AJ is a fast current of AW flowing through the Strait of Gibraltar into the Alboran Sea. Although the speed of the AJ can be modulated within the Strait by the tidal currents, its average value is around 1 m/s (Perkins et al. 1990).

Figure 4.3 shows the most common features of the Alboran Sea upper layer circulation. The circulation of the Alboran Sea is very complex and many different situations can be observed. Nevertheless, from a very simplistic point of view, two main different modes of circulation can be defined. The first one, probably the most frequently described in the scientific literature, is the two-gyre circulation mode (light grey lines in Fig. 4.3, Vargas-Yáñez et al. 2002). The second one is the coastal circulation mode (dark grey lines in Fig. 4.3, Vargas-Yáñez et al. 2002). In the first circulation mode, two anticyclonic gyres are well developed occupying both the Western and Eastern Alboran sub-basins (Western Alboran Gyre, WAG, and

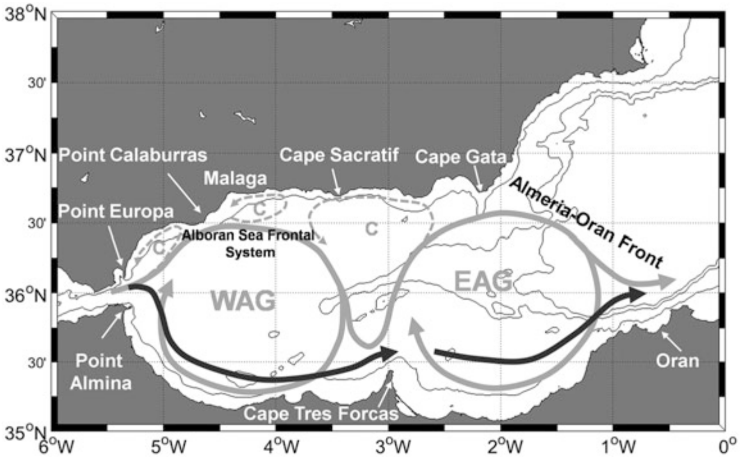


Fig. 4.3 Grey lines are a sketch of the two-gyres circulation mode. The Western Alboran Gyre (WAG), Eastern Alboran Gyre (EAG), the Alboran Sea Frontal System and the Almeria-Oran Front are labelled. The black line is a sketch of the costal-circulation mode

Eastern Alboran Gyre, EAG respectively). In this case, the AJ flows into the Alboran Sea in a northeast direction, due to the orientation of the longitudinal axis of the Strait. It continues in this direction until approximately 4° 30′ W, flowing close to the Spanish coast. Then it turns to the southeast impinging on the African coast to the west of Cape Tres Forcas. Part of the AJ then turns to the northeast, once again approaching to the Spanish coast, while another part re-circulates to the west along the Moroccan coast forming an anticyclonic gyre in the western sub-basin. The branch of the AW that turns to the northeast at Cape Tres Forcas describes a new anticyclonic gyre within the Eastern Alboran Sea.

The inner parts of the anticyclones are areas of convergence of surface waters. Therefore, AW sinks and the thickness of this layer increases within the gyres. The result is that the surface waters have a marked Atlantic character (low salinity values), and the interface between AW and Mediterranean waters, which can be identified as the 37.5 isohaline, deepens. The AJ surrounds the gyres. Its geostrophic adjustment produces the tilting of isopycnals and the elevation of deep waters to the left of the current (according to the sense of the movement, see Figs. 4.4, 4.5 and 4.6). As a consequence, strong temperature and salinity differences between the waters to the north and to the south of the jet can be observed. This thermohaline front extends all along the AJ from the Strait of Gibraltar to at least 1° W. It was named by Cheney and Doblar (1982) as the Alboran Sea Frontal System. When the EAG is well developed, the easternmost part of the frontal system extends from Cape Gata to Oran (Algeria), coinciding with the limits of the Alboran Sea. This frontal area creates a natural frontier between the AW recently advected into the Mediterranean Sea through the Strait of Gibraltar and the AW which has re-circulated within the WMED and, consequently, has a larger degree of modification. Although the Alboran Sea frontal system is a continuous feature, its eastern part has received a

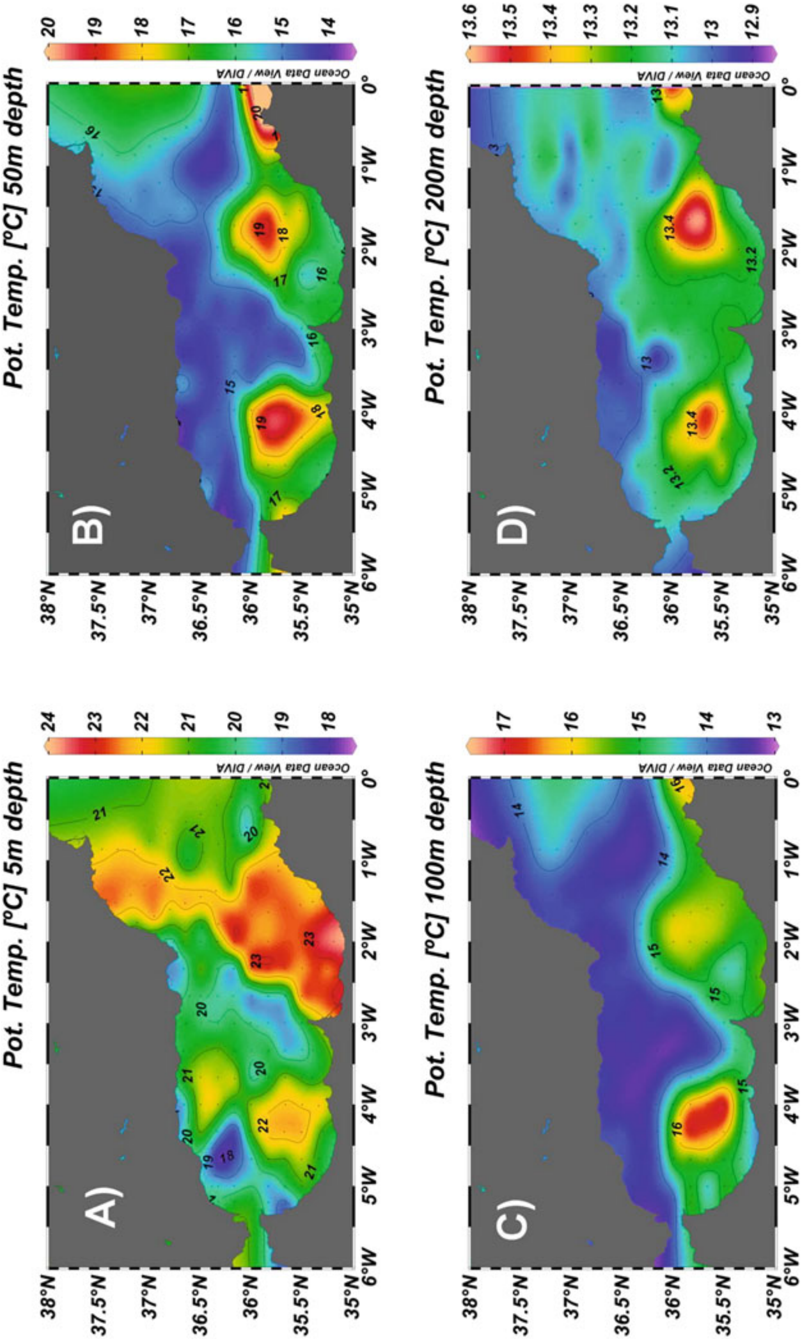


Fig. 4.4 Horizontal distributions of potential temperature at 5 m depth (**a**), 50 m (**b**), 100 m (**c**) and 200 m (**d**)

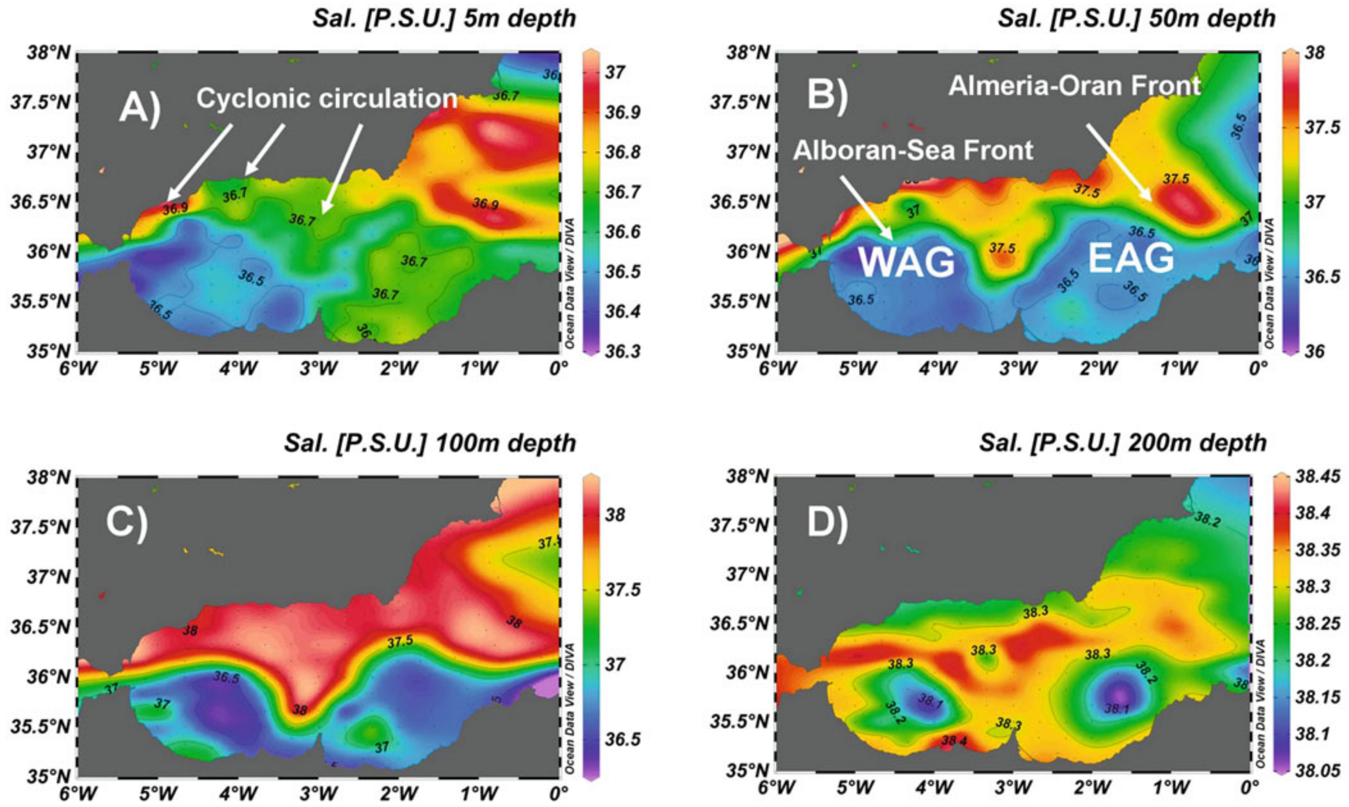


Fig. 4.5 Horizontal distributions of salinity at 5 m depth (**a**), 50 m (**b**), 100 m (**c**) and 200 m (**d**)

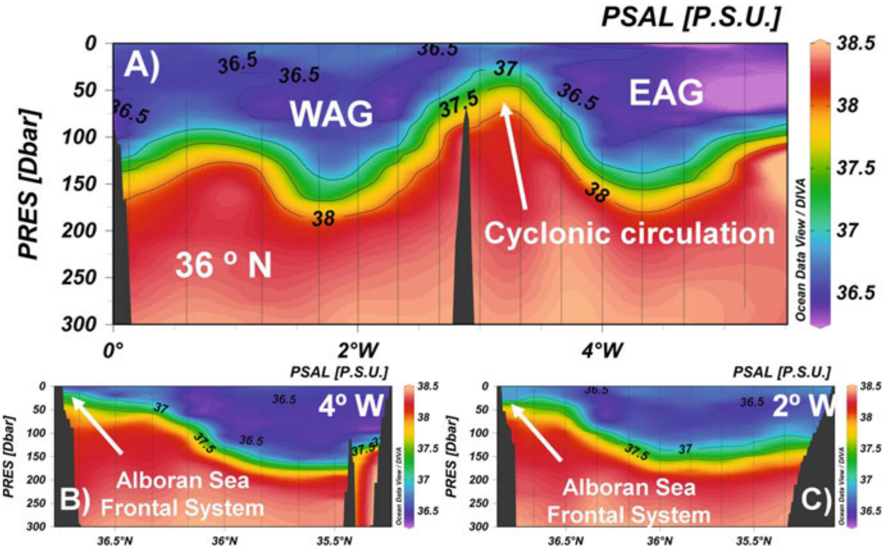


Fig. 4.6 (**a**) is a zonal salinity vertical section along 36° N. (**b**) and (**c**) are north-south salinity vertical sections along 4° W and 2° W, respectively

differentiated name and is usually referred to in the literature as the Almeria-Oran Front (Troupin et al. 2018; Olita et al. 2017; Tintoré et al. 1988).

The area between Point Europa and Point Calaburras (see Fig. 4.3) and the areas in front of Malaga Bay and between Cape Sacratif and Cape Gata, in the northern coast of the Alboran Sea, are frequently occupied by cyclonic circulation cells. These structures produce the divergence of surface waters at the inner part of the gyres and the upwelling of deep waters. The effect of the Alboran Sea frontal system and the cyclonic circulation areas is the presence at the sea surface or close to it, of waters saltier and cooler than the AW which is already flowing through the Strait of Gibraltar (see Fig. 4.2).

Figures 4.4 and 4.5 show the temperature and salinity horizontal distributions at 5, 50, 100 and 200 m depth. The data used correspond to the cruise FE-92 (MEDAR/MEDATLAS database). These distributions illustrate the two-gyre circulation mode and the generation of down and upwelling areas within the Alboran Sea.

Figures 4.4 and 4.5 show the presence of waters with a surface temperature higher than 22 °C and salinity values lower than 36.5 in the areas of the WAG and EAG. The position of the temperature and salinity frontal system is especially clear in the 50 m depth distribution. It is also clear the salinity increase and the low-temperature values in the areas between Point Europa and Point Calaburras and in the sector to the north of the frontal system, mainly in front of Malaga Bay and Cape Sacratif. These regions have been marked in Fig. 4.5a, b.

The vertical extension of the AW upper layer is also modulated by the different circulation structures. Figure 4.6a shows a zonal salinity section along 36° N. The interface separating the AW from the Mediterranean waters is between 150 and 200 m at the centre of the anticyclonic gyres. It is shallower than 50 m close to 3° 30′ W coinciding with the cyclonic circulation area located in front of Cape Sacratif and to the north of the Alboran Sea frontal system. Figure 4.6b, c are north-south transects along 4° W and 2° W. These figures also show the upward tilting of isohalines to the north, reaching depths lower than 50 m at the position of the Alboran Sea frontal system.

The circulation scheme described by means of Figs. 4.4, 4.5 and 4.6, and sketched with light grey lines in Fig. 4.3, is the most frequently described in the literature. Nevertheless, this circulation pattern is far from being stationary and it has a strong temporal variability.

One of the first descriptions of the water masses and geostrophic circulation for the whole Alboran Sea, was the one made by Lanoix (1974) using data from a summer cruise in 1962. In his work, the WAG was fully developed, while the EAG was absent and the AJ flowed in the eastern Alboran sub-basin along the African coast. It is very likely that because of this early work, the WAG was initially considered as a permanent feature of the Alboran Sea while the EAG was considered a more elusive circulation pattern. The use of thermal infrared images, mainly from the early 1980s, revealed that both the WAG and EAG could disappear and it could be established that the disappearance of any of them had the same frequency (Heburn and Laviolette 1990). Other works, using SST images and Empirical Orthogonal Function decomposition showed that the dynamics of the Alboran Sea is very complex and has a strong temporal variability on a sub-inertial scale (Baldacci et al. 2001).

Renault et al. (2012), Flexas et al. (2006), Vélez-Belchí et al. (2005), Vargas-Yáñez et al. (2002) observed that the circulation of the Alboran Sea could develop more complex structures. In some situations, the AJ does not surround the WAG. Instead of it, the AJ impinges on the WAG and then turns to the right flowing close to the African coast. The AJ finally develops a new anticyclonic gyre that pushes and displaces the "old" WAG. During several days or weeks, three anticyclonic gyres can coexist within the Alboran Sea, until a new two-gyre system is re-established. In some cases a more dramatic change can be observed. The AJ, instead of flowing in a northeast direction after getting out of the Strait of Gibraltar, turns to the southeast, surrounding Point Almina (black lines in Fig. 4.3), and then flows along the African coast. In this case, the northern shore of the Alboran Sea is not affected by the AW and its temperature/salinity takes lower/higher values. Renault et al. (2012), using altimetry data, classified the monthly circulation patterns from 1993 to 2010. The different situations described included the existence of one anticyclonic gyre (the western one), two gyres, three gyres, and a coastal jet. The two-gyre circulation situation and the coastal circulation mode are depicted in Fig. 4.3. Several hypotheses have been proposed for explaining these changes in the direction of the AJ and the migration or disappearance of the Alboran Sea gyres. These hypotheses include changes in the AJ velocity or blocking of the AJ caused by the size increase of the WAG (Flexas et al. 2006; Velez-Belchi et al. 2005; Bormans and Garrett 1989). In any case, after their disappearance, the development of the WAG and EAG requires several weeks or even months (Vargas-Yáñez et al. 2002).

Besides the WAG migration episodes and the transition to the coastal circulation mode, other processes with shorter spatial scales can be observed at the sub-inertial scale (with periods of several days). These processes would include the north-south oscillations of the AJ (Sarhan et al. 2000) which can induce the upwelling of Mediterranean waters at the northern sector of the Alboran Sea, and the advection of mesoscale structures (~20 km diameter) around the anticyclonic gyres (García-Lafuente et al. 1998; La Violette 1984).

The circulation of the upper layer of the Alboran Sea seems to be also subject to a seasonal variability, although the studies and information concerning this time scale are scarce. García-Martínez et al. (2018) and Vargas-Yáñez et al. (2017) have revealed the existence of a salinity seasonal cycle in the continental shelf and slope waters of the northern coast of the Alboran Sea. This cycle exhibits lower salinity values and a higher influence of the AW in autumn. Salinity would reach maximum values during winter and spring. It has been hypothesized that this cycle could be linked to the wind seasonal cycle in the Alboran Sea. Westerly winds are the prevailing ones during winter and spring. This would favour wind-induced upwelling at the northern coast of the Alboran Sea. During summer, the wind intensity decreases considerably and the easterly winds are more frequent. This could explain the observed decrease of salinity during summer. Nevertheless, westerly winds recover during autumn when the salinity reaches its minimum value in the northern waters. This phase difference between winds and salinity could be linked to the different time resolution of wind and salinity time series used, or to a recent extension of the summer season during the 1990s and beginning of the twenty-first century, when TS data were collected in the mentioned literature (García-Martínez et al. 2018; Vargas-Yáñez et al. 2017). Another possibility is that the Alboran Sea anticyclonic gyres have a larger size and affect in a much more direct way to the Spanish coast during summer and autumn.

The transport through the Strait of Gibraltar and the AJ speed is a factor that could affect the development of the Alboran Sea gyres (Velez-Belchí et al. 2005). Therefore, it is important to consider the existence of a seasonal cycle for the exchange through Gibraltar (García-Lafuente et al. 2007), with maximum outflow in April. These authors relate this increase of the outflow to the formation and replenishment of deep waters during winter. Although it is very speculative for the moment, we suggest that the seasonal changes in the volumes exchanged through Gibraltar could influence the circulation of the Alboran Sea.

4.7 Intermediate and Deep Water Circulation

The circulation of intermediate and deep waters in the Alboran Sea is not as well known as that of the upper layer. Much of the information concerning the upper layer circulation comes from geostrophic calculations. These estimations require the knowledge of a no motion reference level which is usually considered as the 200 or 300 dbar level. Bryden and Stommel (1982) considered that the anticyclonic circulation of the upper layer extended to the intermediate and deep layers below, and the sea bottom should be used as the reference layer for geostrophic calculations. Nevertheless, the velocity of the currents at the deep layers is of the order of a few centimetres per second, while the AW velocities can reach 1 m/s. Therefore, the error induced by the selection of the no motion reference level does not affect the description of the main features of the upper layer circulation. In the case of the LIW, WMDW and TDW circulation, the low-velocity values make it difficult to extract conclusions from geostrophic calculations. Our knowledge about the pathways followed by these water masses is inferred from their θS values and from direct measurements using current meters or drifters.

Lanoix (1974) considered that the LIW is divided into three branches within the Alboran Sea. One of them would flow to the north because of the Coriolis force. The other two branches flow to the north and south of the Alboran Island. Auffret et al. (1974) concluded that the intermediate and deep waters flow close to the Spanish coast. These authors, once again, invoked the Coriolis force as the responsible mechanism. Bryden and Stommel (1982) deployed a current meter at the Moroccan continental slope close to the Strait of Gibraltar (between 4° and 5° W). The instrument depth was 500 m and the average speed was 4.6 cm/s, directed to the Strait of Gibraltar, along the direction of the isobaths. According to these results and using hydrographic measurements, these authors considered that the WMDW flows along the African slope, uplifting as it approaches the Strait of Gibraltar. The presence of the LIW was also stronger at the central and southern parts of the Alboran Sea. The results concerning the behaviour of the WMDW were confirmed by Gascard and Richez (1985) using free drifters deployed between 600 and 800 m depth at the Moroccan continental slope. The average speeds found in this work were around 4 cm/s with peaks that could reach 12 cm/s. Kinder (1984) and Parrilla et al. (1986) analyzed time series from several current meters deployed in the central and northern sectors of the Western Alboran Sea. At 540 m, the currents were directed towards the Strait of Gibraltar with average speeds between 1 and 3 cm/s. According to these results, the authors concluded that the LIW does not follow an anticyclonic circuit, but flows as a slow current (1–2 cm/s) across the central and northern parts of the Alboran Sea, not being so clear the LIW behaviour in the southern sector. Concerning the deep water circulation, results in Parrilla et al. (1986) coincide with previous ones and show that the WMDW flows in an SW direction to the north of the Alboran Island because of bathymetric constrictions. Then it flows along the Moroccan slope uplifting to 400–500 m as it approaches the Strait of Gibraltar. According to these authors, it is not clear if the WMDW partially recirculates anticyclonically in the northern sector of the Alboran Sea. More recently it has been accepted that the deep currents in the Alboran Sea that finally outflow through the Strait of Gibraltar because of Bernoulli's aspiration (Kinder and Bryden 1990; Kinder and Parrilla 1987), are not formed just by WMDW, but they also have an important contribution from TDW (Naranjo et al. 2015; Millot 2009).

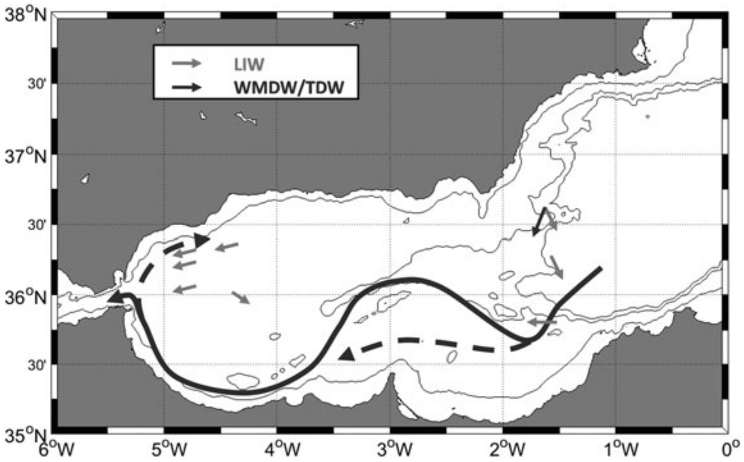


Fig. 4.7 Some features of the intermediate and deep circulation in the Alboran Sea. The dark line is a sketch of the WMDW/TDW circulation within the Alboran Sea. Dashed lines are used when some controversy exists in the literature. The grey arrows show the average current direction for the LIW estimated from current meters or drifters at the 500–700 m depth range. A black arrow shows the average direction for the deep layer (>1000 m) from one of the current meter measurements

Current measurements in the Alboran Sea (Fabres et al. 2002) show a westward current at 470 and 974 m depth at the northwestern sector of the Alboran Sea (4° 15.4′ W, 36° 14.4′ W). The average velocity in this case was between 3.7 and 5 cm/s, with peaks of 22 cm/s close to the sea bottom. Sánchez-Vidal et al. (2005) analyzed three lines of current meters at a section at the eastern limit of the Alboran Sea (1° 30 W). These lines were located at 36° 40.5′ N, 36° 13.1′ N and 35° 55.5′ N. At 680 and 645 m depth, the average current was directed to the SE in the northern and central lines. The deep current meters at 1190 m at the northern line and at 1170 and 2210 m at the central line also showed a SE average direction. The average velocities ranged between 2 and 4 cm/s. Currents at 510, 1050 and 2070 m at the southern line were directed to the West (see Fig. 4.7).

Figure 4.7 attempts to sketch the mean features of the WMDW/TDW circulation, according to the review presented above. For the LIW, discrepancies between different works prevent us from proposing a circulation scheme. Average directions from direct observations using current meters or drifters in the depth range 500–700 m are included. Black lines correspond to the WMDW/TDW circulation. Dashed lines are used when the works reviewed do not show conclusive results as could be the case for the recirculation in the northwestern sector of the Alboran Sea. According to results from numerical models in Parrilla et al. (1986), the WMDW would flow to the south of the Alboran Island. Nevertheless, Vargas-Yáñez et al. (2002) found that the average current between the Alboran Island and Cape Tres Forcas at 770 m depth was close to zero. For this reason this branch of the WMDW/TDW is presented using dashed lines. The grey arrows show the average directions for the 500–700 m layer from the works: Fabres et al. (2002), Sanchez-Vidal et al. (2005), Parrilla et al. (1986) and Kinder (1984).

As already stated, all the Mediterranean waters must finally get out of the Mediterranean Sea. The contribution of each water mass to the Mediterranean outflow is variable and our perception about it has changed over the last decades. Initially, it was assumed that most of the outflow was made of LIW. Kinder and Parrilla (1987) showed that deep waters would also contribute to the outflow as they were sucked by the swift Mediterranean current within the Strait (Bernoulli's aspiration). More recently, García-Lafuente et al. (2017) have shown that the proportion of the different water masses contributing to the outflow could be variable and dependent on the circulation pattern in the upper layer of the Alboran Sea. Well-developed anticyclonic gyres would help to evacuate deep water masses, whereas a coastal mode circulation would inhibit their outflow, favouring the flow of LIW.

4.8 Long-Term Variability

Since mid-1980s, many works have revealed changes in the temperature and salinity of the water masses of the WMED. Lacombe et al. (1985) compared the results from different campaigns carried out during the twentieth century and concluded that the WMDW had increased its potential temperature and salinity from 12.66 °C/38.38 to 12.712 °C/38.406 from 1909 to 1977. The warming and salinification of the WMDW were confirmed by Bethoux et al. (1990) who considered that the warming of the Mediterranean waters was the result of the climate change affecting the world oceans. Leamann and Schott (1991) and Rohling and Bryden (1992) also observed the warming and salting of the WMDW and reported the salinity increase of the LIW. According to these authors, the LIW salinity increase was the result of the damming of the river Nile and of those rivers draining into the Black Sea. The salinity increase of the LIW would be the cause for the warming of deep waters. As the LIW takes part in the WMDW formation, saltier waters would reach the deep water density with temperature values higher than those from the beginning of the twentieth century. Krahmann and Schott (1998) detected positive linear trends for the temperature and salinity of the WMDW, but not for the LIW. These authors considered that the warming of deep waters was caused by the salinity increase of the AW, associated with the damming of the river Ebro.

Vargas-Yáñez et al. (2010a, b, 2012b, 2017) showed that the WMDW had increased its temperature and salinity along the second half of the twentieth century and that the LIW had increased its salinity. These authors showed that the changes in the WMDW were robust, and were not sensitive to the data analysis methods. On the other hand, the LIW results were influenced by the methodology used for the construction of the annual time series. Nevertheless, more recent works have clearly shown the temperature and salinity increase of LIW in the Sicily Channel, at least from 1992 (Schroeder et al. 2017).

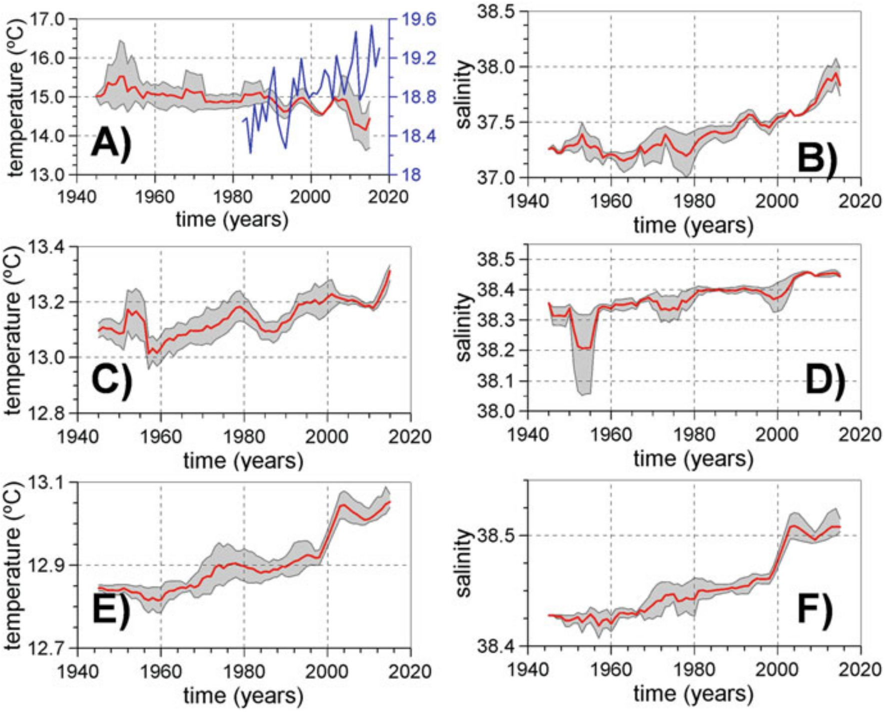


Fig. 4.8 Time series for SST and potential temperature and salinity at the upper, intermediate and deep layers of the Alboran Sea. (**a**) Blue line is the Sea Surface Temperature obtained from satellite data averaged for the Alboran Sea. Red line is the annual time series of potential temperature for the upper layer of the Alboran Sea (0–150 m). The shaded grey area in all panels represents the uncertainty associated to the different data analysis methods. (**b**) Red line is the annual salinity time series for the upper layer of the Alboran Sea. (**c**) and (**d**) are respectively the same as (**a**) and (**b**) for the intermediate layer (150–600 m) and (**e**) and (**f**) are for the deep layer (600 m to the sea bottom)

The sensitivity of the results to the data processing methodology seems to be caused by the data scarcity. Llasses et al. (2015), Jordà and Gomis (2013), Beuvier et al. (2010) showed that the oceanographic data available during the twentieth century and the existing monitoring programs were not adequate for the detection of temperature and salinity long-term trends at the different layers of the WMED. Vargas-Yáñez et al. (2010a, b, 2017) pointed out that the detection of trends in the upper layer of the WMED was not possible because of the data scarcity and the high temporal variability at short time scales, but considered that the existence of warming trends in the deep waters could not be explained only on the basis of the salinity increase of the AW and/or LIW. Garcia-Martinez et al. (2018) showed by means of a simple box model that the salinity increase of the AW and LIW, which contribute to the WMDW formation, could partially explain its warming, but the temperature increase of the upper layer was also necessary to explain the observed trends. The use of SST data from radiometers operated from satellites has shown that, at least since the beginning of the 1980s, the surface temperature of the WMED has warmed with linear trends higher than 1 °C/100 year (Skliris et al. 2011; Nikjaer 2009).

Figure 4.8 shows the evolution of the temperature and salinity for the upper (0–150 m), intermediate (150–600 m) and deep (600 m bottom) layers for the Alboran Sea. These time series have been constructed using data from MEDAR/MEDATLAS (MEDAR 2002) database and from the monitoring program RADMED, operated by the Spanish Institute for Oceanography (Lopez-Jurado et al. 2015).

The intermediate layer of the Alboran Sea (Fig. 4.8c, d) has increased its temperature and salinity at rates of 0.22 ± 0.05 °C/100 year and 0.24 ± 0.04/100 year. The linear trends estimated for the deep layer of the Alboran Sea are 0.30 ± 0.04 °C/100 year and 0.13 ± 0.01/100 year for the temperature and salinity, respectively. The salinity of the upper layer has increased at a rate of 0.81 ± 0.11/100 year. Nevertheless, no warming is observed for the upper layer from in situ data. This latter result seems to be the consequence of the data scarcity and the strong variability of the surface layer. If satellite data from 1982 to 2017 are considered, there is a clear positive trend of 2.1 ± 0.7 °C/100 year which is coincident with the results obtained in other areas of the Mediterranean Sea (Nikjaer 2009) and with the upper layer warming of the world ocean (Levitus et al. 2012).

4.9 Summary and Conclusions

The main water masses and their circulation within the Alboran Sea are the results of the exchange between the Mediterranean Sea and the Atlantic Ocean through the Strait of Gibraltar. This exchange is the consequence of the freshwater deficit and the heat losses to the atmosphere in the Mediterranean Sea, but is also conditioned by the geometry and the intense mixing within the Strait, associated to internal tides.

The intermediate and deep layers of the Alboran Sea are occupied by intermediate waters of both Eastern (LIW) and Western (WIW) origin, and by deep waters: WMDW and TDW. These water masses have a slow circulation within the Alboran Sea with velocities around a few cm/s. Their pathways are not very clear, but it seems that the LIW flows preferentially to the north of the basin, forced by the Coriolis force, whereas WMDW and TDW flow close to the African coast at the Western Alboran Sea, because of topographic restrictions, and then they are uplifted by Bernoulli's aspiration to finally outflow through the Strait of Gibraltar.

The upper layer of the Alboran Sea is filled by waters of Atlantic origin: SAW and NACW. This layer occupies the upper 150–200 m and has a very energetic dynamics. A frontal thermohaline system is associated with the fast Atlantic Jet (AJ), which describes anticyclonic and cyclonic structures. The circulation scheme of this upper layer can present different situations: two anticyclonic gyres at the western and eastern Alboran Sea sub-basins, only one anticyclonic gyre at the western sub-basin, three anticyclonic gyres, and a coastal mode circulation with the AJ flowing close to the African coast. These different circulation patterns do not only affect the Alboran Sea itself, but also influence the water exchange through Gibraltar. The two-gyre circulation system would favour the outflow of deep Mediterranean waters (WMDW and TDW) whereas the coastal mode circulation would favour the LIW outflow.

Several cyclonic gyres are frequently found in front of the northern coast of the Alboran Sea. These structures, mainly between Point Europa and Calaburras and in front of Malaga Bay and Cape Sacratif are responsible for the upwelling of sub-surface waters.

The different circulation schemes briefly depicted above are subject to time variability at sub-inertial, seasonal and inter-annual time scales. Lon-term changes in the temperature and salinity of the water masses that fill the Alboran Sea have also been observed since, at least, mid-twentieth century, showing warming and salting of the whole water column.

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Chapter 5

A Geological History for the Alboran Sea Region

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5.1 Introduction

The paleogeography of a marine basin is strongly controlled by its geodynamic evolution, particularly in the case of active basins such as the Alboran Sea. Tectonics are responsible for the widening or narrowing of the marine basin, the modification of bottom surface reliefs through the creation of subsidence zones that can evolve to sedimentary sub-basins, or the formation of positive reliefs—by tectonic deformation, volcanic activity, and diapirism, and even the generation and destruction of oceanic gateways and/or straits to adjacent seas. The modification and formation of such physiographic reliefs can give rise to critical situations for the habitat. Closure of a strait can mean the isolation of biological populations between adjacent seas and could favor the development of endemic species or of new relationships among species. In turn, the opening of gateways can generate episodes of colonization or invasion by non-native species that may leave a print on the biological history of the basin. Therefore, sound knowledge of the geological and geodynamic evolution of a marine basin is needed to face problems involving its current biogeography.

The Alboran Basin is a Neogene-Quaternary basin formed since the late Oligocene through extensional processes, located within the Betic-Rif alpine cordillera and forming part of this orogenic system. The Betic-Rif belt is characterized onland by ranges that form a tight orocline at the junction between the Atlantic Ocean and the Mediterranean Sea. At present, the Alboran Basin has relatively small dimensions, both in length and width (Chap. 6). The basin has been progressively restricted in the last 10 Ma (Tortonian) due to uplift of the adjacent mountainous reliefs, producing the isolation of intramontane and foreland basins (onland) in addition to the current Alboran Sea. Other changes in the basin's dimensions can be traced to shifts in the sea level, most notably desiccation during the Messinian salinity crisis, and eustatism in Pliocene-Quaternary times.

Nowadays, the Alboran Basin is situated along the boundary between the current plates of Africa and Eurasia (Fig. 5.1), and it occupies a strategic position from an ecological/oceanographic standpoint: this basin harbored the connection of water masses and biological populations from the Atlantic Ocean and the Mediterranean Sea.

Thus, ongoing tectonics and the geodynamic evolution tied to differential kinematics of the African and Eurasian plates, plus the Alboran Domain's westward drift since the late Oligocene, are key factors in the configuration of the current basin and continental margins. They likewise determine Atlantic-Mediterranean oceanic

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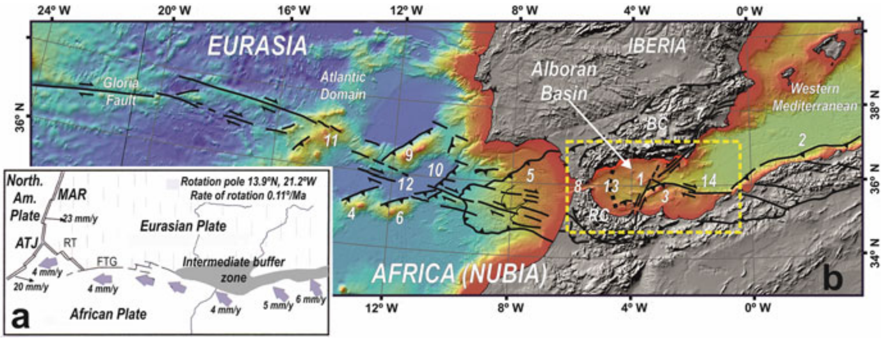

Fig. 5.1 (**a**) Present plate tectonic setting of Africa-Eurasia interaction (taken from Vegas et al. 2008). (**b**) Geodynamic framework between the Western Mediterranean Basin and Gloria Fault in the Atlantic Domain. FTG: Gloria Transfer Fault; MAR: Mid-Atlantic Ridge; RT: Terceira Ridge-Transform plate boundary. BC: Betic Cordillera; RC: Rif Cordillera; 1: Al-Idrissi Seismic Zone; 2: Algerian Margin Subduction Zone; 3: Alboran Ridge Indenter; 4: Ampere Seamount; 5: Allochthonous Unit of the Gulf of Cadiz; 6: Coral Patch Seamount; 7: Eastern Betic Seismic Zone; 8: Gibraltar Arc; 9: Gorringe Bank; 10: Horseshoe Abyssal Plain; 11: Josephine Bank; 12: South West Iberian Margin Fault Zone; 13: Western Alboran Intermediate Seismic Zone; 14: Yusuf-Habibas Fault Zone; Yellow box: Alboran Basin location

dynamics and the sedimentary infilling of basins. The geological and oceanographic framework of this region therefore reflects the dynamics of the Africa-Eurasia plate boundary, the role of the Iberian microplate, and the development of diverse kinematic styles throughout its evolution (Srivastava et al. 1990a; Vergés and Fernàndez 2012).

5.2 Plate Tectonic Settings: Evolution of the African-Eurasian Plate Boundary

To gain a full view of the geodynamic evolution of this region it is necessary to envisage the stages prior to the formation of the basin and understand the influence of African-Eurasian plate interaction. The evolution of these plates during the Mesozoic and Cenozoic—their kinematics and boundary relations—conditioned the formation and evolution of the ocean basins, first the Atlantic and Tethys oceanic basins, and later the Western Mediterranean basin.

The regional background to establish the post-Triassic evolution of the African and Eurasian plates was derived from kinematic reconstructions, adjusting oceanic fracture zones, bathymetric data, and conjugate magnetic alignments (Le Pichon et al. 1977; Srivastava et al. 1990a, b; Roest and Srivastava 1991; Olivet 1996; Schettino and Turco 2009, 2011; Macchiavelli et al. 2017). The geodynamic evolution of the African and Eurasian plates began with the rupture of the supercontinent Pangea at the Permian-Triassic boundary and through middle Jurassic times. Plate reconstructions set Iberia facing Newfoundland and North Africa, approximately between Algeria and Tunisia. During this stage, the Paleotethys oceanic lithosphere was located to the east of the African and Eurasian plates (Stampfli and Borel 2002). Later, relative movements between Africa and Eurasia could be synthesized into four main evolutive phases) (Fig. 5.2) (Dewey et al. 1989; Srivastava et al. 1990a; Schettino and Turco 2011) in which the Iberian plate worked as a single plate or else in association with the African and Eurasian plates.

During the Jurassic (154 Ma) and part of the Lower Cretaceous (120 Ma), the opening of the Central Atlantic and Western Tethys basins took place (Ligurian and Alpine Tethys) (Fig. 5.2a). The motion of Africa with respect to Eurasia (including Iberia) was eastward, implying senextral movements along a plate boundary located south of Iberia. In this paleogeographic scenario, the Central Atlantic opening was prolonged southeast of Iberia into the Ligurian Tethys basin, thus providing for an oceanographic connection between the Atlantic and Tethys oceans, most likely through the Subbetic continental margin (Vegas et al. 2016; Michard et al. 2018; Gómez et al. 2019).

From the Lower Cretaceous (120 Ma) to Late Cretaceous (83.5 Ma), the North Atlantic basin opened, including the Bay of Biscay, whereas the Tethys opening ceased. Hence, processes of divergence and convergence between the two main plates coexisted, maintaining Iberia as an intermediate plate (Fig. 5.2b, c). The opening velocity of the North Atlantic basin was greater than that of the Central Atlantic, causing a relative motion of Africa toward the west (with respect to Iberia and Eurasia), producing dextral movements along the southern plate boundary of Iberia and sinistral movements in the northern boundary (Fig. 5.2b) (Srivastava et al. 1990b). The opening of the Bay of Biscay basin produced an anti-clockwise rotation of Iberia, implying some convergence toward the southeast with Africa, and oblique divergence with Eurasia northward (Sibuet and Collette 1991; Olivet 1996; Vegas et al. 1996; Sibuet et al. 2004; Osete et al. 2011; Vissers and Meijer 2012). The oceanographic connection between the Atlantic and the Tethys basins was maintained in this period, probably through oceanic portals both south and north of Iberia, though in a more restricted gateway to the north (Martín-Chivelet et al. 2019).

Since the Late Cretaceous (83.5 Ma) the opening of the Central and Northern Atlantic basins has continued (Fig. 5.2c). The region was deformed during late Cretaceous-Paleogene times by relative convergence toward the north of Africa with respect to Eurasia (Dewey et al. 1973; Biju-Duval et al. 1978) as a result of South Atlantic and Indian oceanic spreading (Olivet 1996). An orogenic Alpine phase was produced through the subduction of the Ligurian Tethys oceanic lithosphere and the collision of Africa and Eurasia, along with several intermediate continental lithospheric blocks involved in this plate boundary, including minor plates such as Iberia and Apulia (Fig. 5.2c) (Schettino and Turco 2011; Verges and Fernàndez 2012; Vissers et al. 2016). The Pyrenean connection between the Atlantic and the Tethys basins was closed by the convergence between Eurasia and Iberia, and only the south Iberian connection remains.

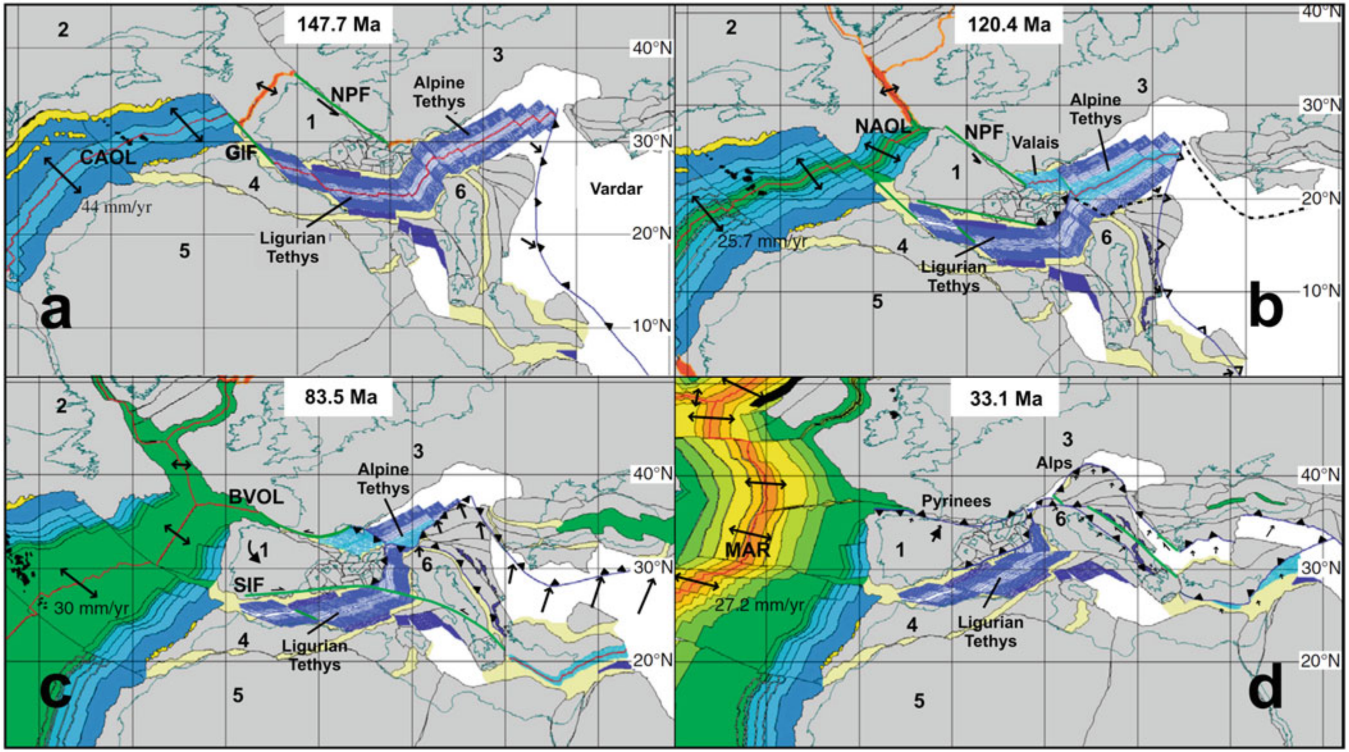

Fig. 5.2 Plate tectonic maps showing the evolution of Africa, Iberia, and Eurasia from the late Jurassic (**a**) to lower Cretaceous (**b**), late Cretaceous (**c**) and middle Oligocene (**d**) times (modified from Schettino and Turco 2011). 1: Iberia; 2: North America; 3: Eurasia; 4: Morocco; 5: NW Africa; 6: Adria; BVOL: Bay of Viscay Oceanic Lithosphere; CAOL: Central Atlantic Oceanic Lithosphere; GiF: Gibraltar Fault; MAR: Mid-Atlantic Ridge; NAOL: North Atlantic Oceanic Lithosphere; NPF: North Pyrenean Fault; SIF: South Iberian Fault

Late Paleocene (33.1 Ma) to Present. The Western Mediterranean oceanic basin began to open inside the western part of the Eocene Alpine Orogen (Fig. 5.2d) in the early Oligocene. The spreading of this basin caused the splitting of several continental fragments (the Alboran domain among them) around it. They collided with the continental margins of southern Iberia, northern Africa, Sicily, and western Apulia to form the Western Mediterranean Belt since the Miocene to the Present Alpine orogenic phase. At this time, the plate boundary between Africa and Eurasia is situated to the south of Iberia and Iberia is part of the Eurasian plate since 10 Ma (Roest and Srivastava 1991).

5.3 Current Africa-Eurasia Tectonics

The relative movements of the current African and Eurasian plates could be explained as an anti-clockwise rotation of Africa with respect to Eurasia around a rotation pole that would be situated within the African plate, in the vicinity of the Canary Islands (Buforn et al. 1988) or the Cape Verde Islands (Argus et al. 1989). This tectonic frontier is characterized by progressively changing kinematics (DeMets et al. 2015), implying a gradual transition from convergent areas eastward to wrench zones and divergent areas westward. The plate boundary is framed to the east by the Dead Sea Transform Fault (Weber et al. 2009), which bounds the African and Arabian plates and connects northward with the Alpine-Himalayan orogenic belt. To the west, this plate boundary ends in the Mid-Atlantic Ridge at the Azores triple junction, which separates the plates of Africa and Eurasia from the North American plate (Fig. 5.1). These tectonic characteristics allow the plate boundary to be divided into three sectors as can be summarized from the literature (Serpelloni et al. 2007; DeMets et al. 2010; Argus et al. 2011).

1. The Eastern Mediterranean Basin between the Dead Sea Transform Fault and the Calabrian Arc. The relative movements between Africa and Eurasia are convergent, directed toward the north (DeMets et al. 1990, 2015), where a relict Tethyan oceanic lithosphere is subducting under Eurasia (Hellenic and Cypriot arcs) and Apulia (Calabrian Arc) (Makris et al. 1986; Jolivet and Faccenna 2000; Speranza et al. 2012; Faccenna et al. 2004, 2014).
2. The Western Mediterranean/Gulf of Cadiz region extends between the Arc of Calabria and the Horseshoe Abyssal Plain (Fig. 5.1). It includes the Western Mediterranean basin, the Gibraltar Arc, the Gulf of Cadiz, and the submarine highs around this abyssal plain (Vázquez and Vegas 2000). The convergence direction between Africa and Eurasia progressively rotates from an NW trend in the central Mediterranean to a WNW trend in the Gibraltar Arc and Gulf of Cadiz areas (Dewey et al. 1989; Reilly et al. 1992).

   The plate boundary in this area could be traced by southward subduction along the Algerian continental margin (Aïdi et al. 2018; Hamai et al. 2018), continuing to the west along the Yusuf-Habibas right-lateral transfer fault, the northern

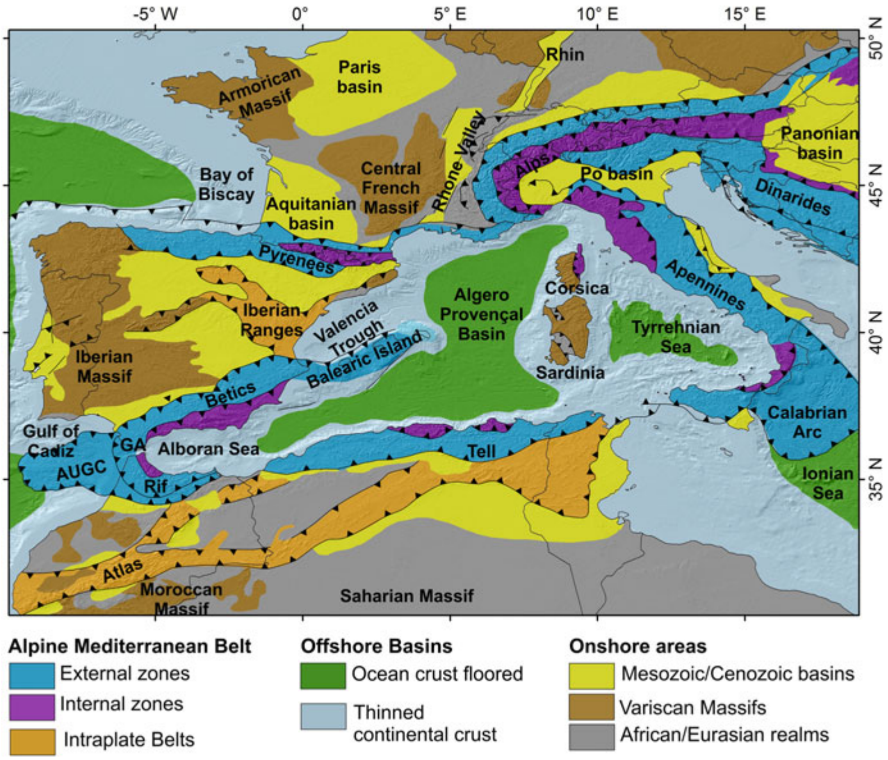

Fig. 5.3 The Western Mediterranean Alpine belt (modified from Sanz de Galdeano and Vera 1992; Faccenna et al. 2014; Leprêtre et al. 2018). GA: Gibraltar Arc; AUGC: Allochthonous Unit of the Gulf of Cadiz

reverse flank of the Alboran Ridge, the Al-Idrissi left-lateral transfer fault (Estrada et al. 2018), and compressive structures at the southern limit of the Rifian belt (Jimenez-Munt et al. 2003; Chalouan et al. 2006, 2014; Pedrera et al. 2011) (Fig. 5.1). In the Gulf of Cadiz sector, the contemporary WNW-ESE convergence produces the SWIM right-lateral transfer zone as well as compressive structures of NE trend that affect the Miocene Allochthonous Unit of the Gulf of Cadiz and several oceanic features (Medialdea et al. 2004; Zitellini et al. 2009; Terrinha et al. 2009; Rosas et al. 2009, 2012; Duarte et al. 2011; Cunha et al. 2012; Neres et al. 2016; Hensen et al. 2019) (Figs. 5.1 and 5.3).

Some debate is related to the relevance of current subduction processes in this sector. Proposals include slow subduction of the Atlantic oceanic lithosphere under the Gibraltar Arc in relation to the Betic-Rif wedge and seismic tomography characteristics of the mantle under the Alboran Sea (Gutscher et al. 2002; Spakman and Wortel 2004; Gutschter et al. 2012, Spakman et al. 2018) or incipient subduction processes associated either with Gorringe Bank or with the transition between the continental and oceanic lithosphere (Maldonado et al. 1999; Duarte et al. 2013).

3. The Atlantic Domain located approximately to the west of Josephine Bank is characterized by the Gloria transform fault (Argus et al. 1989), as demonstrated by the earthquake focal mechanisms analyzed in the region (Buforn et al. 1988; Custódio et al. 2016). This fault has a slightly curved geometry as corresponds to the Africa-Eurasia sliding vector in this sector (Neres et al. 2016; Hensen et al. 2019). The Gloria fault connects to the west with the Azores triple divergent junction between North America, Eurasia, and Africa. The Africa-Eurasia boundary (Terceira Ridge) is directed ESE and interpreted as a transfer-divergent system (Fig. 5.1a) characterized by a transtensive (oblique divergence) regime (Madeira and Ribeiro 1990; Madeira et al. 2015).

5.3.1 Western Mediterranean

The Western Mediterranean region features elongated Alpine orogenic belts, to both the north and south, surrounding marine basins floored by thin continental or Cenozoic oceanic lithospheres (Fig. 5.3). This region has undergone widespread plate tectonic movements since the early Oligocene, comprising divergence and convergence. This area's complex geodynamic evolution entails plate subduction, slab fragmentation, slab rollback and delamination (Lonergan and White 1997; Faccenna et al. 2004; Jolivet et al. 2009; Carminati et al. 2012), escape (Chalouan et al. 2006) and indentation tectonics (Estrada et al. 2018). These large-scale lithospheric movements occurred within a context of continuous Africa-Eurasia convergence (Dewey et al. 1989; Vissers and Meijer 2012) and caused intense crustal deformation in the surrounding orogens (Jolivet et al. 2009). The Western Mediterranean Alpine belt is constituted by several arched orogenic belts. In the westernmost Mediterranean region, the Rif and the Betic Cordillera are connected through the Gibraltar Arc and they extend to the Gulf of Cadiz, forming a tectonic/gravitational wedge known as the Allochthonous Unit of the Gulf of Cadiz (Medialdea et al. 2004). Northward, the Iberian Ranges and the Pyrenees constitute the main alpine chains, which finally connect with the Alps. The Apennines constitute the eastern boundary and delineate a close orocline in the Calabrian Arc, finally extending through northern Africa toward the Tell, in continuity with the Rif.

Development of the Western Mediterranean Alpine belt was mainly governed to progressive southward slab retreat detachment associated with northwestward subduction of the former oceanic lithosphere attached to the African plate, and the development of back-arc basins in an initial Eocene alpine orogenic phase (Cohen 1980; Rehault et al. 1985; Carminati et al. 1998a, 2012; Gueguen et al. 1998; Rosenbaum et al. 2002a; Faccenna et al. 2004). After 35 Ma the northwestward subduction and detachment process of the former oceanic Ligurian Tethys (Carminati et al. 2012) caused extensional processes on the upper plate and formed the Western Mediterranean basin since the early Oligocene. These processes separated and rotated (anti-clockwise) Corsica and Sardinia lithospheric blocks, thereby opening the Algero-Provencal basin as the main oceanic back-arc basin along the Miocene (20–10 Ma) between the Balearic Islands, Tell, Corsica, and Sardinia.

The Alboran Sea, most of the Tyrrhenian Sea (between the Apennines and Corsica-Sardinia block), and the Valencia Trough, developed by the clockwise rotation of the Balearic Promontory with respect to Iberia, constitute the main sedimentary basins formed on strongly stretched thinned continental crust. Moreover, small areas of the Tyrrhenian Sea are floored by Pliocene-Quaternary oceanic crust. The absence of clear seafloor linear magnetic anomalies (Galdeano and Rossignol 1977) impedes a detailed study of the oceanic spreading.

Deformation continues up to the consumption of the Ligurian Tethys oceanic lithosphere (Fig. 5.2) and collision of the accretionary prisms with the forelands that represent the main alpine belts surrounding the Western Mediterranean (Jolivet and Faccenna 2000; Handy et al. 2010). In this context, the Alboran Sea is generated in the interior of the Betic-Rif orocline by extensional forces linked to the contraction resulting from African-Eurasian convergence, which continues up to Present, with the coetaneous retreating of an eastward-dipping slab below the Gibraltar Arc (Pedrera et al. 2011; Faccenna et al. 2014; Molina-Aguilera et al. 2019).

5.3.2 *Evolutive Models*

In the literature, no consensus exists regarding the tectonic evolution, however, the scientific community agrees that a major change occurred in the subduction regime during the Oligocene (Faccenna et al. 1997; Jolivet and Faccenna 2000). In the Western Mediterranean basin, several hypotheses approach the lithosphere dynamics. They could be synthesized in (1) double westward (Gibraltar Arc) and eastward (Calabrian Arc) slab retreat, (2) slab fragmentation, and (3) continental delamination. These models have been proposed to explain the formation of forearc and back-arc basins, involving the extension, exhumation of metamorphic core units in internal zones and collapse of orogens (Royden 1993; Lonergan and White 1997; Jolivet and Faccenna 2000; Wortel and Spakman 2000; Faccenna et al. 2004; Spakman and Wortel 2004; Handy et al. 2010). In response to slab retreats, several back-arc basins have opened in the Western Mediterranean region: the Liguro-Provençal basin, Algerian basin, Alboran Sea, and the Tyrrhenian Sea, among others (Faccenna et al. 2001).

The Alboran Sea remains one of the most controversial issues in Western Mediterranean geodynamics. The present-day complex geometry of seismic tomography anomalies in the mantle show clear evidence of subducted remnants resulting from progressive slab tearing and detachment (Carminati et al. 1998a, b; Wortel and Spakman 2000; Bezada et al. 2013; Spakman et al. 2018; Molina-Aguilera et al. 2019) associated with a complex mantle convection pattern (Faccenna et al. 2004; Spakman and Wortel 2004; Jolivet et al. 2009; Faccenna and Becker 2010; Sternai et al. 2014). Nevertheless, the exact nature of subducted material remains unclear, varying from oceanic lithosphere to hyper-extended margin (Vergés and Fernàndez 2012; van Hinsbergen et al. 2014).

Numerous hypotheses have been proposed to explain the formation of the Alboran Basin in the context of the surrounding Betic-Rif orogen: (1) extensional collapse of a thickened crust due to convective removal of the continental lithospheric mantle (Platt and Vissers 1989; Platt et al. 2003, 2013); (2) continental lithosphere delamination processes (Seber et al. 1996; Calvert et al. 2000); (3) W-SW retreat of the subduction zone (Royden 1993; Lonergan and White 1997; Gutscher et al. 2002); (4) W-NW retreat of the subduction zone (Vergés and Fernández 2012); or (5) complex models which integrate subduction, delamination event and rollback westward as Bezada et al. (2013).

The geodynamic evolution of the Alboran Domain—comprising the basement of the Alboran Sea as well as the internal domains of the Betic and Rif cordilleras—is mostly controlled by the extension and exhumation of metamorphic core units, driven by the westward retreat of the subduction zone that interplays with African-Eurasian convergence. The metamorphic basement of the Betic Cordillera is made up of three stacked metamorphic complexes, from bottom to top: the Nevado-Filabride, Alpujarride, and Malaguide (Fig. 5.4). In the Rif Cordillera, where no equivalent of the Nevado-Filabride complex exists, the Alpujarride and Malaguide complexes are, respectively, known as the Sebtide and Ghomaride complexes. Today, these metamorphic complexes are separated by crustal-scale extensional detachment shear zones (Galindo-Zaldívar et al. 1989; García-Dueñas et al. 1992; Lonergan and Platt 1995; González-Lodeiro et al. 1996; Augier et al. 2005a; Platt et al. 2005). Exhumation of the Alpujarride/Sebtide complex occurred during the lower Miocene (22–18 Ma) in an N–S to NNE–SSW extensional setting (Monié et al. 1994; Crespo-Blanc et al. 1994; Crespo-Blanc 1995; Kelley and Platt 1999; Platt et al. 2005) while exhumation of the Nevado-Filabride complex occurred from the Lower to Upper Miocene (20–9 Ma—de Jong 1991; Monié and Chopin 1991; Johnson et al. 1997; Augier et al. 2005b; Platt et al. 2005; Vázquez et al. 2011) through ~E-W regional-scale extension (Galindo-Zaldívar et al. 1989; Jabaloy et al. 1992). Two nearly perpendicular superimposed directions of stretching in the basement nappes complexes (Alpujarrides and Nevado-Filabrides) show a progressive yet drastic change in the direction of extensional crustal-scale shear from N-S to E-W, which occurred between 20 and 14 Ma (Jolivet et al. 2008). The exhumed low-angle normal faults are inactive at present; yet the present-day tectonic motion determined by GPS measurements would indicate that E-W extension continues in the Betic Internal Zones (Mancilla et al. 2013; Galindo-Zaldívar et al. 2015a, b; Gil et al. 2017), where it interplays with NW-SE compression that affects the entire Alboran Domain under continual Africa-Iberia convergence.

After the late Oligocene, several sedimentary basins formed above the basement in response to extensional deformation (Galindo-Zaldívar et al. 2019). In the Betics onshore, two main generations of sedimentary basins were formed: the first subsidence pulse took place early in the Aquitanian-Burdigalian up to the Langhian, and the second during the Serravallian-Tortonian (Sanz de Galdeano and Vera 1992; Vissers et al. 1995; Vera 2000). The first generation of sedimentary basins lies

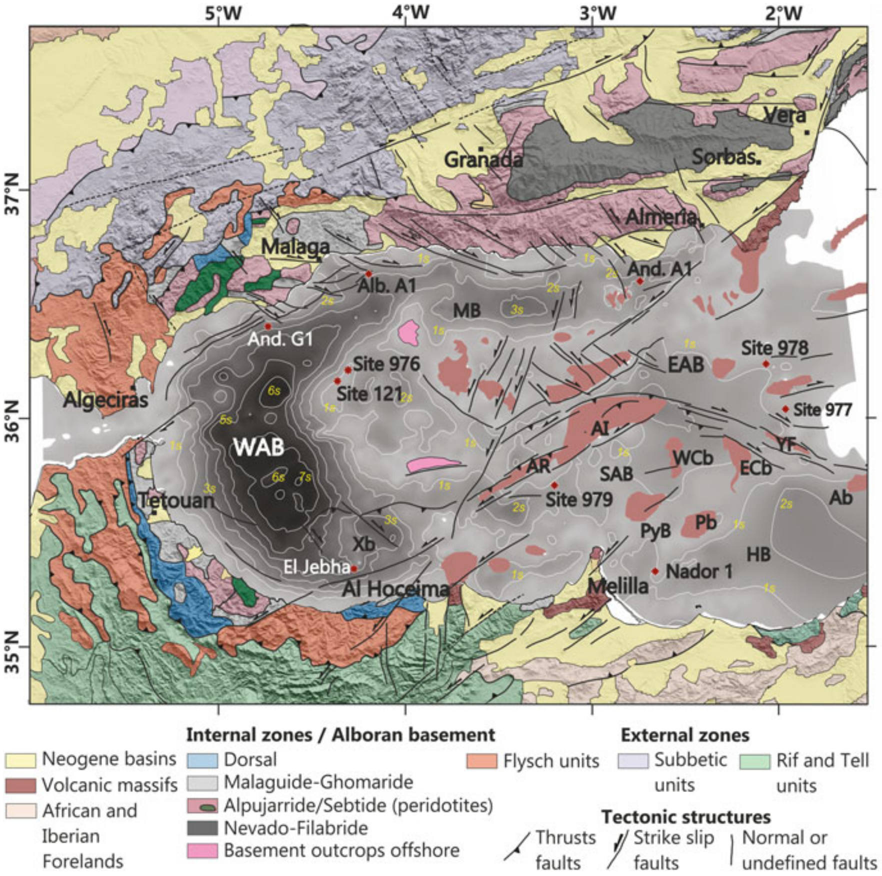

Fig. 5.4 Alboran Sea Region geological map showing major tectonic features of the Betic-Rif belt. Gray shaded background of the Alboran Sea marks the thickness of the sedimentary pile (given in seconds of two-way travel time as interpreted from the seismic records, from <1s, the lightest, to >7s the darkest). ODP sites 976–979, DSDP site 121, and industrial wells are located offshore (And G1: Andalucía-G1; Alb A1: Alborán-A1; And A1: Andalucía-A1; El Jebha and Nador 1). Ab: Alidada Bank; AR: Alboran Ridge; AI: Alboran Island; EAB: Eastern Alboran Basin; ECb: East Cabliers Bank; HB: Habibas Basin; MB: Motril Basin; PyB: Pytheas Basin; SAB: South Alboran Basin; WAB: Western Alboran Basin; WCb: West Cabliers Bank; Xb: Xauen Bank; YF: Yusuf Fault. Modified from Do Couto et al. (2016)

unconformably over the Malaguide-Alpujarride basement and is associated with E-W trending, generally top-to-the-E and top-to-the-N extensional structures (Crespo-Blanc 1995; González-Lodeiro et al. 1996; Suades and Crespo-Blanc 2013). The oldest sedimentary series rework pebbles, blocks, and olistoliths of basement rocks, thus evidencing denudation and intense erosion accompanying the tectonic activity (Serrano et al. 2007; Suades and Crespo-Blanc 2013). The asymmetric geometry of the sedimentary basins, the transgressive character of the older sedimentary series, and the expansion and subsidence of the depocentres demonstrate the intense tectonic activity of this period (Serrano et al. 2007).

The second generation of sedimentary basins formed under a top-to-the-WSW extensional regime (Sanz de Galdeano and Vera 1992; Vera 2000; Rodríguez-Fernández et al. 2011). These basins, defined as intramontane basins (e.g., Sorbas Basin) are mostly located in the southeastern Betics and have similar stratigraphic successions (Rodríguez-Fernández et al. 2011). Extensional structures observed at the border of the basins or within the earlier deposits lead some authors to link their initiation with the latest exhumation stages of the Nevado-Filábride complex (Crespo-Blanc 1995; Meijninger and Vissers 2006; Rodríguez-Fernández and Sanz de Galdeano 2006; Augier et al. 2013; Do Couto et al. 2014). In detail, the asymmetrical distribution of the sedimentary series (e.g., Sorbas, Alpujarras corridor) combined with paleostress analysis show that numerous normal faults accommodated the subsidence of the basin.

Ongoing debates surround the amount of westward movement of the Alboran Domain and its palaeogeographic origin (Jabaloy-Sánchez et al. 2019), the occurrence of STEP faults (Subduction-Transform-Edge-Propagator) (Mancilla et al. 2012, 2013, 2015; d'Acremont et al. 2020), the vergence of the subduction slab and the direction of spreading in the Algerian oceanic basin (Fig. 5.5). In the Alboran Region, recent geophysical measurements show that a remnant of relatively cold lithosphere lies beneath the Gibraltar arc, under the subduction zone, displaying an overall curved shape anomaly that reaches a depth of 600 km (Bezada et al. 2013). The curvature of this anomaly roughly mimics the orogenic arc, hence its length suggests the extent of the Tethys lithosphere slab retreat (Bezada et al. 2013).

5.3.3 Magmatism

The main positive reliefs on the Alboran seafloor are of igneous rocks. The late Eocene—Pleistocene magmatism in the Alboran Domain is related to the collisional orogenic processes resulting from Africa-Eurasia convergence (Duggen et al. 2004, 2008). A roughly 200 by 500 km NE–SW trending belt of middle Miocene to Pleistocene volcanic rocks crops out in this region, which extends from southeastern Spain through the central-eastern Alboran Sea into northeastern Morocco (Fig. 5.6). The igneous activity took place in four main stages (Duggen et al. 2004, Gill et al. 2004; El Azzouzi et al. 2014) that are explained mostly in a context of an eastward subduction and westward roll back of predominantly oceanic lithosphere model (Lonergan and White 1997; Duggen et al. 2003). Nevertheless, there is still discussion about the mechanisms, convective removal of thickened lithosphere and delamination of the continental lithospheric mantle have also been proposed to explain in part the magmatism (Platt et al. 1998; Duggen et al. 2005).

Stage 1 It corresponds to the intrusion of tholeiitic to calc-alkaline dyke swarms at the Malaga area (Fig. 5.6) during the late Eocene to lower Miocene (Turner et al.

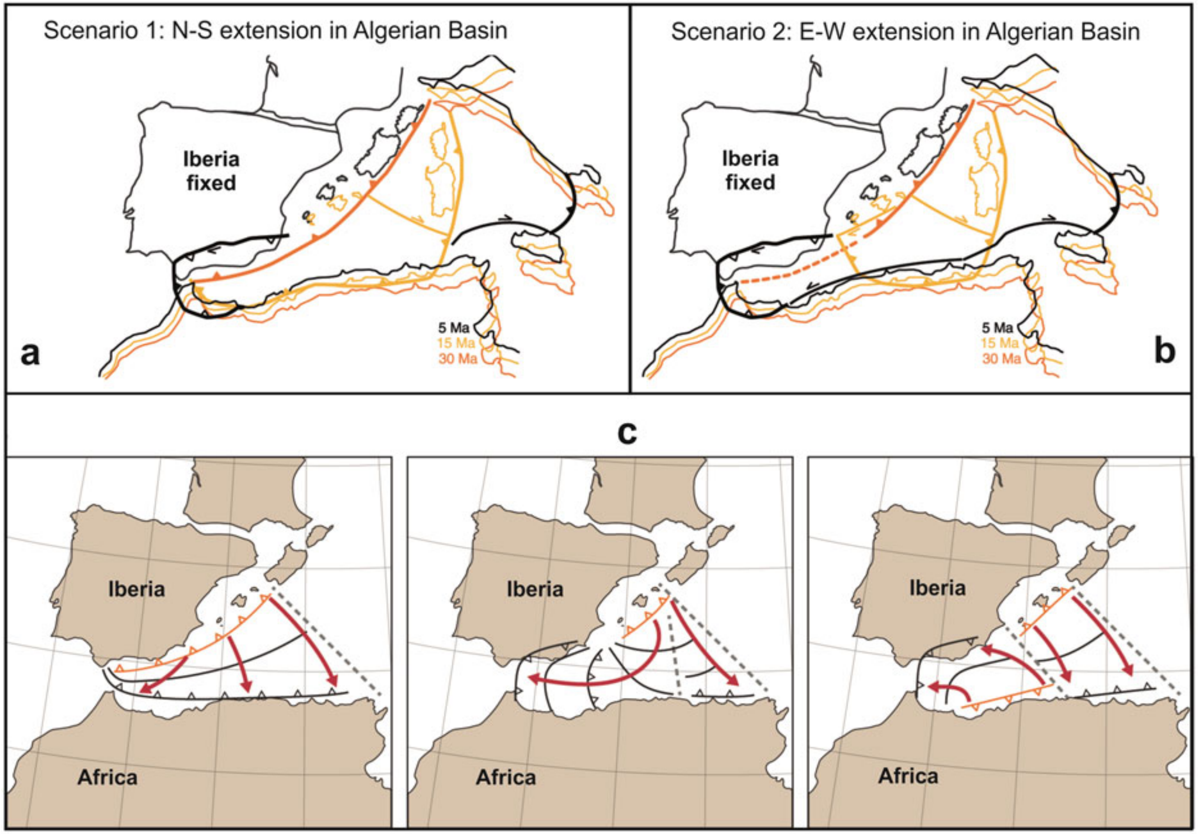

Fig. 5.5 Top: Schematic illustration of the relative position of the subduction zones in the Western Mediterranean since the Oligo-Miocene, assuming (**a**) N-S extension or (**b**) E-W extension in the Algerian basin (from van Hinsbergen et al. 2014). (**c**) Schematic illustration of the three different reconstruction scenarios shown in the paleogeography at ~35 Ma (from Chertova et al. 2014)

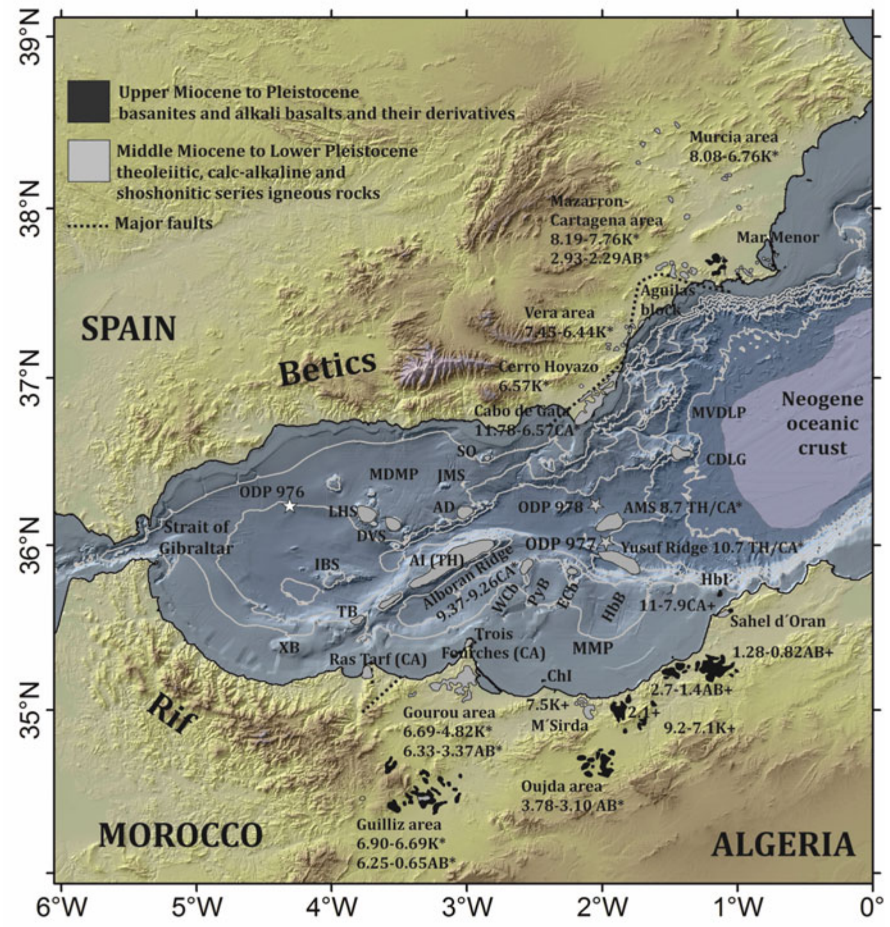

Fig. 5.6 Map of the Alboran magmatic region (westernmost Mediterranean) including southern Spain and northern Morocco. Middle-late Miocene volcanic rocks are distributed in a NE-SW trending belt. Volcanism includes submarine volcanic structures (Al Mansour Seamount—AMS, Yusuf Ridge, Alboran Ridge and ODP Leg 161, sites 977 and 978), Alboran Island (AI), Cabo de Gata and Aguilas area in southern Spain, and Ras Tarf and Trois Fourches in northern Morocco. AR: Adra Ridge; ChI: Chafarines Islands; CDLG: Los Genoveses Ridge; DVS: Djibouti Ville Seamount; ECb: East Cabliers Bank; HB: Habibas Basin; HI: Habibas Islands; JMS: José Medialdea Seamount; LHS: La Herradura Seamount; MDMP: Motril-Djibouti Marginal Plateau; MMP: Moulouya Marginal Plateau; MVDLP: La Polacra high; PyB: Pytheas Basin; SO: El Seco de los Olivos (Chella) Bank; TB: Tofiño Bank; WCb: South western Cabliers Bank. Modified from Duggen et al. (2008)

1999). They were located within the Malaguide Complex and after emplacement (were transported toward the northwest (Torres-Roldan et al. 1986; Martínez-Martínez and Azañón 1997). Geochemistry data and Sr-Nd isotope data favor derivation of the Malaga dykes from a peridotitic (mantle) source through the subduction of oceanic lithosphere (Torres-Roldan et al. 1986; Duggen et al. 2004).

Stage 2 It includes cordierite-bearing volcanic dacite at the Mar Menor, a granitic volcanic clast from ODP Site 977 (Fig. 5.6), and intrusive igneous leucogranites from southern Spain of early Miocene ages (Zeck et al. 1989). These rocks point to a large-scale thermal event occurring in the Alboran region between 23 and 18.5 Ma. There was a partial melting of continental crustal and these rocks formed through crustal anatexis (Munksgaard 1984; Zeck et al. 1989) associated with nappe movement (Platt et al. 2003) during the collision of the Alboran block with the South Iberian and North-African continental margins.

Stage 3 A low-K tholeiitic through high-K calc-alkaline series of volcanic rocks erupted in the Alboran Sea region during the Middle to Late Miocene. Main volcanic complexes onshore include Cabo de Gata, Ras Tarf and Trois Fourches; they correspond to strike-slip fault-bounded blocks on the Alboran Sea margins (Coppier et al. 1989; Aït Brahim and Chotin 1990; Martínez-Díaz and Hernández-Enrile 2004). It also includes most of the volcanic buildings located in the basin: banks of Chella, Djibouti and E and W Cabliers, ridges of Adra, Alborán and Yusuf, and Al Mansour seamount between them (Fig. 5.6). This stage corresponded to the greatest volcanic activity in the basin, especially in the central and eastern sectors, and meant a substantial modification of the seafloor. Age data for Alboran Sea volcanic rocks range from 12.1 ± 0.2 to 6.1 ± 0.3 Ma (Al Mansour Seamount, Alboran, and Yusuf Ridges, ODP 161 Site 977) (Hoernle et al. 1999; Duggen et al. 2008). The volcanism is explained by subduction of oceanic lithosphere in the westward roll back model (Hoernle et al. 1999; Zeck 1996; Duggen et al. 2003; Gill et al. 2004) and the release of hydrous fluids and sediment melts from subducted lithosphere into the mantle wedge beneath the Alboran Basin (Duggen et al. 2004).

Stage 4 The magmatic stage 3 ceased with the occurrence of Late Miocene to Early Pliocene shoshonitic and lamproitic magmatism in Spain and Morocco (Hoernle et al. 1999; Duggen et al. 2003; Gill et al. 2004) that shifted to an intraplate-type, and finally Early Pliocene to Quaternary alkali basalt erupted in southeastern Spain and northern Morocco (Hoernle et al. 1999; Duggen et al. 2003; El Azzouzi et al. 2014). This stage has been explained in the context of a transition from subduction-related to intraplate-type volcanism by lithospheric tearing in the borders of the subducting slab that provides a possible mechanism to explain the shoshonitic volcanism by local melting of the lithospheric mantle (Gill et al. 2004). An associated positive thermal relief is also proposed that overlaps with the Messinian Salinity Crisis (Duggen et al. 2003).

5.4 The Alboran Basin

The Alboran Sea is about 350 km long and 150 km wide, exhibiting a complex seafloor physiography with several ridges and seamounts (Chap. 6). It currently hosts three main sub-basins named after their respective geographic locations: the Western Alboran Basin (hereafter WAB), Eastern Alboran Basin (EAB), and Southern Alboran Basin (SAB). The basins are separated at seafloor by morphostructural features (Fig. 5.4).

5.4.1 Input from Potential Field Data

Gravity and magnetic data constitute what is known as "potential fields" and provide information about the deep structure of a basin. In this case, Bouguer gravity anomalies (Fig. 5.7) were obtained from a global free air dataset (Sandwell et al. 2014) with a resolution of 1 nautical mile. Magnetic anomalies correspond to the second version of the World Digital Magnetic Anomaly Map Project at sea level, which has a resolution of 3 nautical miles (Catalán et al. 2016) (Fig. 5.8). The Analytic Signal (AS) of the magnetic field anomaly is a mathematical expression that highlights the location of magnetic contacts (Roest et al. 1992; Roest and Pilkington 1993; Salem et al. 2002).

The Bouguer gravity anomaly smoothly decreases and narrows from the east (190 mGal) to the west (30 mGal at 4.5° W) in the Alboran Sea (Fig. 5.7). West of 4.5° W it shows low values, yet locally high values are identified at 5° W (M1 and M2, Fig. 5.7) near the African and Iberian coasts respectively.

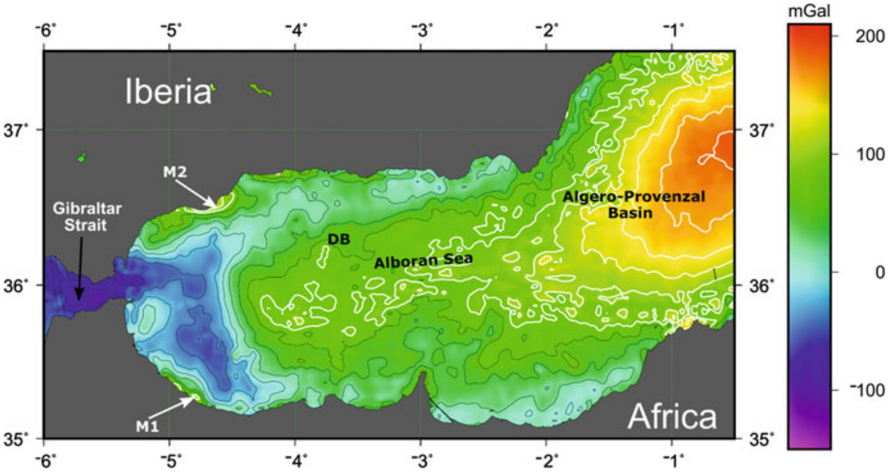

Fig. 5.7 Bouguer gravity anomaly map of the Alboran Sea at 2 km resolution. Contour lines every 20 mGal. M1 and M2: local highs. DB: Djibouti Bank

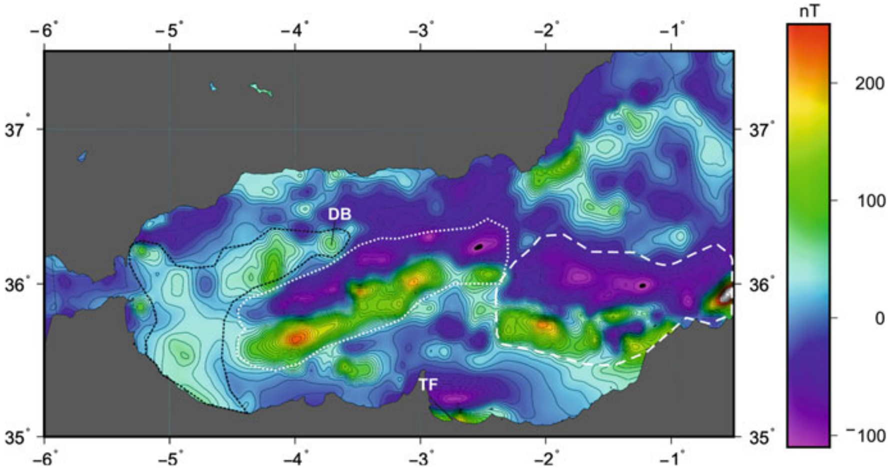

Fig. 5.8 Magnetic anomaly map of the Alboran Sea at 3 nautic miles resolution. Contour lines every 10 nT. Polygons: White dotted lines highlight an ENE-WSW magnetic anomaly; white dashed lines surround a WNW-ESE magnetic anomaly; black dotted line surrounds an N-S magnetic domain turning NE at 4.5° W. DB: Djibouti Banks, TF: Trois Fourches Cape

The Magnetic anomaly map evidences two main ENE-WSW and WNW-ESE linear dipoles (Fig. 5.8) that intersect approximately at 2°30′ W. The ENE-WSW dipole is continuous with an average amplitude of 120 nT, reaching over 200 nT at three locations. The lows show an almost constant value of −80 nT. The NW-SE anomaly shows a more discontinuous picture—its trend changes at 1° W, becoming eastward parallel to the shoreline (Fig. 5.8). East of Trois Fourches Cape, an E-W magnetic anomaly that extends onshore is identified. The westernmost part of the Alboran Basin is dominated by a positive N-S high. North of 36° N this anomaly turns, showing NE trending (Fig. 5.8). This NE elongated anomaly has two peaks geographically correlated with the Djibouti Bank (Fig. 5.8).

Analysis of the ENE-WSW and WNW-SE magnetic anomalies, considering the AS map and the complete Bouguer gravity anomaly map (Fig. 5.9) allows its origin to be determined. The AS signature evidences that the southern boundary of the ENE-WSW magnetic anomalous body lies north of the Alboran Ridge (Fig. 5.9), contrary to what was proposed by Galdeano et al. (1974) but in agreement with Galindo-Zaldívar et al. (1998). This anomaly is also related to a narrow axis of elongated Bouguer anomaly maxima identified at 4.5° W, extending to the east toward the Argelo-Provenzal Basin, whose amplitude is 100 mGal on average (Fig. 5.7), which is interpreted as caused by crustal thinning (Galindo-Zaldívar et al. 1998). The AS signature of the ENE-WSW trending magnetic anomaly fits reasonably well along this axis (seen in thick black contour lines in Fig. 5.9). Its source is located in the lower crust or even beneath the crust.

The AS map suggests an alignment between the WNW-ESE magnetic anomaly and another AS high at the northeast margin that reaches southeast of Cabo de Gata.

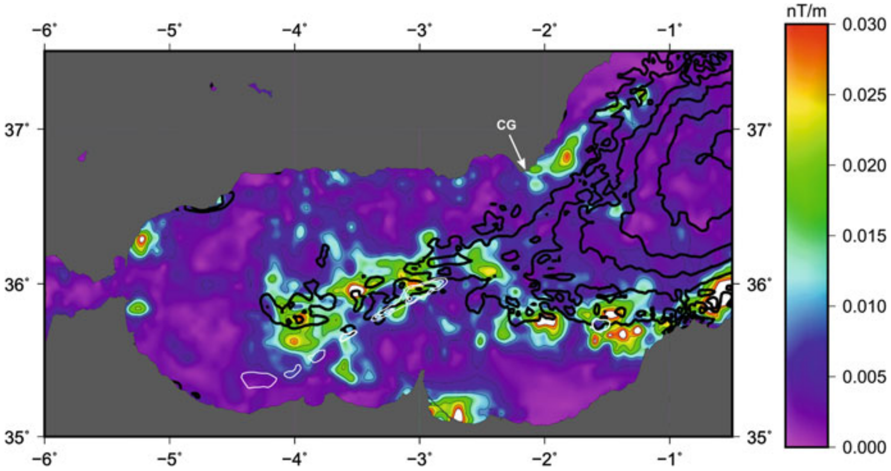

Fig. 5.9 Analytical signal map of the magnetic anomalies of the Alboran Basin. Total Bouguer gravity anomalies are displayed as thick black contour lines. Thick white lines delineate the Alboran Ridge topography. CG: Cabo de Gata

It coincides with the boundary of the complete Bouguer gravity anomaly, which dominates the middle and eastern Alboran Basin. This appoints to the AS maxima lineations are related to a magnetization contrast between the Argelian-Balearic Basin oceanic crust and the northern Iberia and southern African continental crusts (WNW-ESE magnetic anomaly).

In summary, gravity and magnetic anomalies mark three crustal domains: East 1° W denotes amplitude values corresponding to the very thin continental crustal Iberian and African domains, surrounding oceanic areas, or the Algero-Provenzal Basin. From 1° W to 4° W the continental crust has an ENE-WSW magmatic thinning axis. Finally, westward of 4° W, according to the AS map and gravity anomaly values, lies a continental domain. Such a cortical configuration is similar to that proposed by Gomez de la Peña et al. (2018) based on the reflective character of the crust studied by deep seismic reflection profiles; yet these authors discern a continental crust thinned to the north and west of the Alboran Ridge that would correspond to the Alborán Domain, plus a segment of northern Africa crust to the south and east of this morphological elevation.

5.4.2 *Basement Configuration and Major Structure*

The basement paleotopography and main structures are derived from seismic reflection profiles obtained from academia and industry (Bourgois et al. 1992; Comas et al. 1992; Maldonado et al. 1992; Watts et al. 1993; Docherty and Banda 1995; Chalouan et al. 1997; Vázquez 2001; Soto et al. 2010, 2012; Martínez-García

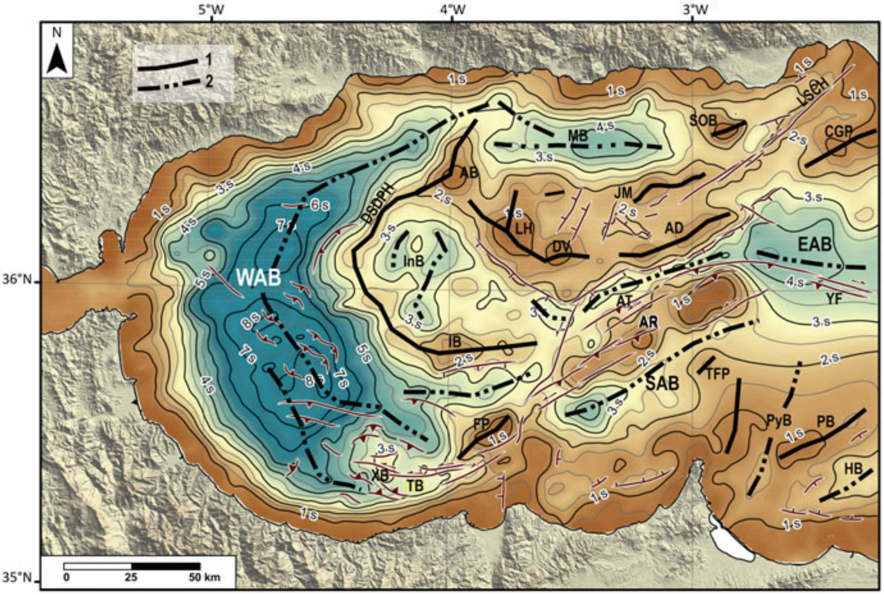

Fig. 5.10 Depth to basement map interpolated from the 2D seismic dataset (in seconds of two-way travel time). This horizon is affected by post-Tortonian deformation (Modified from Do Couto 2014). 1: Structural or volcanic highs axis; 2: Basin axis. AB: Avempace Bank; AD: Adra Ridge; AR: Alboran Ridge; AT: Alboran Central Trough; CGP: Cabo de Gata Promontory; DSDPH: Deep Sea Drilling Project High; DV: Djibouti Ville Bank; EAB: East Alboran Basin; FP: Francesc Pagés Bank; HB: Habibas Basin; IB: Ibn-Batouta Bank; InB: Intermediate Basin; JM: José Medialdea Bank; LH: La Herradura Bank; LSCH: La Serrata-Carboneras High; MB: Motril Basin; PB: Provençaux Bank; PyB: Pytheas Basin; SAB: South Alboran Basin; SOB: El Seco de los Olivos (Chella) Bank; TFP: Trois Fourches Promontory; WAB: Western Alboran Basin; XB: Xauen Bank; YF: Yusuf Fault

et al. 2013, 2017; Do Couto et al. 2016; Gómez de la Peña et al. 2018). Depth to basement map (Fig. 5.10) mainly represents the morphology of the metamorphic and volcanic basement beneath the basin infill.

The basement top surface is characterized by a structure of paleotopographic highs and depressions (Fig. 5.10). The two main sub-basins, WAB and EAB, stand out together with a secondary set of satellite basins found in the central segment (Motril, Southern Alboran, Central Alboran Trough, and Intermediate basins; Vázquez 2001) and the southeastern margin of the Alboran Sea (Habibas and Pytheas basins; Martínez-García et al. 2013) (Figs. 5.6 and 5.10). In addition, several structural highs are seen to have a different expression in the current seafloor morphology. They correspond to the highs of the Motril-Djibouti marginal plateau (Palomino et al. 2011), the Alboran Ridge, the DSDP high (whose superficial expression corresponds to Ibn-Batouta Bank), and the highs related to the Moulouya marginal plateau (Fig. 5.6; Chap. 6). The basement paleotopography would be partially distorted due to renewed uplift of the structural highs produced by the post-Tortonian compressive deformation, especially in the central sector of the Alboran Sea.

The main sedimentary basin formed on the strongly thinned crust of the Alboran Domain corresponds to the WAB, which is also the deepest depression and reaches 8 s twtt at Morocco offshore and 7 s twt at Spain offshore (Figs. 5.4 and 5.10). It is the thickest sedimentary depocenter in the Alboran Basin, estimated to lie at a depth between 10 and 12 km (Soto et al. 1996, 2010; Mauffret et al. 2007; Iribarren et al. 2009; Do Couto et al. 2016). Its geometry in plain view is arched, its axis mimicking the arcuate geometry of the orogenic arc, forming a curvilinear "bean" shape that continues toward the north to a secondary E-W basin. The northern branch has a NE-SW trend that changes to NNW-SSE southward, from latitude 36° N. This basin is largely affected by shale tectonics (Soto et al. 2010, 2012) and associated mud volcanism (Pérez-Belzuz et al. 1997; Sautkin et al. 2003; Talukder et al. 2003; Blinova et al. 2011; Somoza et al. 2012; Gennari et al. 2013).

The Motril Basin has an E-W direction, arranged approximately parallel to the northern coast of the Alboran Sea, with a slightly trapezoidal to elongated geometry, and its maximum thickness is greater than 4 s twtt (Fig. 5.10). The basin lies in the eastern extension of the northern branch of the WAB, just slightly disconnected from it (Vázquez 2001). The Intermediate Basin has no influence on the current physiography of the Alboran Sea. It is situated between the La Herradura-Djibouti Ville Banks and the DSDP highs (Fig. 5.10). Its geometry is oval, with a maximum axis of trend NNW-SSE. The maximum sedimentary thickness (>3.5 s twtt) is found in its northern part. This basin could be considered as an eastern secondary marginal sub-basin related to the main WAB. In turn, the southern sector of the Intermediate Basin would extend to the east along the Alboran Central Trough, of NE-SW orientation, that has a maximum thickness greater than 3 s twtt and a corridor geometry that is highly controlled by post-Tortonian compressive processes.

The continental crust described as belonging to the North Africa domain hosts three sedimentary basins. The longest is the SAB, located between the southern flank of the Alboran Ridge and the Trois Fourches Promontory (Vázquez 2001), having a NE-SW direction and a slightly trapezoidal to elongated geometry. The maximum thicknesses (>4 s twtt—Do Couto et al. 2016; locally ~4 km of sediments—Martínez-García et al. 2017) are located in its southwestern sector (Fig. 5.10). The formation of this basin and its current geometry are controlled by the post-Tortonian compressive deformation. It is separated from the WAB owing to progressive Alboran Ridge uplift since the upper Tortonian (Martínez-García et al. 2017) by folding and thrusting northward (Estrada et al. 2018).

Two sedimentary basins have been described to the east of the SAB: the Pytheas and Habibas basins. The Habibas basin (at least) is floored by continental metamorphic rocks (Medaouri et al. 2012, 2014). Both basins have an elongated geometry trending NE-SW to ENE-WSW and have an expression on the seafloor at their northern segment. The Habibas basin has a maximum thickness close to 4.5 s twtt (Gómez de la Peña et al. 2018) and is bounded to the north by the Yusuf Fault (Figs. 5.4 and 5.10), to the east by the Alidade Bank, and to the west by the E

Cabliers Ridge and the Provençaux Bank (Fig. 5.4), and progressively shoals southward; meanwhile the Pytheas Basin has a maximum thickness of 4 s twtt (Gómez de la Peña et al. 2018), is bounded to the east by the E Cabliers Bank, to the west by the W Cabliers Bank and the Trois Fourches Promontory, and to the south by the Provençaux Bank (Figs. 5.4 and 5.10).

Finally, above the thinned continental and magmatic crust lies the EAB. It has triangular geometry, its northern flank being controlled by the NE-SW La Serrata-Carboneras fault zone and constituted by the Adra Ridge and the Cabo de Gata Promontory; its southern flank corresponds to the NW-SE Yusuf fault zone and progressively opens eastward in transition with the oceanic lithosphere of the Algero-Provenzal Basin, so that its maximum thicknesses (>4.5 s twtt) would be in the western segment (Vázquez and Vegas 1996; Booth-Rea et al. 2007) (Figs. 5.4 and 5.10).

The structural highs—the NE-SW oriented Alboran Ridge, and its prolongation to the southwest in the Francesc Pagés and Tofiño banks—correspond to an antiform and a volcanic alignment (Figs. 5.4, 5.6 and 5.10), although the bulk of uplift was mainly produced by folding and inversion of its northern flank verging northwards, during the post-Tortonian compressive phase (d'Acremont et al. 2020). The banks of La Herradura and Djibouti Ville are probably located in relation to the NW-SE eastern faulted boundary of the Intermediate basin and correspond to two volcanic edifices formed in the Upper Miocene. However, their relief continues to the NE (in a NE-SW trend) in two branches, the northern one is constituted by the José Medialdea and Chella banks, and the southern one by the Adra Ridge, El Sabinar and Pollux banks and the Cabo de Gata Promontory (Figs. 5.6 and 5.10). The DSDP high displays a horseshoe geometry, its NE-SW directed northern branch taking in the Avempace bank and the smooth high that disconnects the WAB and Motril basins, while a central NNW-SSE branch separates the WAB of the Intermediate Basin and a southern E-W branch includes the Ibn-Batouta Bank (Fig. 5.10). Notwithstanding, some inversion and uplift of the northern and southern branches may have occurred during the post-Tortonian compressive phase.

Several structural highs have been defined to the east of the Alboran Ridge on the African margin. Two of them are the Trois Fourches Promontory and the Porvençaux Bank, of NE-SW trend (Fig. 5.10) and marking metamorphic basement highs (Gómez de la Peña et al. 2018). Another two are the NW and E Cabliers ridges (Figs. 5.4 and 5.6), respectively found in the northward prolongation of the aforementioned basement highs and described as volcanic edifices (Duggen et al. 2008). These structures were uplifted in the post-Tortonian compressive phase and produced tilting of pre-Messinian sedimentary units at least (Gómez de la Peña et al. 2018), a deformation apparently greater to the northeast, especially in relation to the intersection of NE Cabliers Bank and the Yusuf Fault (Figs. 5.4, 5.6 and 5.10).

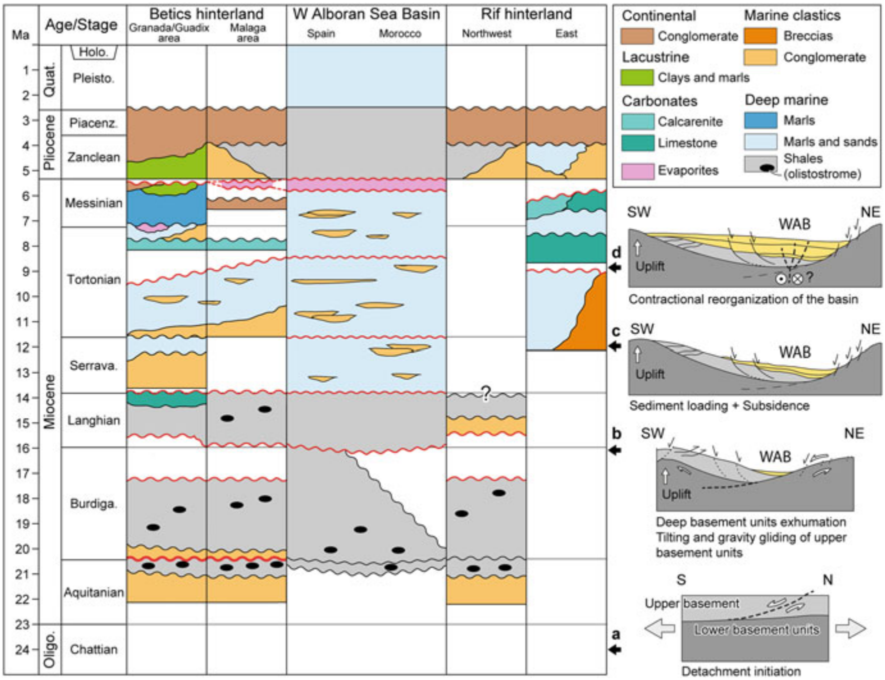

Fig. 5.11 Onshore-offshore chronostratigraphic correlation from Spain to Morocco, showing the main unconformities that affect the whole domain (see Do Couto et al. (2016) for more details), together with synthetic cross-sections reflecting the evolution of the western Alboran basin from late Oligocene (**a**) to late Tortonian, and the shift from extensional to contractional reorganization (**d**)

5.4.3 *Tecto-Sedimentary Evolution*

The different sub-basins share a common Pliocene-Quaternary history, although each of them formed and evolved differently over time (Fig. 5.11). The WAB contains the most complete stratigraphic record, from the lower Miocene (Aquitanian-Burdigalian) to Quaternary (Comas et al. 1999). Analyzing the geometries of seismic stratigraphic sequences sheds light on the evolution of the basin linked with crustal deformation.

5.5 Miocene

In the WAB, most tectonic and stratigraphic markers indicate that the basin began to develop in early Miocene times, probably above an extensional detachment that controlled subsidence (Do Couto et al. 2016). Then, in the middle Miocene, the

WAB underwent relatively homogeneous yet intense subsidence, interpreted as being controlled by the pull of the dipping subducting lithosphere and relative thermal cooling of the crust probably after the magmatic stages 1 and 2 (Torres-Roldán et al. 1986; Duggen et al. 2004), thereby explaining the considerable thickness (10 km) of the sedimentary infill (Do Couto et al. 2016). It is worth noting that deep structures in the basement imaged by means of deep seismic reflection profiles in the northern half of the Alboran Basin have been interpreted as extensional shear zones, associated with major extensional detachments in the Betic Cordillera (Watts et al. 1993; Vázquez et al. 1995; Vegas et al. 1995; Comas et al. 1997). The Motril Basin (northern E-W elongated part of the WAB) exhibits a rather different pattern, with an asymmetric geometry (Comas et al. 1999) comparable in shape to the asymmetric intramontane basins described inland (e.g., Sorbas Basin, Fig. 5.4), even though the total thickness of sedimentary rocks is far greater (<7 km). While the southern branch of the WAB is strongly affected by late-Miocene-to-present compression that produces its inversion, folding, and uplifting to constitute the Xauén and Francesc Pagés banks (d'Acremont et al. 2020; Lafosse et al. 2020).

The SAB and basins located to southeast differ from the WAB in that it lies above a crustal domain pertaining to Africa (Estrada et al. 2018; Gómez de la Peña et al. 2018). The sedimentary record appears to be younger than that of cores drilled in the WAB, starting in the middle Miocene (Serravallian) (Martínez-García et al. 2017). The EAB is located above thinned continental and magmatic crust (Booth-Rea et al. 2007) and the sedimentary record start also in the middle Miocene in its western part (Alvarez-Marrón 1999) but probably the initial age and the total thickness of the sedimentary column increases towards the east, in the transition with the oceanic crust of the Algero-Balearic basin (Comas et al. 1999; Booth-Rea et al. 2007). According to recent studies, whereas the late-Miocene-to-present compression reorganizes the morphology of the Alboran sub-basins, deeply buried Miocene normal faults demonstrate the widespread character of extensional tectonics around Alboran at that period (Martínez-García et al. 2017).

The *Lower Miocene* (Aquitanian-Burdigalian) is marked by the sedimentation of clays with interbedded sandy intervals above a basal pebbly sandstone in a syn-rift setting. Well data point to undercompacted shales, nowadays presenting overpressure in boreholes. Together, the seismic facies and borehole lithologies indicate that the lower Miocene consists of olistostromes containing polymictic rocks (olistoliths and rock breccia) embedded in an undercompacted shale matrix. The spatial distribution of these units is highly heterogeneous, the thickest depocentres occupying the center of the WAB (Do Couto et al. 2016), or Motril Basin (Comas et al. 1999), and so far nowhere else. The lower Miocene undercompacted shales are involved in the mud volcanic activity of the area (Sautkin et al. 2003; Gennari et al. 2013) and likewise in the shale tectonics that affect the WAB (Chalouan et al. 1997; Pérez-Belzuz et al. 1997; Talukder et al. 2003; Soto et al. 2010). It is difficult to estimate a paleobathymetry with respect to the sedimentary facies.

The undercompaction of shales in the lower Miocene series (Jurado and Comas 1992; Soto et al. 2010), the lack of late Oligocene sediments (Martínez del Olmo and Comas 2008), and the metamorphic paths of basement units are cited by authors

(Platt et al. 2013) who suggest rapid subsidence at the WAB initiation. The lower Miocene deposits are found overlying a basement composed of metamorphic units related to the Alpujarride-Sebtide Complex (Comas et al. 1999), or to the Malaguide-Ghomaride Complex (Do Couto et al. 2016). The origin of subsidence responsible for the deposition and fast burial of the sediments (causing undercompaction) can be found in the extreme thinning of the crust associated with the extensional detachments described onshore in the Beticas-Rif system.

The *Middle Miocene* (Langhian—Serravallian) witnesses the deposition of two sub-units: (1) a lower unit made of clays, interbedded silty to sandy clays, and basal coarse-grained sandstone, the unit displaying typical features of undercompaction with abnormal overpressures; and (2) an upper unit consisting of well-graded sand-silt-clay turbidites and turbiditic muds interbedded with volcanogenic layers. The lower Langhian unit, presenting signs of overpressure, was deposited in syn-rift settings as in the lower Miocene. However, at the end of the Burdigalian, the extensional setting of the Alboran Domain changes from regional N-S extension to widespread E-W extension. Such a transition triggered a moderate subsidence step in the WAB and adjacent basins. During the Serravallian, E-W extension proceeded westward, leading to the exhumation of E-W elongated metamorphic domes inland, thereby triggering the onset of subsidence in the southeastern Betics. This modification of the lithospheric configuration largely affected the WAB, which recorded the onset of a strong subsidence phase, signaled by an up to 3 km-thick Serravallian sequence (Do Couto et al. 2016).

The geometry of the Serravallian sequences, exhibiting overall landward to basinward onlap geometry, indicates that the WAB underwent relatively homogeneous yet intense subsidence (“sag basin”) during part of its evolution. This period coincides with high volcanic activity in the Alboran Sea, recorded in the thick volcaniclastic series. Subsidence evaluation indicates two successive Langhian and Serravallian subsidence pulses (e.g., Comas et al. 1999) leading to the deposition of deep sea turbiditic fans. Elsewhere in the Alboran Sea, the Serravallian is also present in the SAB, marking the deepest deposits (Martínez-García et al. 2017). The sag basin geometry is indicative of subsidence along a relative thermal cooling period of the crust (White and McKenzie 1989). Besides, subsidence was accompanied by flexural basement tilting, both to the southeast in the norther margin and to the northwest in the southern one (Vázquez 2001; Soto et al. 2010; Do Couto et al. 2016). These processes favor a slope tectonics of overpressured shales caused a downslope migration, which also resulted in secondary basin subsidence (Soto et al. 2010).

The *Upper Miocene* (Tortonian-Messinian) is a key period in the WAB. It encompasses the transition from a regional tectonic extensional setting to a compressive regime. The lower Tortonian is marked by the deposition of graded sand-silt-clay turbidites interbedded with a few volcanogenic layers. The widespread spatial distribution and rather isopach character of this stratigraphic sequence indicate the end of the mostly extensional period. Its topmost surface is nowadays folded and partly eroded. Above, the upper Tortonian comprises sandstone intervals, with claystones and silty clay beds, also corresponding to turbidite facies with some channel-like features. This sequence was deposited under a mostly compressional regime, flexural subsidence remains, and generated secondary accommodation.

The Messinian features the superposition of two main sub-units in the Alboran Sea: (1) a lower unit made up of marine sandy turbidites interbedded with carbonates and volcaniclastic layers; and (2) an upper unit made up of gypsum and anhydrite embedded in clays, linked to the Messinian Salinity Crisis deposits. Indeed, the continuous compressional regime closed marine corridors linking the Mediterranean Sea to the Atlantic Ocean during the Messinian and led to the drying up (desiccation) of the Mediterranean Sea. While the Messinian deposits containing remnants of evaporites have never been mapped, borehole records tend to show they are relatively thin in the basin and seem to have eroded before the reflooding of the whole basin close to the Pliocene.

In general terms, post-Tortonian (~8 Ma) tectonics can be understood as a contractive reorganization affecting the Alboran Domain and modifying the architecture of Miocene basins and margins (Comas et al. 1992) as well as the local dimensions of sub-basins, favoring uplift of the Alboran Ridge and structural highs, while deforming by folding and faulting the sedimentary record (e.g., Estrada et al. 1997; Ammar et al. 2007; Vázquez 2001; Marín Lechado et al. 2007; Ballesteros et al. 2008; Martínez-García et al. 2011, 2013, 2017; Gómez de la Peña et al. 2018; d'Acremont et al. 2020).

5.6 The Opening of the Strait of Gibraltar

The Messinian Salinity Crisis (MSC) ended in the latest Miocene, when the isolated (or very restricted) the Mediterranean Sea became reconnected to world ocean currents through the Strait of Gibraltar. Initial models of the MSC establish that the Mediterranean Sea was progressively restricted from the Atlantic Ocean as the Gibraltar Arch shifted to the west and the African plate to the north, resulting in the closure of the Mediterranean-Atlantic gateways. However, a key question has remained unexplained: the thickness of salt accumulated in the deep basins would have required intermittent sea water inputs.

Over the past decades some authors have postulated that during the MSC, the Mediterranean was still connected to the Atlantic Ocean through the Strait of Gibraltar. Thus the deep desiccated basin model (Hsü et al. 1973) was replaced by one entailing stratified dense brines upon a deep non-desiccated basin under a normal sea level (Roveri et al. 2014). No direct proof supports a permanent Gibraltar gateway throughout the MSC, leaving its existence as an open question. Unclear as well is the contribution of the Paratethys Sea to the MSC salt precipitation.

The Alboran Basin proves key area to understand how the opening of the Strait of Gibraltar occurred. Detailed analysis of the Alboran Basin stratigraphy, by means of a dense net of seismic profiles correlated with commercial and scientific wells, indicates that the Strait of Gibraltar formed at the end of the MSC, in the transition to the Zanclean period, as a result of an unprecedented catastrophic event—the

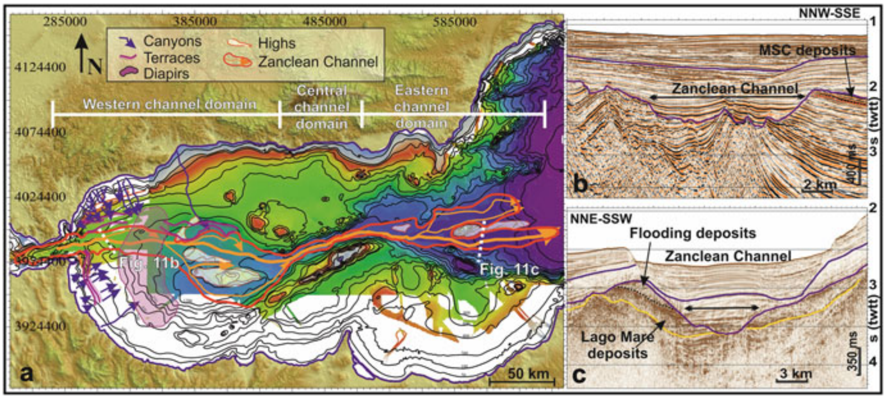

Fig. 5.12 (**a**) Present-day bathymetric map showing the location of the main morphological features related to the opening of the Strait of Gibraltar (modified from Estrada et al. 2011); (**b**) and (**c**) seismic profiles showing the erosive channel related with the Zanclean reflooding of the Mediterranean Sea. Legend: Yellow line corresponds to the time lapse of salt deposition during MSC paroxysm; purple, top Messinian; blue, the base of Quaternary. Horizontal scale in meters and vertical scale in seconds (twtt); see (**a**) for location

Zanclean Megaflood (Fig. 5.12) (Blanc 2002; Garcia-Castellanos et al. 2009, 2020; Estrada et al. 2011). The seismic stratigraphic record of this basin at the transition from Messinian to Pliocene indicates that MSC-related deposits have a characteristic thin, chaotic subunit (Fig. 5.12b) (Martínez del Olmo and Comas 2008) linked to the sea level drop of the MSC (Do Couto et al. 2016). Likewise, remnants of the MSC Lago Mare upper unit (UU) are identified in the easternmost basin (Fig. 5.12c), and patches of primary lower gypsum (PLG) are found in the nearby Malaga and Melilla areas. The lack of salt deposits is remarkable (Mobile Unit, MU). Overlying the MSC erosion and deposits, an open marine Pliocene-Quaternary unit develops, governed by the opening of the Strait of Gibraltar (Fig. 5.12b, c) (Juan et al. 2016).

The Messinian-Pliocene boundary is characterized by a regional polygenic unconformity (Estrada et al. 2011; Do Couto et al. 2016). Unlike other areas of the Mediterranean, where Messinian erosion mainly develops on margins, the Alboran Basin displays its strongest erosion in comparatively deep areas. Several erosional features (channels, terraces, and canyons) characterize this regional surface (Fig. 5.12a). The most prominent feature is an incised E-W channel crossing the entire basin (390 km long and up to 488 m deep) that may signal flooding in the wake of the Atlantic-Mediterranean re-connection (Garcia-Castellanos et al. 2009, 2020; Estrada et al. 2011) (Fig. 5.12). The incision depth of the channel is variable, suggesting local variations in the erosive capacity of Atlantic inflow, conditioned mainly by the regional basin topography and the local presence of topographic highs (Fig. 5.12a). Adjacent to this channel along the Spanish and Moroccan margins, and near the Strait of Gibraltar, several submarine terraces at different depths suggest a pulsed flooding of the Alboran Basin (Estrada et al. 2011).

The age of this striking channel is constrained by the eroded sediments and erosional surfaces. The channel clearly cuts the regional erosional surface as well as the chaotic sediments related to the MSC sea level drop, during coeval salt deposition in other areas of the Mediterranean Sea. In the easternmost Alboran Basin, the channel also incised the lattermost deposits of the MSC (UU), therefore indicating an age between the latest Messinian and Zanclean. As a result of the Zanclean Flooding, and postdating the MSC UU, several chaotic lenticular bodies developed atop the Zanclean channel margins, probably constituting a rare example of megaflood deposits coeval to those described for the Alboran Sea (Periáñez et al. 2019) and the nearby sill of the Strait of Sicily (Micallef et al. 2018).

What caused the opening of the Strait of Gibraltar? This is an unanswered question. Certain hypotheses evoke tectonic control, sea level changes, or retrogressive fluvial erosion, yet the most plausible cause is a combination of tectonics and retrogressive river erosion (Blanc 2002; Loget and Van Den Driessche 2006; Garcia-Castellanos and Villaseñor 2011).

5.7 Pliocene-Quaternary

The Pliocene-Quaternary deformation of the Alboran Sea is evidenced by the change from a mostly compressional regime (Campos et al. 1992; Maldonado et al. 1992; Woodside and Maldonado 1992; Rodriguez-Fernandez and Martin-Penela 1993; Estrada et al. 1997) and by a shift in the orientation of the convergence vector between the Eurasian and African plates, from NW-SE to WNW-ESE (Mazzoli and Helman 1994; Rosenbaum et al. 2002b; Merkouriev and DeMets 2008; Martínez-García et al. 2013). It contributed to the reactivation, propagation, and uplift of the NE-SW oriented structures (Estrada et al. 1997; Comas and Soto 1999; Martínez-García et al. 2013). To accommodate this convergence, indentation tectonics developed in the central Alboran Sea gave rise to two conjugated sets of dextral WNW-ESE and sinistral NE-SW to NNE-SSW faults, while in the same context ENE-WSW-oriented folds and antiforms developed (Estrada et al. 2018).

Three major shortening phases have been defined to characterize the Pliocene-Quaternary tectonic history of the Alboran Sea (Martínez-García et al. 2013): (a) earliest Pliocene (*ca.* 5.33–4.57 Ma), mainly deforming the Alboran Ridge; b) late Pliocene (*ca.* 3.28–2.59 Ma), uplifting the Alboran Ridge until closing the gateway that had connected the SAB and WAB; and c) Pleistocene (*ca.* 1.81–1.19) (e.g., Estrada et al. 1997; Martínez-García et al. 2013), entailing further deformation and uplift of the Alboran Ridge, deformation in the Yusuf Lineament (Martínez-García et al. 2013; Estrada et al. 2018), and northward propagation of the Al-Idrissi Fault zone (d'Acremont et al. 2014; Estrada et al. 2018).

The Alboran Basin narrowed considerably during the Pliocene due to the emergence of onshore sub-basins and the progressive uplifting of the Alboran Ridge as a result of the first two major phases of shortening (Martínez-García et al. 2013). Basement flexure along Pliocene caused a general deepening of sedimentary units (particularly in the WAB) (Docherty and Banda 1992; Rodríguez-Fernández et al. 1999) and tectonics altered the sizes of the easterly sub-basins (Estrada et al. 1997; Comas et al. 1999; Martínez-García et al. 2013). The uplift of the Alboran Ridge propagated from NE to SW, splitting the EAB and WAB (Martínez-García et al. 2013). The Xauen and Tofiño banks area was extensively folded and uplifted (Bourgois et al. 1992; Chalouan et al. 1997; d'Acremont et al. 2020; Lafosse et al. 2020) and, together with the Alboran Ridge, progressively led to the formation of a long morphologic barrier in the late Pliocene that is presently ~130 km long and 1.75 km high (Ammar et al. 2007; Martínez-García et al. 2013; Vázquez et al. 2015). The re-orientation of previous tectonic structures due to the changes in the stress field during the Pliocene and Quaternary, along with the uplifting of diapirs in the WAB (Pérez-Belzuz et al. 1997; Talukder et al. 2003), also conditioned smaller morphotectonic changes behind other evolving tectonic features, such as basement highs, structural scarps, mud volcanoes, and diapiric ridges.

The morphotectonically active setting that characterized the Alboran Sea during the Pliocene and Quaternary involved a changing seafloor landscape and basin configurations. They largely controlled the distribution and lateral continuity of the Pliocene and Quaternary seismic stratigraphic units. The most common stratigraphic boundaries of the overlying Pliocene and Quaternary stratigraphy were described in Ryan et al. (1973) and Campillo et al. (1992), primarily along the Spanish margin. A recent analysis identified the main tectonic/sedimentary reflectors in the SAB and EAB (Martínez-García et al. 2013). All these sources were recently combined and updated by Juan et al. (2016).

The Pliocene-Quaternary sequence of the Alboran Sea has been previously addressed by means of industrial and academic wells (Jurado and Comas 1992; Comas et al. 1999) and is known to consist of pelagic to hemipelagic marls and shales (Fig. 5.11), interlayered with sandy turbidites and/or contourites (Alonso et al. 1999; Juan et al. 2020). Its base is marked by a discontinuity recognized across the entire basin, linked to erosion and the Messinian Salinity Crisis (Estrada et al. 2011). The overall geometric configuration of the Pliocene sequence and its units consists of irregular subtabular sedimentary bodies and roughly wedge-shaped bodies pinching out upslope and, locally, downslope (Juan et al. 2016). The Quaternary sequence and its units primarily display wedge shapes along the Spanish and Moroccan margins (Ercilla et al. 1994; Hernández-Molina et al. 2002), subtabular shapes in the basin domains, and mounded shapes at the bases and walls of the seamounts and escarpments, on the Alboran Ridge, and in the Alboran Trough (Juan et al. 2016).

Throughout the Quaternary, sea level changes related to climate forcing constrained the edification of continental shelf physiography, especially since the middle Pleistocene, as a consequence of the greatest importance of the 100 k year cycles (Hernández-Molina et al. 2002). In low sea level events, the continental shelf is sculpted and grows seaward through the deposit of shelf-margin wedges tied to continental sediment input from river mouths; in turn, high sea level events saw the migration of the coast towards the continent and the deposit of coastal deltas and wedges (Ercilla et al. 1992, 1994; Hernández-Molina et al. 1994, 1996; Chiocci et al. 1997; Chap. 6).

Although early studies mostly carried out along the Spanish margin concluded that confined and unconfined downslope processes and hemipelagic settling have played a dominant role in outbuilding the continental margins and infilling basins, bottom currents recently came under the spotlight (Ercilla et al. 2002, 2016; Palomino et al. 2011; Juan et al. 2016, 2020). The greater depth of Pliocene basins favored the action of a strong, dense countercurrent in the WAB (as modeled by Alhammoud et al. (2010), in a shallow sill situation), which helps explain the thick Pliocene deposits as well as the broad sheeted and plastered drifts. The uplifting of the Alboran Ridge would have weakened this dense countercurrent (Juan et al. 2016); hence, a circulation model conditioned by the complex topography could be established. The Quaternary topography gave rise to a separation of light versus dense water flows into small-scale branches, forming minor contourite features within narrow passages and at the base of the seamounts (Juan et al. 2016). The changes in the contourite systems have allowed to interpretate an increase in the flow energy from the Pliocene to the Quaternary in this area (Juan et al. 2020). Furthermore, the scarcity of turbidite systems in the Morocco margin has been explained by the action of water masses that produces dispersion of the sediments (Ercilla et al. 2019), and the reduction in the number of turbidite systems since the Pliocene and decrease in their sizes could be also related to the enhanced of water mass action on sediment transport (Juan et al. 2020).

5.8 Conclusions: Paleogeographic Implications

The evolution of the area between Africa and Iberia, the region where the Alboran Sea is currently located, has successively been constrained since the Jurassic by the movement of the African and Eurasian plates, by the intermediate role of the Iberian plate, showing a certain independence from the main plates during a period of its development, and by orogenic processes since de Late Cretaceous first in the Ligurian Tethys oceanic basin and later in the Western Mediterranean oceanic basin. Related to the last process, a lithospheric terrane now known as the Alboran Domain collided with the continental margins of South Iberia and North Africa since the Upper Oligocene. The westward drift of this domain during the Miocene generated an extensional basin inside, characterized by a very stretched continental lithosphere and significant magmatic activity in its central and eastern sectors, that evolved to the current basin of the Alboran Sea after compression from the Late Tortonian.

One crucial element of the geological evolution between Africa and Iberia is their geographical location: at the point of connection of two oceanic basins, the geodynamic plates evolution was responsible for the creation and destruction of several ocean basins and their oceanographic gateways. Thus, tectonics controlled

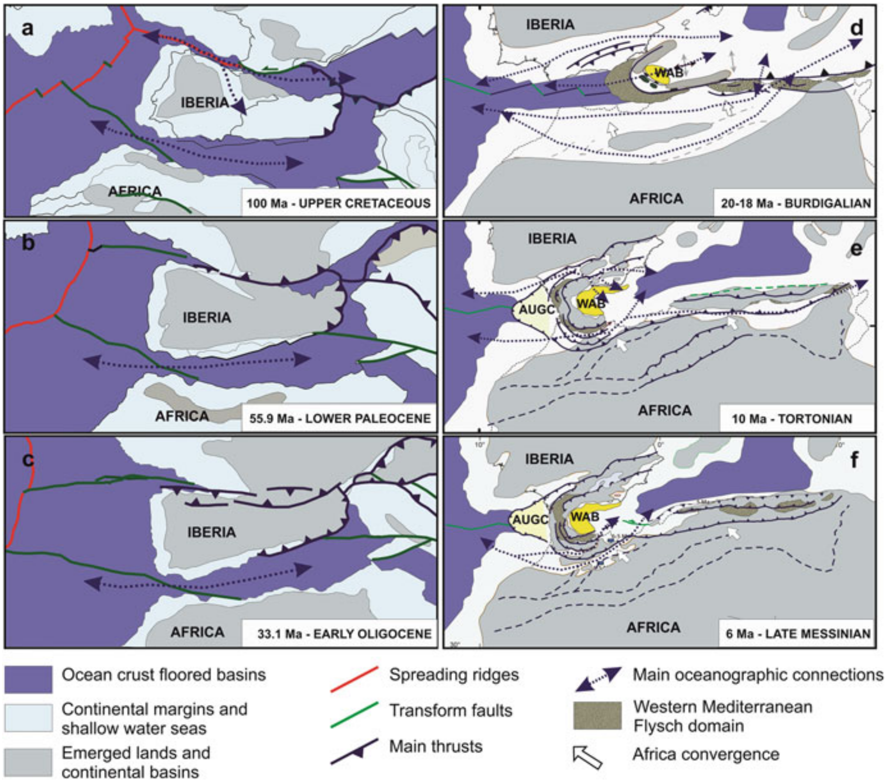

Fig. 5.13 Evolutive scheme of palaeoceanographic relations between the Atlantic Ocean and the different oceans and seas in the Tethys domain, east to the Iberia, (**a**, **b**, **c**) from the Upper Cretaceous to Eocene-Oligocene boundary based on Ziegler (1988), Schettino and Turco (2011), Advokaat et al. (2014) and Martín-Chivelet et al. (2019); (**d**, **e**, **f**) Palaeoceanographic scheme of the Alboran Sea region along the formation and evolution of the Betic-Rif Belt and the Alboran Sea Basin (modified from Do Couto 2014; Do Couto et al. 2016)

the oceanographic connections between the seas situated to the west and the east of Iberia.

Within the specific region currently occupied by the Alboran Basin (yet previous to its formation), there was an oceanographic connection between the Atlantic and Ligurian Tethys oceans in southern Iberia in the Late Jurassic, and a secondary connection occurred in northern Iberia (Ziegler 1988; Schettino and Turco 2011). Since the Late Cretaceous (Fig. 5.13a) the Iberian block has undergone compression due to the convergence between Africa and Eurasia; indeed, it led to the closure of the connection in northern Iberia during the Paleocene (Ziegler 1988; Rosenbaum et al. 2002a) (Fig. 5.13b) and finally to the Pyrenean orogen as part of the Alpine belt in the Eocene phase (Schettino and Turco 2011). Some uncertainty surrounds the characteristics of the southern oceanographic connection. Did it occur only across the continental margins of South Iberia and North Africa? Elsewise, if oceanic seafloor spreading was involved, could it be associated with the stretching of the continental margins located at the western end of the Ligurian Tethys oceanic basin? (Vergés and Fernàndez 2012; Vergés et al. 2019).

The closure of the Ligurian Tethys basin is clearly linked to the subduction of the African oceanic lithosphere northward, under Eurasia, in the Eocene (Fig. 5.13c). It would have favored the progressive disappearance of the Atlantic-Tethys oceanographic connection. Still, the change in subduction described for the Oligocene immediately led to the extensional collapse of the Eocene alpine orogen and opening of the Western Mediterranean oceanic basin. A further consequence was the splitting—to the east, south, and west—of several lithospheric fragments of this orogen (Faccenna et al. 2004; Jolivet et al. 2009; Carminati et al. 2012). This new geodynamic scenario welcomed the maintenance of the oceanographic connection between the Atlantic Ocean and the Western Mediterranean Sea as the Alboran Basin was being formed, and its additional connection to the Ligurian Tethys while this basin was gradually closed due to subduction of its oceanic lithosphere.

Westward drift of the Alboran Domain throughout the Miocene resulted in the formation of the Betic-Rif Belt when it collided with the continental margins of southern Iberia and northern Africa. Inside this orogen, in the back-arc region, a marine basin developed in the wake of extensional stretching of the lithosphere (Comas et al. 1999; Comas and Soto 1999). At this stage, several W-E oceanographic connections resisted, by means of the Northbetic area, the Alboran Sea, and the Rif area (Braga et al. 2001, 2003; Martín et al. 2009; Do Couto et al. 2016; Capella et al. 2017) (Fig. 5.13d). Thus, the Tortonian marine basin would have had a much greater width (even several hundred miles wider) than the current basin (Fig. 5.13e). This is attested to by the distribution of Tortonian coral reefs along the main mountainous reliefs of both the Betic and Rif chains, reliefs that existed as large islands within the Tortonian Sea (Braga et al. 2003; Galindo-Zaldívar et al. 2019).

A shift in the direction of convergence of Africa and Eurasia in the Late Tortonian slowed the Alboran Domain's westward drift. At the same time, tectonic stacking at the Gibraltar Arc front (Balanyá et al. 2007), deformation related to block rotations (Crespo-Blanc et al. 2016), and the progressive uplift of the Betic and Rif ranges onland (Braga et al. 2003), because of increased thickness owing to the emplacement of the Alboran Domain. The Upper Miocene also witnessed the main stage of magmatic activity (Duggen et al. 2008): several volcanos formed in the Alboran Basin, very likely associated with a thermal expansion of the seafloor. Furthermore, it has been proposed that the joint action of mantle resisted slab dragging and slab tearing also influenced the closure of these gateways (Capella et al. 2020). Given this compressional setting, together with the generalized sea level fall in the Messinian (Jolivet et al. 2006; Loget and Van Den Driessche 2006), an imminent consequence was the closure of marine water corridors through which the Mediterranean Sea communicated with the global ocean (e.g., Martin et al. 2001; Betzler et al. 2006; Gibert et al. 2013; Flecker et al. 2015; Achalhi et al. 2016; Capella et al. 2018; Krijgsman et al. 2018) (Fig. 5.13f). The Mediterranean Sea dried out nearly 5.9–5.5 Ma ago. A thick series of evaporites was deposited in the deepest basins, while the margins, including the Alboran Domain, underwent subaerial erosion (Estrada et al. 2011; Gorini et al. 2015). This crisis came to an end after a major breakdown of the Gibraltar dam, which caused quick, intense reflooding into the Mediterranean Sea (Garcia-Castellanos et al. 2009, 2020).

From this point onward, now in the early Pliocene (Zanclean), a new gateway opened between the Atlantic Ocean and the Mediterranean Sea. On the basis of tectonic, gravitational, and erosive effects studies near the Gibraltar Arc, the opening can be situated in close correspondence to the current Strait of Gibraltar (Loget and Van Den Driessche 2006; Estrada et al. 2011). After an initial erosive phase owing to Atlantic water mass flooding, the currently existing oceanographic dynamics progressively prevailed; hence, the region's present state can be traced to the late Pliocene-Quaternary boundary (Juan et al. 2016). Yet coetaneously, throughout this phase, the bulk of uplift affecting main, positive reliefs of the basin took place. In particular, the Alboran Ridge and its continuation toward the SW toward the bank of Xauen were substantially elevated (Martínez-García et al. 2013; Lafosse et al. 2018). This elevation is therefore a consequence of compressive processes that acted during the Pliocene-Quaternary, along with the indentation of a very resistant cortical block associated with the Alboran Ridge, all in conjunction with the compressive ridge uplift and the development of WNW-ESE right-lateral and NNE-SSW left-lateral conjugate fault systems, bounding it respectively to the east and to the west, and propagating deformation toward the northern margin of the basin (Estrada et al. 2018).

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Chapter 6
Seafloor Morphology and Processes in the Alboran Sea

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6.1 Introduction

The Alboran Sea is one of the seas most widely studied by Spanish marine geologists. There are two main reasons: its structural framework and its oceanographic circulation. The Alboran Sea is interesting from a structural point of view because it is the site of collision between the Eurasian and African plates, and the basin is located within the framework of an orogenic process forming the surrounding Betic and Rif mountain belts. The westward displacement of the Alboran Domain (formerly the Alboran Microplate, Andrieux et al. 1971) between the two major plates

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has determined the development of the Arc of Gibraltar, within which the arc-shaped, semi-enclosed basin of the Alboran Sea is formed. The mentioned tectonic collision favours the development and activity of faults with associated crustal earthquakes. It has also contributed to the modelling of a highly irregular seafloor relief that reflects the complexity of the tectonic processes (Galindo-Zaldívar et al. 2018; Estrada et al. 2018). From an oceanographic point of view, the Alboran Sea is interesting because it is where the Mediterranean Waters (MWs) escaping toward the Atlantic Ocean encounter the Atlantic Water (AW) entering the Mediterranean Sea (e.g. Parrilla et al. 1986). This meeting of water masses produces a complex oceanography where the bottom layers of the Atlantic and Mediterranean water masses interact with the complex and irregular seafloor, conditioning the transport, sedimentation, and reworking of the near surface sediments, and forming sedimentary reliefs that increase the topographic complexity of the seafloor (Ercilla et al. 2016).

These geological and oceanographic characteristics of the Alboran Sea make this sea an ideal context in which to analyse the morphological features and sedimentary deposits, from shallow waters, where the continental shelf is generally poorly developed, to deep sea areas, dominated by a highly irregular topography. This contribution summarises the geomorphology of the Alboran Sea, based on recent, local and regional, interdisciplinary studies. After presenting the geological and oceanographic frameworks, we offer an up-to-date summary of the main

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morphological features and near surface sedimentary facies. Then, we look with attention to recent sediment dynamics and tectonic activity using geological and oceanographic approaches. In addition, we assess how the geomorphology of the Alboran Sea offers us clues to determine the main potential geological hazards, as well as how it can play an import role in the bionomy of the seafloor.

6.2 Setting

6.2.1 Geographical and Geological Settings

The Alboran Sea is the westernmost province of the Mediterranean Sea (Fig. 6.1). It is east-west oriented and occupies an area of about 54,000 km^2. It is 150 km wide and 350 km long, presenting a maximum depth of 2294 m. It is partly land-locked, bounded by the Strait of Gibraltar to the west. To the east, the Alboran Basin gives way to the Algero-Balear Basin.

The origin and present-day setting of the Alboran Sea are controversial due to the geological complexity of the region. It is a Neogene-Quaternary extensional basin located within the Betic (Spain) and Rif (Morocco) alpine cordilleras, connected by the Arc of Gibraltar (Andrieux et al. 1971) (Fig. 6.1b). The geodynamic evolution of the Alboran Basin, still under debate, is determined by the relative motion between Eurasia and Africa (Dewey et al. 1989). The westward displacement of the Betic-Rif orogen during the development of the Arc of Gibraltar has been accommodated by the major Trans-Alboran Shear zone (De Larouzière et al. 1988; Frasca et al. 2015). Faults and folds have formed in the framework of recent NNW-SSE shortening and regional Eurasian-African plate convergence (DeMets et al. 2015) (Fig. 6.1b). Seismicity in the Alboran Sea includes mostly shallow (<30 km depth), but also scarce intermediate (30–120 km depth), and a few deep (600–640 km depth) events (Buforn et al. 1991, 2011, 2017; www.ign.es) (Fig. 6.1b)

The shallow seismicity is characterised by low to moderate magnitude earthquakes (generally Mw < 5) and is heterogeneously distributed (www.ign.es; Buforn et al. 2004) (Fig. 6.1b). GPS research shows that the Alboran Sea is undergoing a heterogeneous ENE-WSW extension, increasing towards the Strait of Gibraltar, and an orthogonal NNW-SSE shortening as high as 3.3 mm/year in its central part (Fadil et al. 2006; Koulali et al. 2011; Palano et al. 2015; González-Castillo et al. 2015; Galindo-Zaldívar et al. 2015).

The sedimentation in the Alboran Sea is mostly siliciclastic, primarily from rivers, coastal erosion, and dust from the Sahara Desert (e.g. Moreno et al. 2002; Jiménez-Espejo et al. 2008; Lobo et al. 2015). The Spanish and Moroccan margins bordering the sea are quite similar from the point of view of sediment sources. Many fluvial catchments in the Mediterranean region are characterised by small- to medium-sized rivers and ephemeral streams with abrupt topographies, resulting from the proximity of the mountain ranges and the adjacent coast (Liquete et al. 2009); these erode the Betic Mountains (>3000 m high) and the Rif Mountains

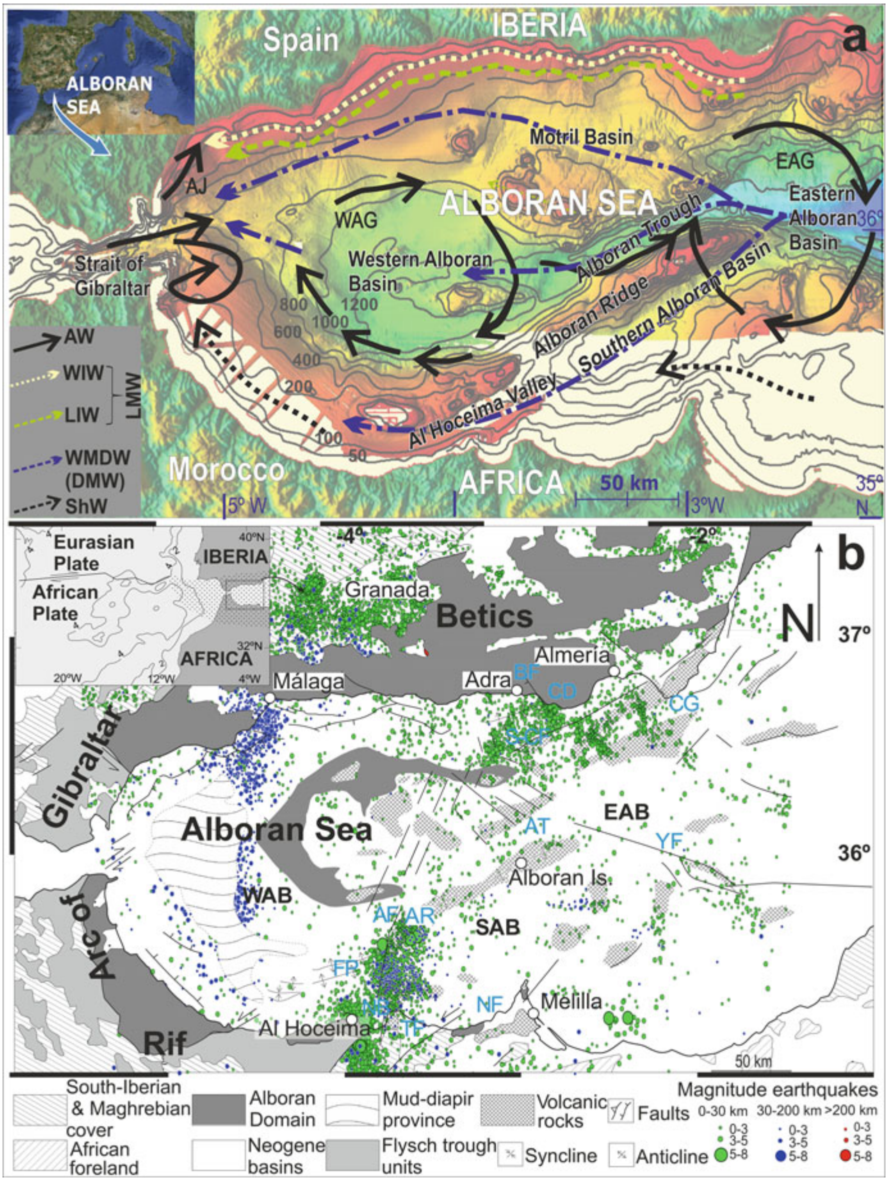

Fig. 6.1 Geographical and geological settings of the Alboran Sea. (**a**) Bathymetric map of the Alboran Sea with the present-day circulation model of the near-bottom water masses affecting the seafloor (modified from Ercilla et al. 2016). Legend: *AW* Atlantic water; *WIW* Western Intermediate Water; *LIW* Levantine Intermediate Water; *LMW* Light Mediterranean Water; *WMDW* Western Mediterranean Deep Water; *DMW* Dense Mediterranean Water; *ShW* Shelf Water; *WAG* Western Alboran Gyre; *EAG* Eastern Alboran Gyre; *AJ* Atlantic Jet. (**b**) Geological map including regional faults and seismicity. Plate boundaries in the Azores-Gibraltar area (modified from Galindo-Zaldívar et al. 2003) and geological sketch of the main structural features and basins of the Alboran Sea (modified from Comas et al. 1999) are shown. Legend: *AF* Al Idrisi Fault; *AR* Alboran Ridge; *AT* Alboran Through; *BF* Balanegra Fault; *CD* Campo de Dalías; *CG* Cabo de Gata; *S-CF* La

(>2000 m). Flood events in the larger rivers result in influential plumes of fine suspended sediments along both margins (Lobo et al. 2006). In contrast, the shorter rivers and streams remain dry for most of the year but have sporadic torrential regimes, discharging anything from gravels to silty sediments (El Moumni and Gensous 1992; Liquete et al. 2005; Lobo et al. 2006; Fernández-Salas et al. 2007). Most of the rivers flowing into the Alboran Sea display a seasonally contrasting pattern, with maximum water discharges in winter and very low discharges for the rest of the year (Stanley et al. 1975; Liquete et al. 2005; Lobo et al. 2006). In addition, water discharge is also very irregular on an inter-annual basis, with alternating dry and humid years.

6.2.2 Oceanographic Settings

Present-day circulation is largely influenced by the exchange of water through the Strait of Gibraltar, the AW flowing into the Alboran Sea and the MWs flowing out into the Atlantic Ocean (e.g. Parrilla et al. 1986). This exchange of water masses is conditioned by the high evaporation rates of the Mediterranean basin (exceeding precipitation and river runoff), which are compensated for by the inflow of the AW.

The AW flows at a maximum water depth of 150–200 m and describes two anticyclonic gyres (Chap. 4) (Fig. 6.1a). Water masses with a Mediterranean origin can be grouped by density (e.g. Millot 1987, 1999). Intermediate water comprises the Western Intermediate Water (WIW) flowing at a depth of 150–200 m in the western Mediterranean; the Levantine Intermediate Water (LIW), which forms in the western Mediterranean and flows towards the west between depths of 200–600 m; and the lightest part of the Tyrrhenian Deep Water (TDW), formed in the Tyrrhenian Sea and flowing below a depth of 500 m. The properties of this water mass vary from being similar to LIW to more like the Western Mediterranean Deep Water (WMDW). Deep water includes the TDW, the densest; and the WMDW, which fills the Alboran sub-basins at greater depths. On the western Moroccan slope, WMDM mixes locally and seasonally with AW, forming the Shelf Water flowing to the northwest (ShW, Gascard and Richez 1985) (Fig. 6.1a).

In the Alboran Sea, the intermediate Mediterranean water masses (WIW, LIW, and upper TDW) are less dense and saline, and are grouped into the Light Mediterranean Water (LMW) (Fig. 6.1a) (Ercilla et al. 2016). LMW circulates mainly along the Spanish margin. The deep Mediterranean water masses (lower TDW and WMDW) are denser and are grouped into the Dense Mediterranean Water (DMW) (Ercilla et al. 2016). DMW circulates along the Moroccan margin and in the deep basin and is forced upwards by the topography (Fig. 6.1a) (Parrilla et al. 1986).

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Fig. 6.1 (continued) Serrata-Carboneras Fault; *DB* Djibouti Bank; *EAB* Eastern Alboran Basin; *FP* Francesc Pagès seamount; *NB* Nekor Basin; *NF* Nekor Fault; *SAB* Southern Alboran Basin; *TF* Trougout Fault; *WAB* Western Alboran Basin; *YF* Yusuf Fault; *Alboran Is.* Alboran Island

6.3 Method

6.3.1 Datasets

The geomorphological study of the Alboran Sea was conducted based on four main databases: (1) the *multibeam bathymetric database*, which consists of high-resolution swath bathymetry data acquired in different expeditions, gridded to a resolution of 25 and 50 m (Fig. 6.1a). The gaps in the bathymetric mosaic were completed with the regional bathymetry from the GEBCO Digital Atlas, resulting in a variable resolution mosaic; (2) the *seismic database* has been compiled in the framework of several Spanish and international research projects, most in collaboration with French and Moroccan institutions, as well as from commercial hydrocarbon exploration projects (http://gma.icm.csic.es/sites/default/files/geowebs/OLsurveys/index.htm). The database comprises single- and multi-channel seismic profiles with different degrees of resolution, extending to various depths and resolutions (>1250 profiles) (Fig. 6.2a). All the seismic profiles were integrated into a Kingdom Suite project (IHS Kingdom) for their accurate correlation and interpretation; (3) *sediment cores* recovered in various cruises (http://gma.icm.csic.es/sites/default/files/geowebs/OLsurveys/samples.htm) and aligned along seven N-S transects of the Alboran Basin (1–7 in Fig. 6.2b); five cross (transects 1–5) the Western Alboran Basin; one (transects 6) crosses the Motril Basin, Alboran Trough, and Southern Alboran Basin; and the last (transects 7) crosses the easternmost Alboran Trough and Sothern Alboran Basin. The N-S transects enable the sedimentary facies to be defined and downslope and alongslope sedimentary processes to be compared; and (4) the *hydrographic databa*se, which comprises (Fig. 6.2c): (a) more than 3000 CTD (Conductivity, Temperature, and Depth) data points, downloaded from open-access sources (Medatlas II: http://odv.awi.de/en/data/ocean/medatlasii/); (Sea Data Net: http://www.seadatanet.org), allowing water mass characterisation; Acoustic Doppler Current Profiler (ADCP) data, that provides the module and direction of the different layers of the water column down to a water depth of 700 m.

6.3.2 Data Analysis

Three main types of analysis were carried out using different approaches and techniques: (1) geomorphological and sedimentary analysis combining the multibeam bathymetric mosaic and the seismic profiles; (2) sedimentological analysis of the sediment cores; and (3) descriptive hydrographic analysis. In the *geomorphological and sedimentary analysis* the features were defined based on their overall dimensions, morphology and geometry, along slope and downslope elongations, acoustic facies, and strata patterns; the *sedimentological analysis* consisted of a characterisation of the sedimentary facies, carried out based on grain-size distribution, carbonate content, presence of sedimentary structures, and sand fraction

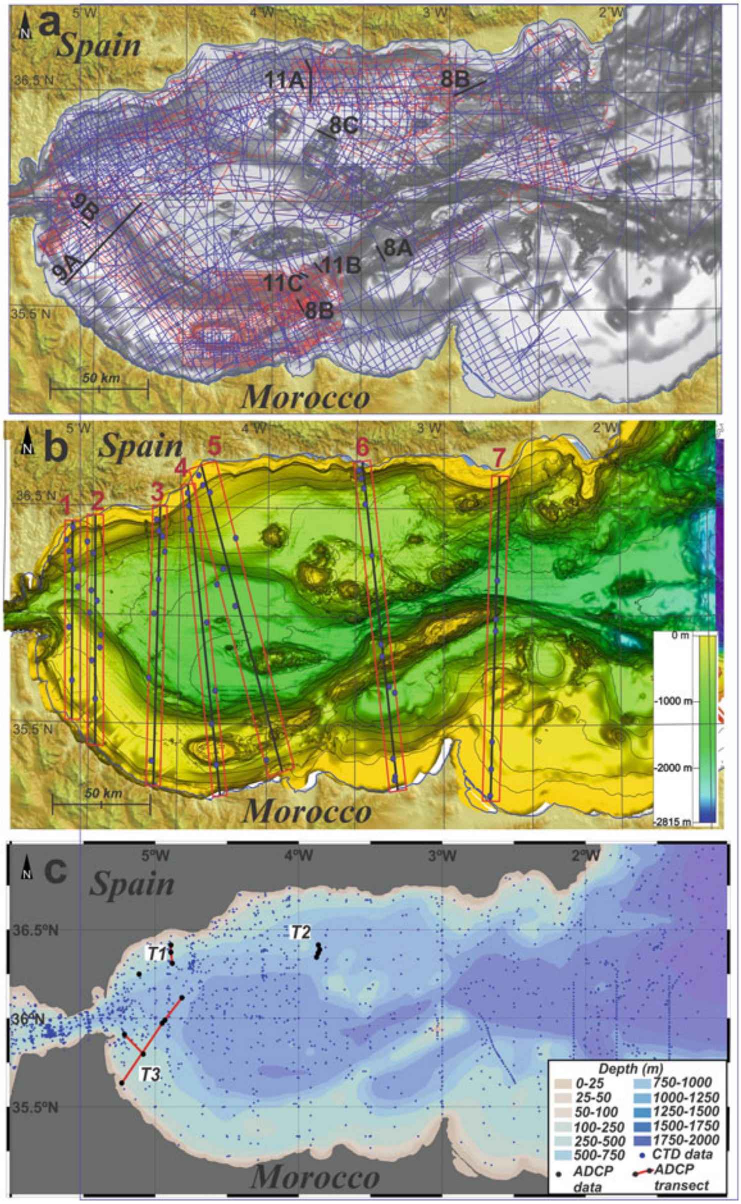

Fig. 6.2 Maps displaying the location of the different datasets used in this study. (**a**) Location map of single- and multi-channel seismic records with high to low resolution (lines in blue) and very high-resolution records (in red), from the ICM-CSIC database (http://gma.icm.csic.es/sites/default/files/geowebs/OLsurveys/index.htm). (**b**) Transects displaying the location of the sediment cores displayed in Fig. 6.14. These cores are from the ICM-CSIC database (http://gma.icm.csic.es/sites/default/files/geowebs/OLsurveys/samples.htm). (**c**) Location of the CTDs (Conductivity, Temperature, and Depth) from the Sea Data Net website (http://www.seadatanet.org) and ADCPs (Acoustic Doppler Current Profilers) analysed. T1–T3 point to the location of contouritic terraces mapped in the Alboran Sea. For more details see also Fig. 6.6b and explanation in the text

composition. Textural analysis was performed using settling-tube techniques for the coarse-grained fraction (<50μm) and Sedigraph 5000D techniques for the silt and clay fractions (<50μm). Total carbonate content was determined using a Bernard calcimeter. The sedimentary structures were examined based on digital images of the split cores. The sand fraction composition was examined using a binocular microscope. For the *hydrographic analysis*, the CTD dataset was analysed with the Ocean Data View (ODV) software using T/S diagrams, as well as N-S and E-W transect of the key properties of the water masses. In addition, the ADCP data (Ercilla et al. 2016) also allowed an analysis of the variation in the E and N components of the water flow with depth and the variation in the backscatter intensity of these components along the vessel track.

6.4 Physiography

Four physiographic domains have been defined in the Alboran Sea: continental shelf, continental slope, base of slope, and basins (Fig. 6.3a).

The continental shelf extends down to a depth of 90–115 m on the Iberian margin and 100–150 m on the North African margin. It is characterised by an abrupt outer limit, with the exception of the easternmost African shelf, which has a poorly defined ramp shape. The continental slopes of both margins are irregular: the Iberian margin ranges from 10 to 83 km wide, and the African margin is 10–105 km wide, extending to depths of up to 945 m in the west and 2294 m in the east (Fig. 6.3a). The continental slopes also have intraslope basins, including the Southern Alboran Basin (1180 m deep), and the Motril Basin (920 m deep). The other intraslope basins are the Al-Hoceima Valley (470 m deep), the Habibas Basin (928 m deep), and the Pytheas Basin (880 m deep) (Fig. 6.3a). The base of slope is defined in the Alboran Sea by an important decrease in slope gradients (<2–0.8°). This province is locally defined on the western Iberian margin at water depths of between 600 and 945 m, and on the eastern Iberian margin at water depths of between 1400 and 1850 m. The basin domain comprises the Eastern Alboran Basin (2294 m deep); the Western Alboran Basin (1510 m deep); the northeast/southwest-oriented Alboran Trough (up to 1800 m deep); and the Yusuf Basin (up to 2340 m deep) (Fig. 6.3a).

6.5 Geomorphology

6.5.1 Shelf Features

Most of the observations on shelf geomorphology refer to the northern shelf of the Alboran Sea. However, recent studies have provided geomorphological descriptions of limited sectors of the southern shelf (e.g. Lafosse et al. 2018). The main

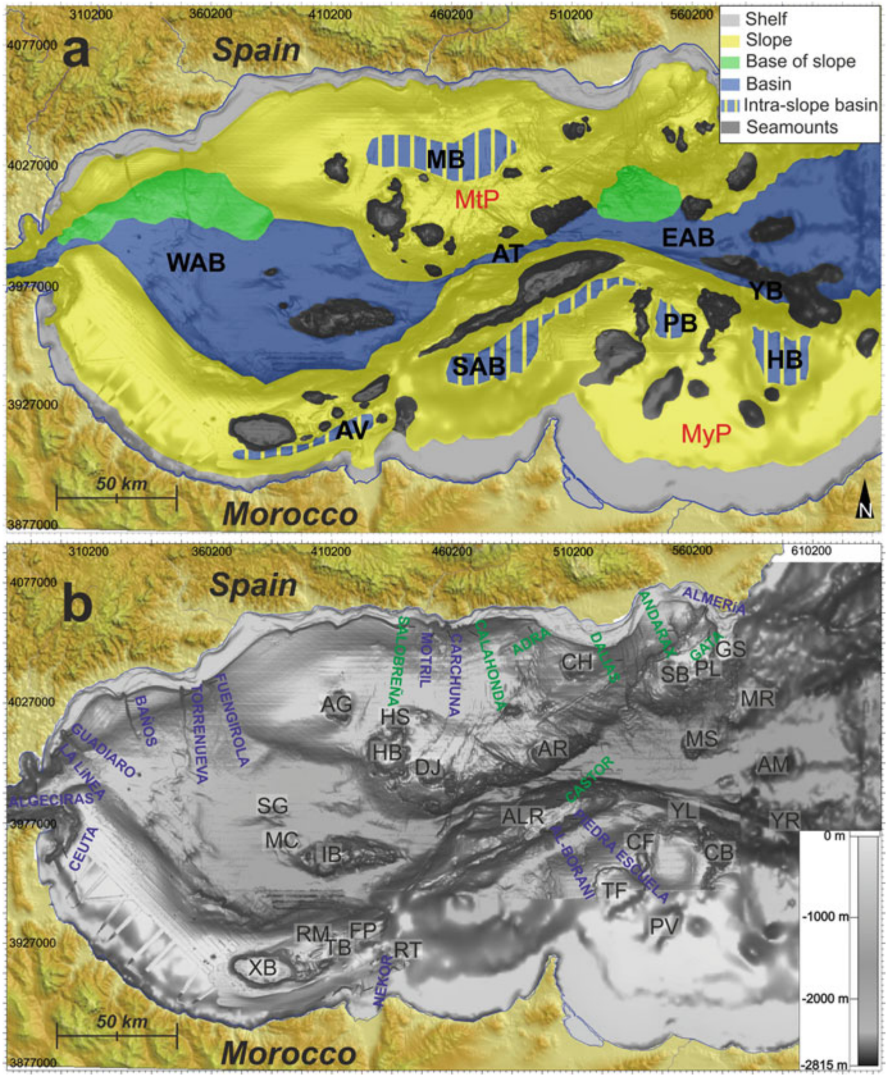

Fig. 6.3 Physiography of the Alboran Sea. (**a**) Map showing the shelf, slope, base of slope provinces on the Iberian and African continental margins, the basins (*AT* Alboran Trough; *EAB* Eastern Alboran Basin; *WAB* Western Alboran Basin; *YB* Yusuf Basin), the intraslope basins (*AV* Al-Hoceima Valley; *HB* Habibas Basin; *MB* Motril Basin; *PB* Pytheas Basin; *SAB* Southern Alboran Basin) and plateaus (*MtP* Motril Plateau; *MyP* Moulouya Plateau). Modified from Juan et al. (2016); and (**b**) bathymetric map showing submarine canyon (in blue) and gully (in green) systems, as well as the structural highs dotting the margins and basins. Legend: *AB* Alidade Bank; *AG* Algarrobo Bank; *ALR* Alboran Ridge; *AM* Al-Mansour High; *AR* Adra Ridge; *CB* Câbliers Bank; *CF* Catifas Bank; *CH* Chella Bank; *DJ* Djibouti Bank; *GS* Cabo de Gata Spur; *HB* Herradura Bank; *HE* Habibas Escarpment; *HS* Herradura Spur; *IB* Ibn-Batouta Bank; *MC* Maria del Carmen High; *MS* Maimonides Seamount; *MR* Maimonides Ridge; *PL* Pollux Bank; *PV* Provençaux Bank; *RT* Ras Tarf Ridge; *SB* El Sabinar Banks; *SG* Segoviano High; *TB* Tofiño Bank; *TF* Tres Forcas Cape Ridge; *XB* Xauen Bank; *YL* Yusuf Lineament; *YR* Yusuf Ridge

geomorphological types can be classified according to their genesis in depositional, erosive, gravitational, and anthropogenic origins (Bárcenas et al. 2016).

6.5.1.1 Depositional Features

The most important types are prodeltaic wedges and infralittoral prograding wedges (IPWs). Additionally, bedform fields at various scales have been documented in specific locations (Fig. 6.4).

Prodeltaic bodies are wedge-shaped morphologies with variable seaward extensions, depending on the dimensions of the parent drainage basins (Fig. 6.4a, b, c). They exhibit very narrow topsets (relatively flat proximal segments) bounded seawards by a shallow break of slope, close to the coast. Seawards, the seafloor gradient is higher in the foresets and becomes distally asymptotic in the bottomsets. These geomorphological boundaries are controlled by the wave base levels associated to medium and high-energy conditions (Bárcenas et al. 2015). Overall, the vast majority of cross-sectional geometries are concave-upward (Fig. 6.4c, d). In plain view, these dominant geometries mostly produce lobate and elongate patterns (Bárcenas et al. 2015). The seismic facies of prodeltaic bodies are mainly stratified with progradational and aggradational patterns. The progradational pattern is characterised by an oblique-sigmoidal configuration and varies from perpendicular to oblique to parallel with respect to the shoreline (Lobo et al. 2014). Most of the prodeltaic wedges of the Alboran Sea exhibit superimposed seafloor undulations over the foresets and bottomsets (Fig. 6.4a, b, c, d). The undulations can be up to a few metres high and the wavelengths range between tens and hundreds of metres (Bárcenas et al. 2009; Lafosse et al. 2018). These undulations are generally regarded as sediment waves (Fernández-Salas et al. 2007).

Infralittoral prograding wedges (IPWs) are narrow (i.e. a few kilometres wide) wedge-shaped clinoform bodies which have been mapped in the inner shelf stretches of the Iberian margin (Fig. 6.4c, e). A well-marked break of slope occurs at water depths of about 20–25 m; seawards, a steep slope of greater than 2° extends to water depths of up to 60 m (Hernández-Molina et al. 2000). The characteristic slope break may be relatively linear and continuous or instead be composed of arcuate, discontinuous segments (Fernández-Salas et al. 2009). These wedges have been recognised in several sectors, but the most important bodies occur off Carchuna-Calahonda, Campo de Dalías, and Gata Cape (Hernández-Molina et al. 2000; Fernández-Salas et al. 2009). In some particular cases, such as off the Adra River the infralittoral wedges develop laterally from the main deltaic protuberances, representing the morphological response of an evolving deltaic system (Jabaloy-Sánchez et al. 2010) (Fig. 6.4c). In the Carchuna-Calahonda shelf area (Iberian shelf) and the Nekor Basin shelf (African shelf), marine-built terraces observed at different water depths from the outer to the inner shelf, are regarded as the morphological expression of IPWs (Martínez-Martos et al. 2016; Lafosse et al. 2018).

Fields of large-scale bedforms such as elongated bars and ridges have been described in specific outer shelf settings of the Iberian shelf (Lobo et al. 2006;

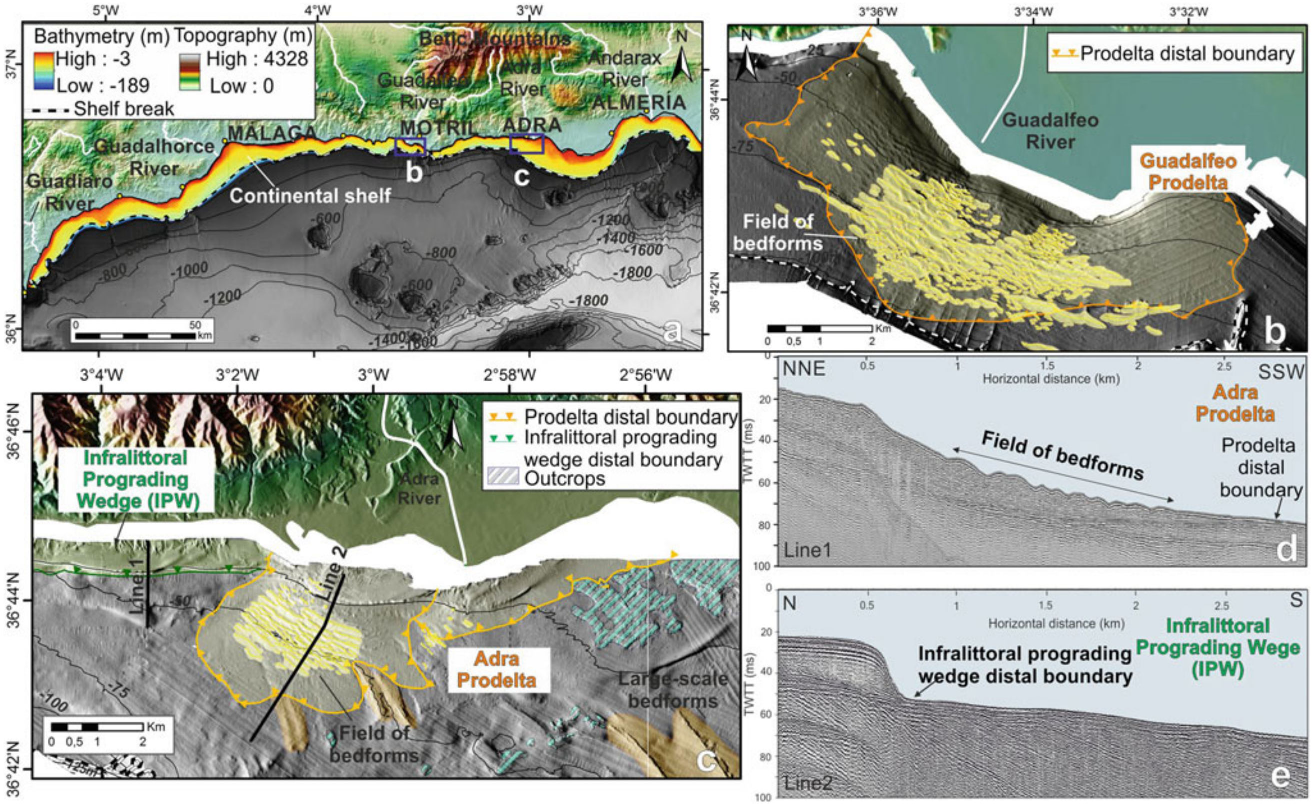

Fig. 6.4 Examples of the morphosedimentary features observed in the continental shelf of the Alboran Sea. (**a**) Map showing the location of the examples. (**b**) Prodeltaic wedge and field of bedforms associated to the Guadalfeo River. (**c**) IPW, large-scale bedforms and prodeltaic wedge associated to the Adra River. (**d**) Seismic profile showing the large-scale bedforms and prodeltaic wedge associated to the Adra River. (**e**) Seismic profile showing the IPW off the Adra River

Bárcenas 2012). Besides, around Al-Hoceima Bay (African shelf), at least two fields of subaqueous dunes have been related to reworking processes during the postglacial sea-level rise (Lafosse et al. 2018).

6.5.1.2 Erosive Features

These features include different types of submarine valleys and wave-cut terraces. The Iberian shelf is indented by several submarine canyons (Figs. 6.3b and 6.5b). A *shelf-incising canyon* (the Carchuna Canyon) occurs off Cape Sacratif, with its head located only a short distance from the coastline (Fig. 6.5a, b). The recent activity of the canyon is evidenced by the fact it is eroding the Carchuna-Calahonda IPW (Ortega-Sánchez et al. 2014). The incision of the outer shelf by canyon heads is particularly frequent along the westernmost northern shelf in the vicinity of the Strait

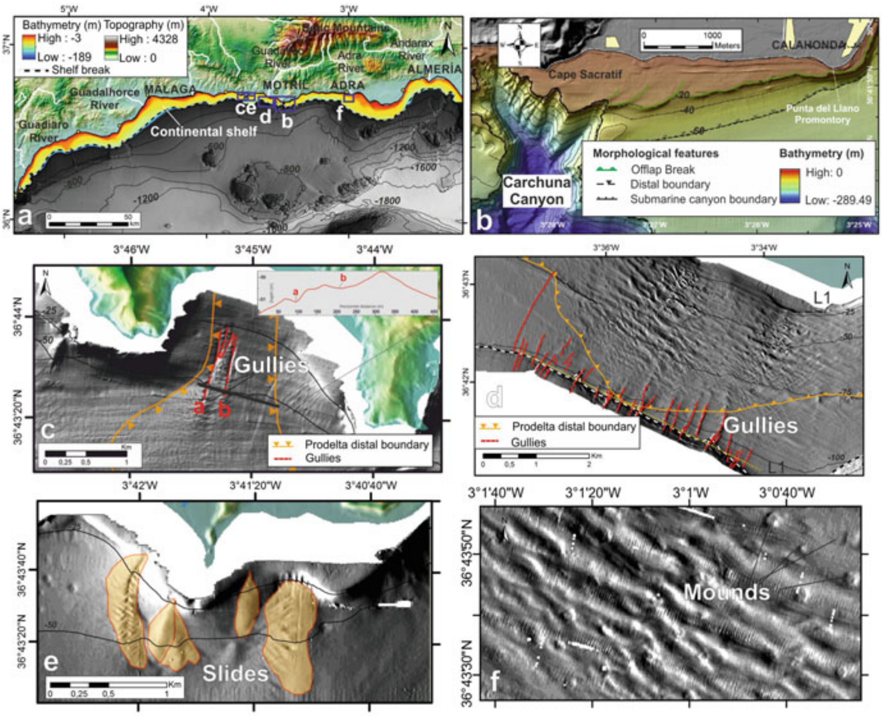

Fig. 6.5 Examples of the erosive, gravitational, and anthropogenic features observed in the continental shelf of the Alboran Sea. (**a**) Map showing the location of the examples. (**b**) Carchuna canyon head incising the continental shelf (Ortega-Sánchez et al. 2014). (**c**) Gullies developed in the prodeltaic topset. (**d**) Gullies eroding the prodeltaic foreset. (**e**) Shallow-water slides. (**f**) Spherical mounds of anthropogenic origin located near the harbour of Adra

of Gibraltar and around the Carchuna Canyon (e.g. the Motril Canyon head) (Alonso and Ercilla 2003; Vázquez et al. 2015a).

Small-scale submarine valleys comprise *prodeltaic channels and/or gullies*, documented in a few prodeltaic deposits along the Iberian shelf (Bárcenas et al. 2016), as well as a *prodeltaic deposit* located in Al-Hoceima Bay, on the African shelf (Lafosse et al. 2018) (Fig. 6.5a, c, d). The gullies are straight and very shallowly incised (Bárcenas et al. 2016). They initiate over the prodeltaic topsets and generally extend over the foresets (Bárcenas et al. 2016; Lafosse et al. 2018), although they may be restricted to the outer shelf, as occurred in the case of the Guadalfeo River prodelta (Lobo et al. 2006).

Wave-cut terraces are represented by abrupt escarpments with high lateral continuity. They are particularly frequent on the westernmost shelf of the northern margin at various bathymetric levels (Hernández-Molina et al. 1996).

6.5.1.3 Gravitational Features

These are mostly represented by scarce shallow-water *slides*, occurring at water depths of more than 60 m (Bárcenas et al. 2016). The slides range from 38 to 1000 m long and 56 to 629 m wide (Fig. 6.5a, e).

6.5.1.4 Anthropogenic Features

These include spherical mounds and straight lineations, usually found in proximity to harbours due to dredge activities (Bárcenas et al. 2016) (Fig. 6.5a, f). Mounds with reliefs of between 25 and 50 m are around 80 m long and up to 100 m wide. The lineations that have been mapped between water depths of 25 and 47 m, are 420–850 m long and have average widths of 20 m.

6.5.2 Deep-Sea Features

These include features of varying genesis that may be grouped as tectonic, seamount, fluid-flow, contourite, mass-movement, and biogenic features (Figs. 6.6 and 6.7).

6.5.2.1 Tectonic Features

The main tectonic structures influencing the seafloor morphology are folds and faults. These affect mainly the central and eastern seafloor of the Alboran Sea (Fig. 6.7).

Folds have a dominant ENE-WSW strike and are up to several kilometres in length, with the most representative being the Alboran Ridge, Francesc Pagès and

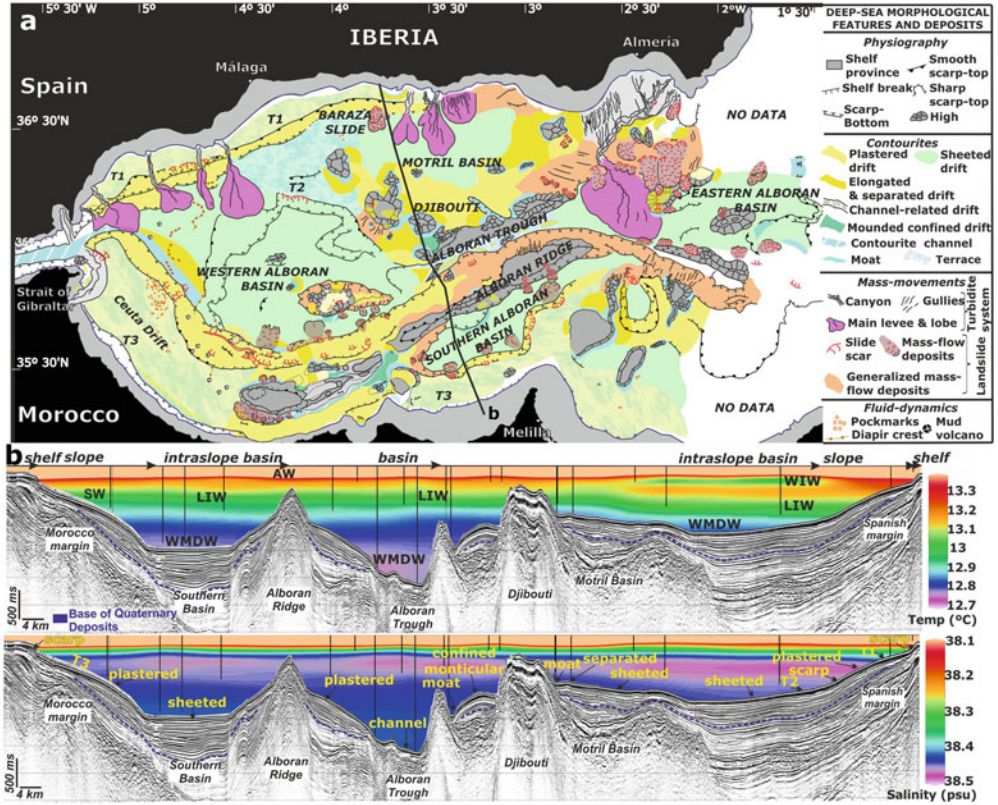

Fig. 6.6 Deep-sea geomorphology and seismic and oceanographic architectures of the Alboran Sea. (**a**) Deep-sea morphological features and deposits mapped from the shelf-break down to the deep-sea areas of the Alboran Sea. Legend: T1–T3 refer to the location of contouritic terraces. (**b**) N-S seismic–hydrographic section crossing the continental margins and some basins (location in **a**). Note the correlation between the water mass interfaces [AW, WIW+LIW (i.e. LMW), WMDW (i.e. DMW)] and the main physiographic domains. Contourite features are indicated on the seismic profile (letters in yellow). Colour-coding: temperature (°C) and salinity (psu, practical salinity units). Black vertical lines within the water column show the vertical and horizontal distribution of CTDs. Legend of water mass names in Fig. 6.1a. Modified from Ercilla et al. (2016)

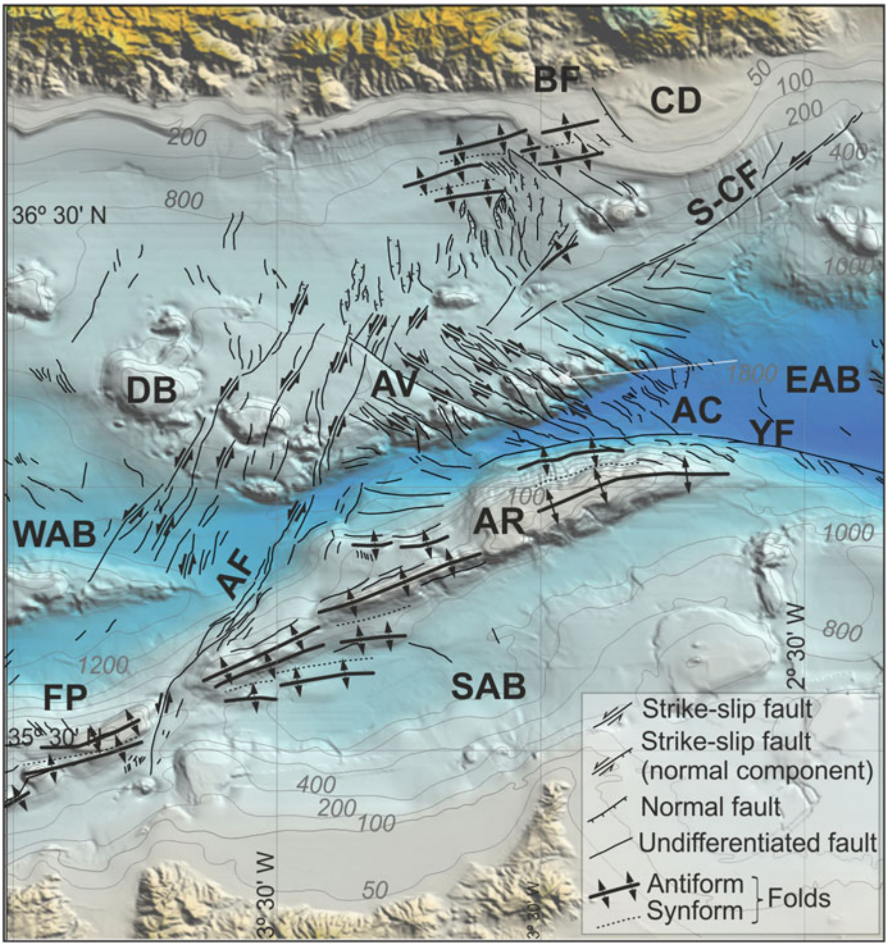

Fig. 6.7 Map showing the main tectonic features (faults and folds), formed in the framework of recent NNW-SSE shortening and regional Eurasian-African plate convergence. Legend: *AF* Al Idrisi Fault; *AR* Alboran Ridge; *AV* Averroes Fault; *BF* Balanegra Fault; *CD* Campo de Dalías; *S-CF* La Serrata-Carboneras Fault; *DB* Djibouti Bank; *EAB* East Alboran Basin; *FP* Francesc Pagès seamount; *SAB* South Alboran Basin; *YF* Yusuf Fault

Xauen seamounts, which are three aligned antiforms (Bourgois et al. 1992; Martínez-García et al. 2011, 2013; Estrada et al. 2018), and the Campo de Dalias folds (Pedrera et al. 2015) (Figs. 6.7 and 6.8a, b). These last folds form three smooth, elongate elevations (N50-60), located to the W of Chella Bank, which are 15–20 km long and 30–80 m high (Vázquez et al. 2016). They are interpreted as anticlines associated with blind thrusts affecting the recent sediments.

Faults are grouped into two main sets of N25° E sinistral and N130° E dextral kinematics (Fig. 6.7). Fault traces are evidenced in the seafloor by different features

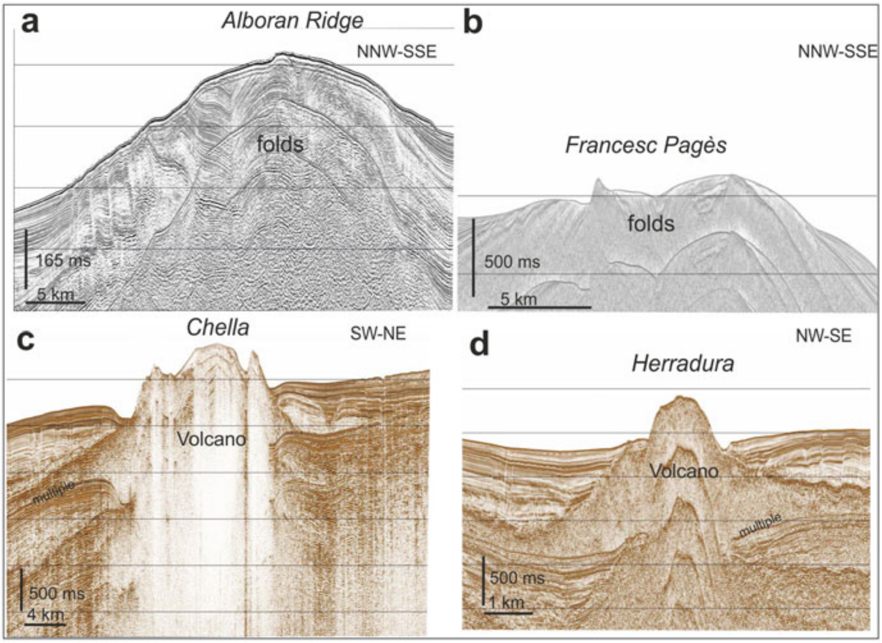

Fig. 6.8 Seamounts in the Alboran Sea. Seismic profiles showing two different types of seamounts: the Alboran Ridge (**a**) and Francesc Pagès Seamount (**b**) related to structural folds; and the Chella or Seco de los Olivos (**c**) and La Herradura (**d**) volcanic seamounts. Location of profiles in Fig. 6.2a

as scarps, ridges, depressions, and lineations (Vázquez et al. 2014). The N25° E set is mainly located to the NW and W of the Alboran Ridge, comprising a fault zone that is 25 km wide and more than 120 km long. The most significant fault in this set is the Al Idrisi Fault, which has a straight seafloor trace, including continuous segments, more than 38 km long (Martínez-Garcia et al. 2013; d'Acremont et al. 2014). This fault displaces the boundary between the Alboran Ridge and Francesc Pagès seamounts (Figs. 6.1b and 6.7). In the northern margin, the activity of the N25° E faults produces on seafloor marked scarps and sets of longitudinal and rhombic depressions (Vázquez et al. 2018). The N130° E set is mainly located to the N and NE of the Alboran Ridge, in a zone more than 60 km wide. The main structure of this set is the Yusuf Fault, which has a straight trace up to 120 km long (Figs. 6.1b and 6.7). The Averroes Fault is another significant structure in this set, and its trace can be mapped on the seafloor as a straight scarp and related longitudinal depression. Its morphology shows evidence of vertical displacements related to dextral strike-slip at the NW fault edge (Vázquez et al. 2016; Estrada et al. 2018). Several related faults and scarps with similar directions occur on the seafloor to the east of Averroes Fault (Pedrera et al. 2015; Estrada et al. 2018). Moreover, other normal faults trending between N130° E and N170° E have been recognised, mainly west of Campo de

Dalías (longitudes between −3° and −3.5°), with the Balanegra Fault being one of the most significant, and which determine the location of the coastline (Galindo-Zaldívar et al. 2013) (Figs. 6.1b and 6.7). The sinistral Serrata-Carboneras Fault has been identified south of Campo de Dalías, and its straight trace is characterized by push-up ridges and sharp scarps on the seafloor (Vázquez et al. 2016). This sinistral fault extends 80 km offshore towards Cape Gata (Figs. 6.1b and 6.7) and is one of the main faults affecting the northeastern Alboran Sea although its present-day activity is still under discussion (Moreno et al. 2016; Estrada et al. 2018).

6.5.2.2 Seamounts

The Alboran Sea is characterised by the presence of several highs scattered along the continental margin and basins (Figs. 6.3b and 6.6) (Würtz and Rovere 2015). They have different origins and sizes related to the complex geodynamic evolution of the Alboran Sea (e.g. Palomino et al. 2015; Vázquez et al. 2015b). Seamounts mostly consist of a series of folds of Miocene to Quaternary units (almost all represented by the Xauen Bank, Frances Pagès Seamount, and the Alboran Ridge) and/or volcanic bodies (e.g. Ammar et al. 2007; Martinez-Garcia et al. 2013; Vázquez et al. 2015b; Estrada et al. 2018; Galindo-Zaldívar et al. 2018) (Fig. 6.8). They are hundreds of metres high (400–1750 m), with the Alboran Ridge—located in the central sector—being the major elevation that emerges locally, forming Alboran Island and crossing the Alboran Sea obliquely with a NE-SW trend (Figs. 6.3b and 6.6a). The top of the seamounts is relatively flat (in most of the shallowest ones, <300 m water depth) and subrounded, and they usually present folded layers, structural ridges, and biogenic features that favour the settling of benthic species associated with hard bottoms, like cold water corals (Palomino et al. 2011). Indeed, these highs comprise heterogeneous habitat types and are considered hotspots for biodiversity. The seamount walls have high-gradient slopes shaped by downslope features, like turbidite systems and landslides (Fig. 6.6a). At their feet, seamounts are also characterised by along slope features, such as contourite drifts and moats (Fig. 6.6).

6.5.2.3 Features Related to Fluid Outflow

Various fluid outflow related features in the Alboran Sea, including mud diapirs, mud volcanoes, pockmarks, and authigenic carbonates, have been mapped in the Alboran Sea (Figs. 6.6a and 6.9) (e.g. Pérez-Belzuz et al. 1997; Somoza et al. 2012; León et al. 2014; Palomino et al. 2016) mostly piercing contourite deposits. They occur mainly in the western part of the Alboran Basin, mostly affecting the Ceuta contourite Drift.

Diapirs are dome-shaped features that rupture the overlying mobile sediments, which in the Alboran Sea are muddy in nature (Fig. 6.9a). Diapirs are mainly located in the Western Alboran Basin (Pérez-Belzuz et al. 1997). Although most diapirs are buried below the Pliocene-Quaternary sediments, a few produce a morphological

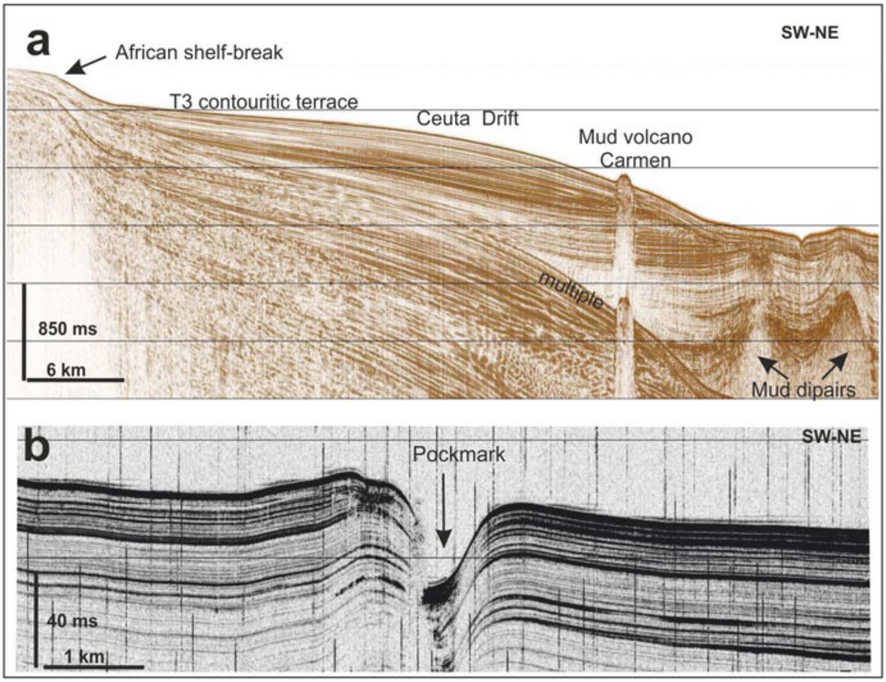

Fig. 6.9 Fluid-dynamic features in the Alboran Sea. (**a**) Seismic profile showing sub-bottom mud diapirs piercing and deforming the recent sediments of the Ceuta contourite Drift in the western Moroccan continental slope. Mud is forced to move upwards due to overpressures in the subsoil units. Also, the Carmen mud volcano piercing seafloor is showed. (**b**) Seismic profile showing the cross-section of a pockmark. Location of profiles in Fig. 6.2a

expression on the surface, forming relatively small seamounts tens of metres high (Pérez-Belzuz et al. 1997).

Mud volcanoes can be defined as conical edifices built up by mud sediments and fluids expelled from a deep source layer as the result of degassing processes (Kopf 2002). In recent decades, ten mud volcanoes have been documented in the Western Alboran Basin (Fig. 6.9a) (e.g. Somoza et al. 2012; Kenyon et al. 2000). They present different heights varying from 30 m (Mulhacen volcano) to 185 m (Granada volcano), and diameters of up to 1635 m (Dhaka volcano) (Somoza et al. 2012). It has been documented that some of these volcanoes could be active, or have had recent activity, as methane gas bubbling in the water column and evidence of chemosymbiotic fauna have been observed (Blinova et al. 2011; Hilário et al. 2011).

Two *pockmark fields* have been reported in the Ceuta Drift, and another field has been described in the vicinity of the Avempace Seamount, also on a contourite drift deposit (Palomino et al. 2011; Somoza et al. 2012) (Fig. 6.6a). Pockmark craters form abruptly, when pockets of local overpressured porewater and gas erupt through the seafloor surface sediments (Cathles et al. 2010). Pockmarks in the Alboran Sea occur as circular and oval depressions on the seafloor, mostly as isolated features, and they vary in size from 50 to more than 500 m in diameter, with a few tens of metres of relief (Fig. 6.9b). The presence of these pockmarks has been attributed to fluid seepage and interstitial fluids from the underlying sediments that in the Ceuta Drift have been detected near the surface sediments (Mathys et al. 2005).

Other seepage fluid flow features, such as hydrocarbon-derived *authigenic carbonate crusts and chimneys* have been identified and sampled in the pockmark field of the Ceuta Drift (Blinova et al. 2011), also pointing to seepage flow emissions as these are necessary for their formation.

6.5.2.4 Contourite Features

The term contourites refers to those deposits formed by the action of alongslope bottom currents, including wind-driven, thermohaline, geostrophic, contour, boundary, and abyssal currents (Rebesco et al. 2014). A wide spectrum of depositional (drifts and sediment waves), erosional (moats, channels, and scarps), and mixed (terraces) contourite features have been characterised from the shelf-break (>90 m water depth) to the basin (Ercilla et al. 2002, 2016; Palomino et al. 2011; Juan et al. 2016) (Fig. 6.6). The drifts differ in magnitude: the largest appear along the slopes, the base of slope, and basin domains. Plastered and sheeted drifts are the dominant largest (a few hundreds of km long, a few to tens of km wide, and tens to a few hundreds of m of relief) type of drifts. The Iberian and Moroccan slopes are mainly characterised by *plastered drifts*. *Sheeted drifts* contribute to shaping the base of the slope and infill the basin irregularities generating a roughly flat and smooth seafloor. With respect to the small-scale drifts (a few to tens of km long and wide and a few hundreds of metres high) they are dispersed throughout the Alboran Sea, particularly around the different seamounts of the northern margin, the Alboran Ridge and highs, in the narrow passages formed by the steep structural walls, within the Alboran Trough and in the Al-Hoceima Valley. In addition to small-scale plastered and sheeted drifts, another type of minor-scale drift includes *channel-related drifts*, *mounded confined drifts*, and *mounded, elongate and separated drifts*. All drifts show similar seismic facies and are defined by stacked layered deposits with regional erosive unconformities. In cross-sections their stacking defines aggradational mounds with upslope-and-downslope prograding clinoforms for the plastered, elongated, separated, an onlap-infilling pattern with subparallel, parallel and deformed strata for the sheeted drifts, and aggrading mounds with subparallel strata for the confined drifts and channel-related drifts (Fig. 6.6b). With respect to the *sediment waves*, they have been locally mapped at the main entrance of the Strait of Gibraltar. They comprise 3D sediment waves mostly characterized as sand waves (metric in relief, and few to tens of metres in length) (Heezen and Johnson 1969; Kelling and Stanley 1972).

Erosive contourite features are also dispersed along the margins and basins (Fig. 6.6). The *moats*, which have U-shaped cross-sections of tens of m of relief, are mainly mapped associated to the separated and confined drifts. Their dimensions vary between hundreds of m and a few km in length and <6 km in width. *Contourite channels* are represented by the U-shaped structural corridors of Al-Hoceima Valley, formed between the aligned Xauen Bank and Frances Pagès seamounts and the Moroccan margin, and of the Alboran Trough, which could be considered a deep-gateway connecting the east and west basins. They are a few km wide and up to tens of km long. The *scarps* represent the along slope boundaries of terraces. They are narrow (<16 km wide) and steep (2°–11°) escarpments, hundreds of km long, which play a major role in shaping the transition between the physiographic provinces, the shelf-break-upper slope being the most proximal, and the transition from the Iberian slope to the base of slope and the West African slope to the basins, the most distal (Fig. 6.6b). Erosive contouritic features are generally easily recognisable due to the truncation of the underlying deposits, hyperbolic, and prolonged facies with high acoustic reflectivity.

On top of the large slope plastered drifts and sheeted drifts, *contourite mixed terraces* extend, producing flat areas <30 km wide on the Iberian and African slopes, where the truncation of reflectors against the seafloor is easily recognisable in the proximal sectors. Three terraces have been mapped, T1 and T2 on the Spanish margin and T3 on the Moroccan margin (Figs. 6.6 and 6.9a).

6.5.2.5 Mass-Movement Features

The term 'mass-movement' used here refers to a general term by Locat and Lee (2000) that defines sediment movement driven by gravity rather than by interstitial fluid motion and comprises a great variety of sedimentary instabilities, from slides to turbidity currents. The main evidence for mapping recent features resulting from mass-movements in the Alboran Sea is the following: the disappearance of deposits, deformation and/or loss of the sedimentary structure, and associations of genetically related features. Based on these criteria three main sedimentary systems comprise these mass-movement features: turbidite systems, lone valleys, and landslides (Fig. 6.6a).

Turbidite systems are one of the most significant clastic accumulations in deep-sea areas of the margins and adjacent basins (Normark et al. 1993). Turbidite systems are formed by various architectural elements, including canyons, main and distributary channels, overbanks/levees, and lobes (Mutti and Normark 1991). In the Alboran Sea, these systems interrupt the lateral continuity of contourites and have only been mapped on the Spanish margin and Alboran Ridge (Fig. 6.6a). Eleven turbidite systems have been defined, with variable dimensions (length/width: 7.7 × 7 km to 123 × 25 km), exhibiting two main types of sedimentary models: submarine fans (La Linea, Guadiaro, Baños, Torrenueva, Fuengirola, Sacratif, Almería on the Iberian margin; Al-Borani and Piedra Escuela on the southern face of the Alboran Ridge), and submarine ramps Salobreña and Calahonda) types on the Iberian margin (Fig. 6.10). The submarine fan model comprises a U- or V-shaped feeder canyon, generally with axial incisions at the base (i.e. talwegs), that crosses the continental slope and evolves into a main, leveed

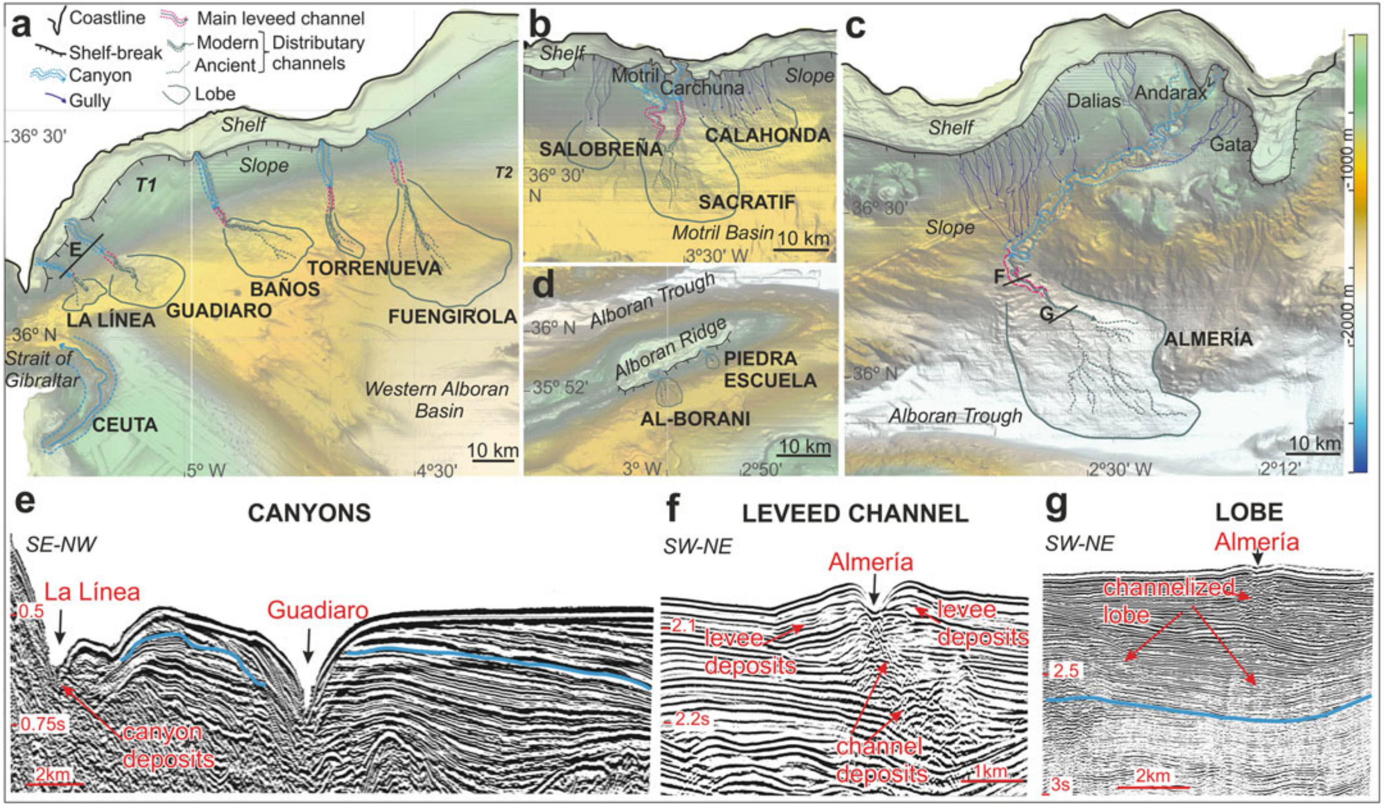

Fig. 6.10 Turbidite systems in the Alboran Sea. (**a**)–(**d**) Multibeam bathymetry showing the architecture of the turbidite systems on the present-day seafloor of the Alboran Sea. (**a**) La Linea, Guadiaro, Baños, Torrenueva, and Fuengirola in the western sector of the Iberian Margin. (**b**) Salobreña, Sacratif, and Calahonda in the central sector. (**c**) Almería in the eastern sector. (**d**) Al-borani and Piedra Escuela on the southern flank of the Alboran Ridge. (**e**)–(**g**) Single-channel seismic records showing the main acoustic facies that characterise the architectural elements (canyon, leveed channel, and lobe) of the turbidite systems. The blue seismic boundary refers to the base of the Quaternary deposits. Modified from Ercilla et al. (2019)

channel on the lower slope that mouths directly into a channelised lobe at the base of slope and basin. The submarine ramp model comprises a feeder system with gullies linked downdip to amalgamated lobe deposits. Seismic facies analysis of turbidite systems involves complex patterns of chaotic and discontinuous stratified facies with different configurations (prograding-, divergent-, and mounded-fill) for the canyons and channels and vertical stacking of asymmetric and roughly symmetric mound bodies of stratified facies that stand out from the seafloor. The architecture and dimensions of these systems suggest their sedimentary model ranges mostly from sandy to mixed sand-mud fans, and they describe a continuum between both end-member types from west to east.

The *lone valleys* are characterized by the lack of channel leveed and lobe deposits at their mouths and because of that they are considered separately from the turbidite systems. The valleys mapped comprise (Fig. 6.3b): the 10 km long Adra Channel, eroding the uppermost continental slope of the western Iberian margin; the Castor Canyon and gullies on the northeastern side of the Alboran Ridge; and the Ceuta and Nekor canyons, on the African margin. The Ceuta Canyon is 25 km long and widens down the valley (from 4 to 6 km); it has a curved pathway and mouths onto the entrance of the Strait of Gibraltar. The Nekor Canyon is 3 km long and 1.3 km wide, with a rectilinear pathway that extends down to a water depth of 300 m. Seismic facies analysis shows valleys eroding contourite deposits, generally presenting truncated, stratified, and prograding facies on the canyon margins, and chaotic deposits on the canyon floors.

Isolated *landslide* scars as well as landslide scars with associated mass-transport deposits have been mapped on both the Iberian and African continental slopes, in addition to the steep walls of some seamounts (Figs. 6.6a and 6.11). Landslide scars delineate the headscarp of the failed area, and form a relatively steep scarp (a few to tens of km long, with tens of metres of relief) facing seaward, with concave and amphitheatre shapes (Figs. 6.6a and 6.11). These slide scars are associated, in attached and detached forms (Fig. 6.11a, b), to lobate bodies, from around 5 km to <10 km in length and tens of metres in thickness, with chaotic and transparent sediments producing a wavy and irregular seafloor area, which varies roughly in the area from 5 to >100 km^2. Baraza (110 km^2) on the Iberian slope (Figs. 6.6a and 6.11a), and the Montera slide (90 km^2) in the SAB, are some of the largest landslides affecting the upper Quaternary deposits (Casas et al. 2011; Vázquez et al. 2013; Rodriguez et al. 2017). The Alboran Ridge, Francesc-Pagès Seamount, Djibouti, Pollux and Sabinar Banks, and Maimonides and Adra Ridges are some of the seamounts whose recent sedimentary record, on their walls and in the surrounding areas, are characterised by the vertical stacking of numerous landslides (Figs. 6.6a and 6.11c) (e.g. Palomino et al. 2009; Alonso et al. 2014; Galindo-Zaldívar et al. 2018).

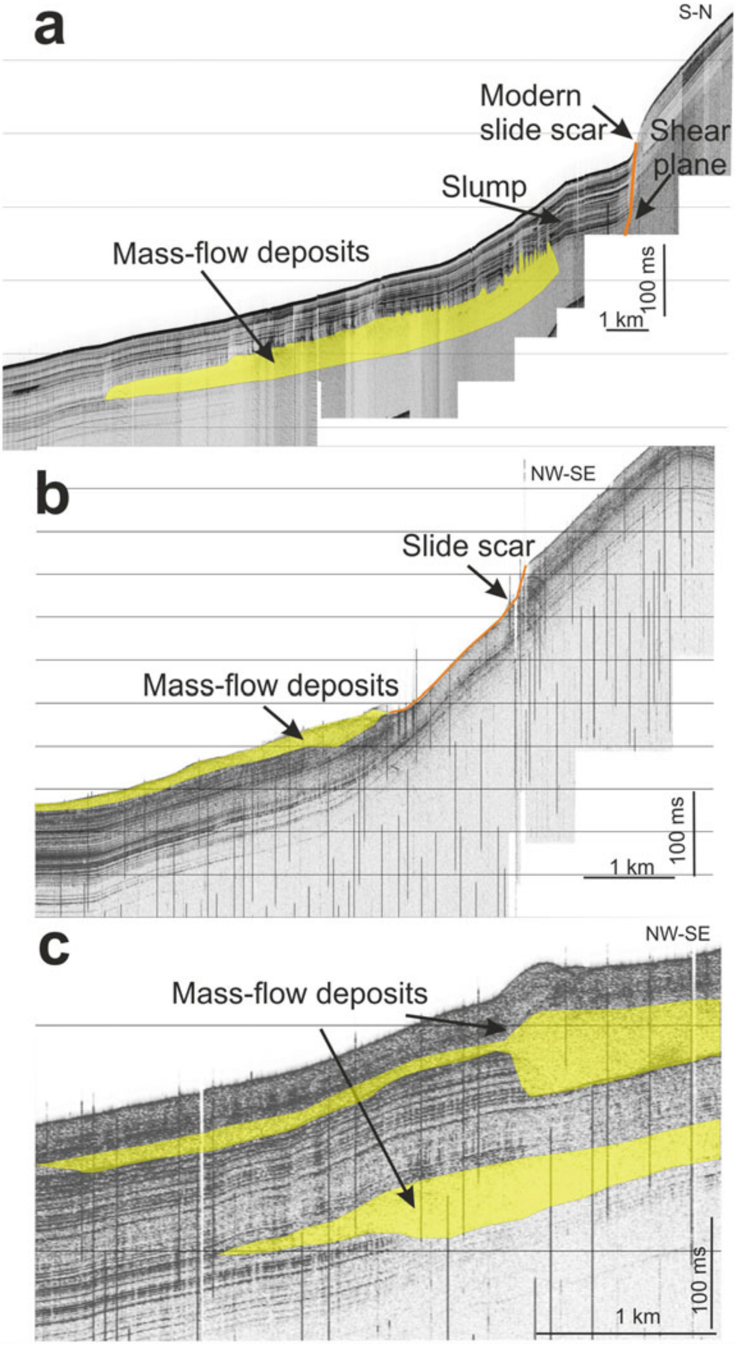

Fig. 6.11 Landslides in the Alboran Sea. Very high-resolution seismic profiles displaying: (**a**) the Baraza slide and (**b**) the mass-flow deposits mapped on the Francesc-Pagès Seamount and (**c**) on the Southern Alboran Basin. Note: The Baraza slide comprises two types of mass-movements—mass-flow type changing to slump type. Location of profiles in Fig. 6.2a. Modified from Casas et al. (2011) and Galindo-Zaldívar et al. (2018)

6.5.2.6 Biogenic Features

Potential clustered carbonate mounds (CM) have been recently reported along the continental slope of the northern and southern Alboran Sea (Fig. 6.12). Three different CM fields with still-undetermined biological activity, are located at similar water depths, on the contouritic terrace of the upper continental slope of the Iberian Alboran Sea (Ballesteros et al. 2008; Sánchez-Guillamón et al. 2018). The Alcantara mounds (Western field) are located at depths of between 250 and 282 m off Estepona (Málaga) (Fig. 6.12b, e), while the Málaga mounds (Central field) (Fig. 6.12c, f), are located between 220 and 282 m off Málaga city. The Aceitunas mounds (Eastern field), are located between 142 and 300 m off El Ejido (Almería) and close to Chella Bank (Fig. 6.12d, g). A total of 150 mounds have been identified in the three fields that range from 2 to 17 m in height, with maximum lengths of 130 m and slopes of between 2° and 18°. Generally, they are circular or NW-SE to N-S elongated, presenting skewed and scalloped distributions. Some have contouritic moats surrounding their basal areas and contourite deposits appear as plastered drifts overlapping and burying the mound flanks (Ercilla et al. 2016).

Two different CM fields also occur in the African Alboran Sea: the West and East Melilla Provinces (WMP and EMP) (Fig. 6.12a). The fields are interpreted as being cold-coral water mounds (Lo Iacono et al. 2014). The WMP is located on the western upper slope sector of the southern Alboran Sea off Cape Tres Forcas, within a water depth range between 130 and 620 m. This field comprises two clusters with a total of 103 mounds, within a depth range of 298–590 m. The main cluster is located between 299 and 420 m water depth, while the second, smaller cluster is located between 347 and 430 m water depth, in the eastern portion of the WMP. The mounds are from 1 to 48 m high, with an average height of 10 m, and maximum slopes of 35°. They are almost circular in outline, with maximum lengths of 476 m, although some are NE-SW elongated in the main cluster and NW-SE elongated in the second cluster, with maximum lengths of 650 m showing a skewed distribution. They also present erosive moats. On the other hand, the East Melilla Province (EMP) is located along the eastern upper and middle slope of the southern Alboran Sea off Cape Tres Forcas, in water depths of between 230 and 450 m (Comas and Pinheiro 2007). Two different CM areas comprise up to 10 mounds and ridges (BigOne, Horse, Elephant, Serpent, Dragon, and New Mounds). BigOne is located at the base of the shallow-water Provencaux Bank, between 300 and 450 mbsl, and comprises three carbonate ridges: Brittlestar Ridge I-III, while the other mounds are located between 230 and 260 mbsl (Hebbeln et al. 2009). They range from 20 to 100 m high, up to 3000 m in length, and always have elongate shapes with varying orientations, mainly E-W and NE-SW. All the mound fields present contourite moats (Comas et al. 2009).

Acoustically, CM are characterized by non-penetrative echoes that produce transparent pinnacles generally buried under a thin (few milliseconds) sediment blanket of variable thickness that stands out from the surrounded layered sediments (Fig. 6.12e, f, g).

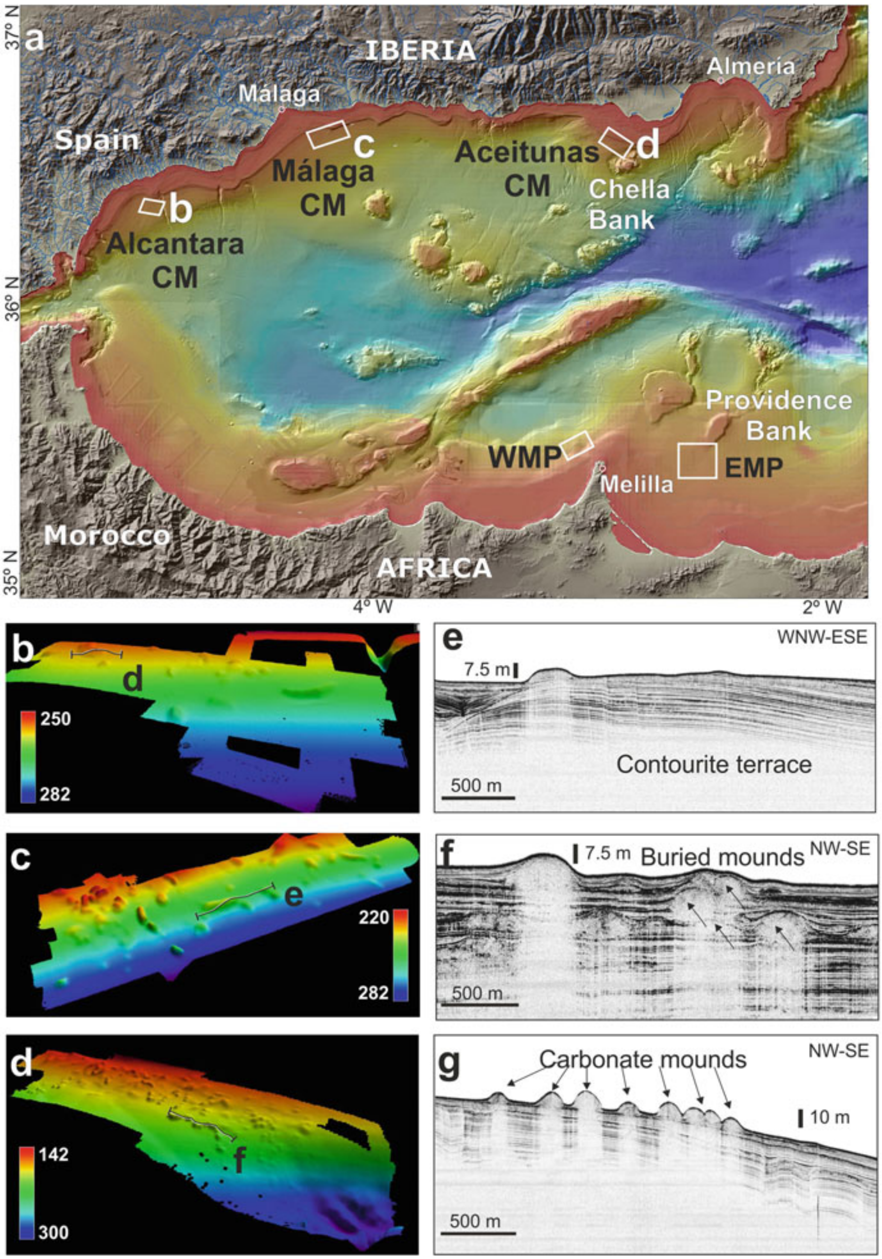

Fig. 6.12 CM in the Alboran Sea. (**a**) Multibeam bathymetric map showing the location of the CM mapped in the Alboran Sea. (**b**)–(**d**) Zooms of multibeam bathymetry showing the Alcantara, Málaga, and Aceituna fields. (**e**)–(**g**) Seismic profiles displaying their cross-sections and internal acoustic character of surficial and buried carbonate Mounds. Acoustically, these CM represent transparent pinnacles that stand out from the surrounded layered sediments. Legend: *WMP* CM in the western Melilla province; *EMP* CM in the eastern Melilla province

6.5.3 Recent Sediments: Facies Model

The surface and spatial distribution of recent sediments have been determined by several regional studies (Zamarreño et al. 1983; El Moumni and Gensous 1992; Ercilla 1992; Hernández Molina et al. 1993; El Moumni 1994; Ercilla et al. 1994, 2019; Bárcenas 2002, 2012). Sedimentation is mainly siliciclastic; only locally it is mixed (terrigenous-carbonate) in the eastern Iberian sector (Almería margin) and on the main, shallowest, and isolated seamounts (Alboran Ridge, Xauen Bank, and Frances Pagès Seamount). Five types of sedimentological facies have been characterized in the Pleistocene-Holocene near surface record; these are (1) nearshore, (2) prodeltaic, (3) contourite, (4) turbidite, and (5) mass-flow deposits (Fig. 6.13). These five facies define the vertical succession corresponding to the regional sedimentary environments of the proximal margin (continental shelf), distal margin (continental slope and base of slope), basins, and morphological highs (Fig. 6.14).

The *continental shelf facies* model involves nearshore and prodeltaic facies, the boundary between them being a sharp surface (Fig. 6.14). *Nearshore facies* (1) form homogenous successions of gravels and sands (up to 140 cm thick), as well as fining-upward successions from heterometric gravels to sands, and from sands to sandy muds (Fig. 6.14, profiles 1, 3, 6, 7). The gravels form successions of bioclastic fragments (relict molluscs, bryozoans, and calcareous algae occasionally replaced by glauconite), rounded and subrounded light and heavy minerals, and glauconite grains. Nearshore facies produce a widespread veneer over the entire continental shelf and are exposed mainly in the outer shelf area. The ages obtained for these facies vary between 21,610 years BP at 208 cm core depth and 1240 years BP at 27 cm core depth. The nearshore facies are overlain by *prodeltaic facies* (2), separated by a well-defined unconformity. The overlying prodeltaic facies are characterised by a vertical succession of terrigenous mud (Iberian prodeltas) and sandy mud (African prodeltas) with coarsening and fining-upward sequences

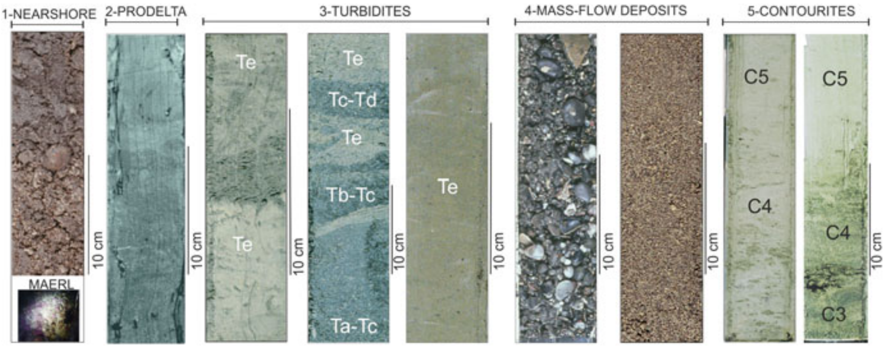

Fig. 6.13 Selected sediments core photos of the recent Alboran sediments and seafloor photo of maerls upholstering the seafloor of Alboran Ridge. Legend: Ta to Te refer to the Bouma divisions, and C3 to C5 refer to the contourite divisions of Stow and Faugères (2008)

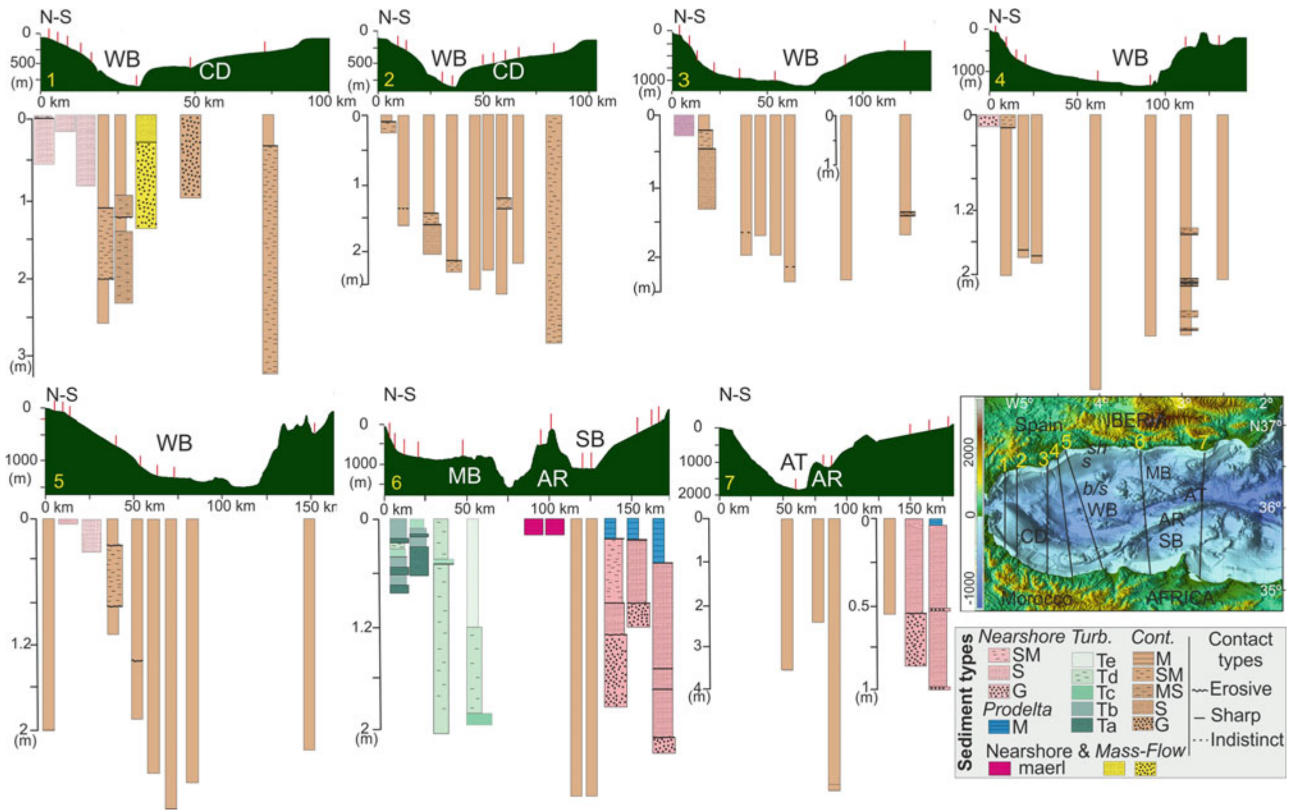

Fig. 6.14 Roughly N-S cross-sections in the Alboran Sea to provided two-dimensional slices of the stratigraphy and distribution of sedimentary facies in the Alboran Sea. Legend: *Turb* Turbidites; *Cont* Contourites; *sh* shelf; *s* slope; *b/s* base of slope; *CD* Ceuta Drift; *G* Gravel; *S* Sand; *MS* Muddy sand; *SM* Sandy mud; *M* Mud; *WAB* Western Alboran Basin; *MB* Motril Basin; *AR* Alboran Ridge; *AT* Alboran Trough; *SAB* Southern Alboran Basin. See also the location of cross-sections and sediment cores in Fig. 6.2b

(Fig. 6.14, profiles 6, 7). These facies occur locally on the inner-middle shelf, off the river mouths in the Iberian (Ercilla et al. 1994; Hernández Molina et al. 1993; Bárcenas 2012) and African (El Moumni 1994) shelf, down to a depth of 70 m, and have a lobate shape in plan-view (Bárcenas 2012). The age obtained for the prodelta sediments analysed is about 1500 years BP at 25 cm core depth.

The *continental slope, base of slope, and basin facies* model consists of contourites, turbidites, and mass-flow deposits. The *turbidite facies* (3) form vertical succession of three textural types (sand, silt, and clay) displaying fining-up sequences (Fig. 6.14, profile 6). These correspond to divisions of the Bouma sequence (Ta to Te). The cores show turbidite sand and silt layers (Ta-d) alternating with mud layers (Te) in the turbidite systems of the Iberian margin (Bozzano et al. 2009; Ercilla et al. 2019). They comprise terrigenous components and, in a minor proportion, the sand fraction contains bivalves and gastropods, similar to those described on the continental shelf (Ercilla et al. 1994). The coarsest-grain size occurs in channel environments, while the finest-grain sizes are in the inter-canyon and levee areas. The *mass-flow facies* (4) form vertical successions of sands and gravels, displaying homogenous sequences with lithic clasts. These are found on the Ceuta and Guadiaro Canyon floors (Ercilla et al. 2019). Coarse and fine contourite facies (5) have been characterised. The *coarse contourite facies* have been sampled from the shelf-break down to about 360 m water depth, on the erosive surface defining the contouritic terrace, on the uppermost Iberian continental slope (Fig. 6.15, profiles 1, 5). There, these facies comprise successions of poorly sorted sand up to 73 cm thick with sparse gravel-size biogenic clasts (shell fragments). The sand fraction of this sediment is terrigenous, mainly comprising subrounded and rounded grains of glauconite (44%) mixed with bioclastic debris (30%). This debris is mainly composed of fragments of molluscs that look old due to their greyish colour and because they show mechanical and chemical abrasion with loss of ornamentation. The *fine contourite facies* form successions of different textures from sandy muds, muds, and silty clays with terrigenous and mixed components (Fig. 6.15 profiles 1 to 7). The vertical succession produces a bi-gradational sequence, with coarsening-up followed by fining-up, and corresponds to the five sediment divisions (C1 to C5) of Stow and Faugères (2008). In addition, there are truncated sequences formed by C1, C3–C4–C5, and C4–C5 (Fig. 6.14). The thickness and vertical/spatial distribution of the contourites indicate that muds (C1 or C5) are predominant, interrupted by levels of sandy muds (C2 or C4). The coarse-grained intervals occur more frequently in the southern and western sectors of the Ceuta Drift (Ercilla et al. 2002). On the other hand, the summits of the *topographic highs* of Tofiño, Xauen, and the Alboran Ridge are surficially covered by nearshore sediments composed mostly of gravels and sands of bryozoans, coralline algae, mollusc fragments, echinoid spines, and foraminifera (benthic and planktonic) with abundant maerl (also known as rhodolith; Bárcenas et al. 2001). The ages obtained for these sediments are around 13,430 to 3085 years (Fig. 6.14, profile 6).

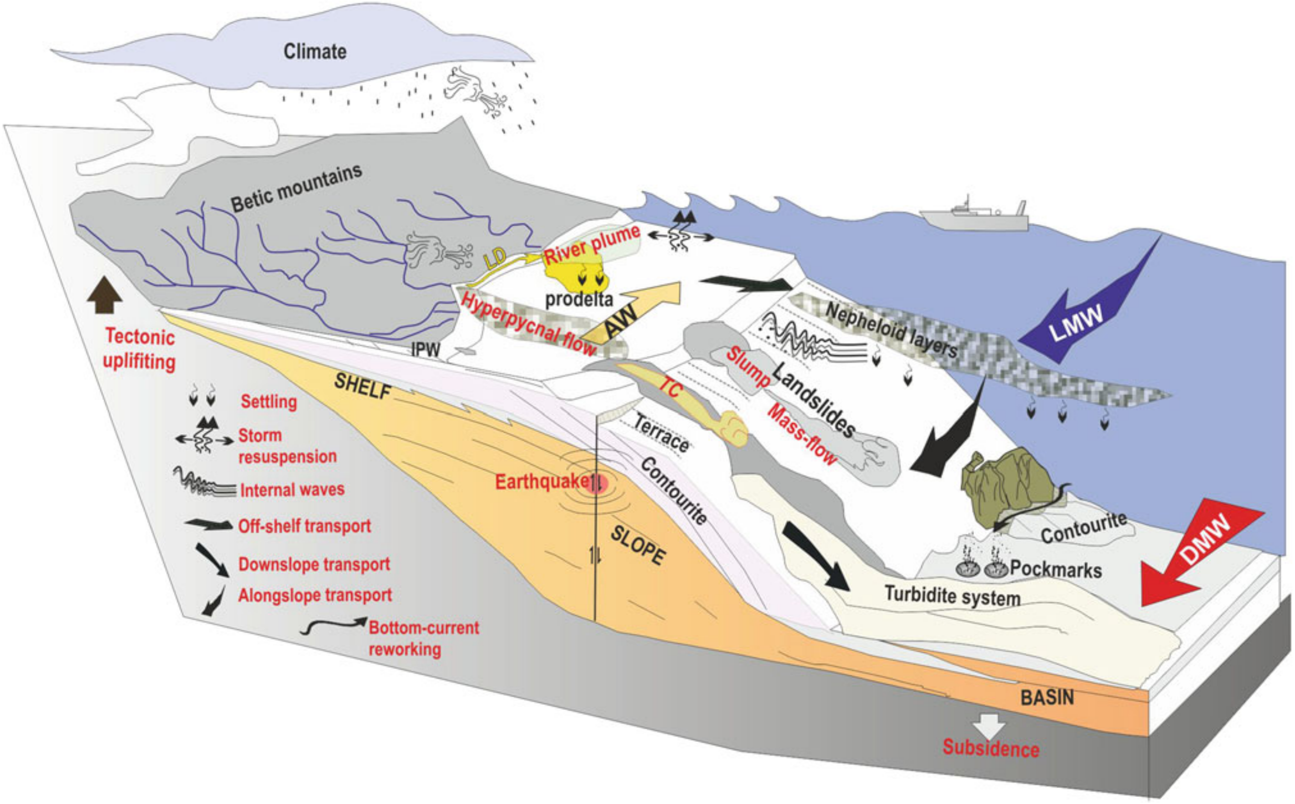

Fig. 6.15 3D diagram summarising the main features and sedimentary dynamics characterising the Alboran continental margins and adjacent sub-basins. Legend: *IPW* infralittoral prograding wedge; *LD* Littoral drift; *TC* turbidity current; *AW* Atlantic Water; *LMW* Light Mediterranean Water (WIW+LMW); *DMW (WMDW)* Dense Mediterranean Water. Figure adapted and modified from Pisias and Delany (1999)

6.6 Discussion

6.6.1 *Active Tectonics*

NW-SE present-day oblique convergence between the Eurasian and African plates at a rate of 4.5 mm/year (DeMets et al. 2015) causes a regional NW-SE shortening and orthogonal extension accommodated by tectonics structures (folds and faults) and that produces a set of seafloor features of structural origin. Basically folded reliefs of different magnitude, push-up ridges, linear scarps and lineations, and rhombic and longitudinal depressions have been mapped (Vázquez et al. 2016).

Tectonics determines the development of large NE-SW to ENE-WSW antiforms that delineates the shape of elongate seamounts (e.g. the Alboran Ridge, Xauen Bank, and Francesc Pagès), the Alboran Trough, as well as smooth bulges anticlines in the Adra margin region (Figs. 6.1b, 6.3b, 6.7 and 6.8a, b). Moreover, plate convergence produced the presence of the two main fault sets, oriented N25° E sinistral and N130° E dextral, where the resistant basement of the African plate indents the thinned continental crust of the Alboran Sea (Estrada et al. 2018) that are strongly marked in the morphology of the seafloor (Fig. 6.7). These faults have a high level of seismic activity and are responsible for the NNE-SSW seismicity band crossing the Alboran Sea, from Campo de Dalías to Al-Hoceima, where the recent 1993–1994, 2004, and 2016–2017 seismic series occurred (Figs. 6.1b and 6.7). The Al Idrisi Fault and new faults developing westwards constitute the present-day most active seismogenic faults in the Alboran Sea (Galindo-Zaldívar et al. 2018), located on the northwestern border of the indenter. The dextral Yusuf Fault constitutes the main WNW-ESE conjugate fault delineating the northern boundary (Figs. 6.1b and 6.7). NW-SE normal faults located along the northern boundary of the Alboran Sea, like the Balanegra Fault (Galindo-Zaldívar et al. 2015) also play an important role in accommodating the ENE-WSW extension related both to the indentation tectonics and rollback processes. The orientation of the ENE-WSW Serrata-Carboneras Fault with respect to the orthogonal NNW-SSE present-day convergence suggests that this fault may currently have limited activity (Figs. 6.1b and 6.7).

The active tectonics is also attested by the fluid-flow features mapped on the seafloor (Fig. 6.9). Fluids flowing from deep layers have been related to regional tectonics. The diapir distribution in the Western Alboran Basin is related to extensional, compressional and strike-slip processes related to the geodynamic evolution of the Alboran Basin (Pérez-Belzuz et al. 1997). Extensional processes reactive though it punctuated diapiric activity during the Pliocene and early Quaternary, and during the late Quaternary that activity was characterized by a generalised collapse phase in many mud ridges (Pérez-Belzuz et al. 1997). The mud volcano activity is related to the tectonically-driven diapirs whose mud forms the source of the focused fluid-flow feeding the volcanoes (Pérez-Belzuz et al. 1997; Somoza et al. 2012). These authors also suggest that active diapirism and mud volcanism was also favoured in the African margin by differential loading generated by a contourite sedimentation, specifically of the Ceuta plastered Drift (Pérez-Belzuz et al. 1997;

Somoza et al. 2012). In contrast, fluids accumulate as reservoirs in near surface sediments and create cold-seep features through fluidification and liquefaction of the unconsolidated sediments; the formation of these structures may also be favoured by the erosion of contourite drifts and sea-level changes (Somoza et al. 2012).

Most of the tectonic deformation of the seafloor has been located in areas of the continental slope or basin, while the tectonic deformation of the continental shelf has been located mostly in the area of the Al-Hoceima Bay. This is consequence first by the source of the tectonic activity which proceeds from the boundaries of the indentation block described by Estrada et al. (2018), where the western limits, the Al-Idrissi Fault, would end up towards the Al-Hoceima area. A second argument must be taken into account, it is the low magnitude of the convergence velocity of Africa-Eurasia convergence (DeMets et al. 2015) that is being accommodated by these structures, so that on the continental shelf the evidences of this deformation can be obliterated by the erosive processes in moments of lowstand level or by deposits related to the last high stand-level episode. In any case, a detailed analysis of the possible tectonic seafloor deformation must still be carried out in areas of the continental shelf.

6.6.2 *The Key Role of Alboran Sea Seafloor Morphology in Characterising Sediment Dynamics*

The Alboran Sea represents the dumping area for sediments coming from the Betic and Rif mountain belts (Fig. 6.1a). The way sediment has been transported and deposited, at least in recent times, is mainly reflected by the morphosedimentary features that characterise the present-day morphology of the Iberian and North African continental margins and the adjacent deep basins (Figs. 6.5 and 6.6a). Their mapping on the seafloor does not imply present-day activity, although they have been, at least, recently active from a geological point of view. The distribution and lateral relationships between these features reveal that each physiographic province is dominated by a cluster of morphosedimentary features that, based on formation processes, indicate at least two main, different sedimentary environments on the continental margins. These two major environments are: (1) the proximal margin defined by the continental shelf; and (2) the distal continental margin, clustering to the continental slope, base of slope, and adjacent basins.

6.6.2.1 Sediment Dynamics on the Proximal Continental Margin

The proximal continental margin of the Alboran Sea is dominated by coastal and fluvio-marine sedimentary processes. The seafloor morphology of the Alboran continental shelf attests to the influence of these processes in different sedimentary environments, including prodeltas, IPWs, bedforms, and relict nearshore sheets (Fig. 6.4).

The sediment dynamics of the prodeltaic systems are mainly related to settling from the suspension of nepheloid layers, or turbid layers of sediment delivered from rivers and streams or wave-supported gravity flows, all with a dominant cross-shelf transport dynamic (Fig. 6.15). The settling process appears to be continuous, operating on the present-day proximal continental shelf since the installation of the Holocene highstand (6500 years BP to present). The well-defined 2D surficial distribution of the prodelta facies, the age of these facies (1500 years BP), and the well-defined 3D geometry (wedge-shape) of the prodeltaic bodies identified from seismic records indicates strong sediment progradation in the submarine environment and low sediment retention levels in the emerged domain (Fig. 6.4a, b, c, d) (e.g. Ercilla et al. 1994; Hernández-Molina et al. 1994; Bárcenas et al. 2009; Lobo et al. 2015). The plan-view geometries are directly related to hydrodynamic control being greater in those with elongate patterns. In this sense, the Guadalfeo River prodelta exhibits lateral morphological plan-view changes from lobate to elongate, reflecting the temporal modification of the balance between fluvial supply and sediment redistribution by the governing hydrodynamics and/or reworking of pre-existing depocentres (Figs. 6.4a, b and 6.15) (Lobo et al. 2006; Jabaloy-Sánchez et al. 2014).

Many prodeltas are affected by conspicuous seafloor undulations (Fig. 6.4a, d). Morphometric, stratigraphic, and sedimentological data indicate the possible activity of hyperpycnal flows (i.e. a particular type of turbidity current generated by river discharge) as a plausible genetic mechanism (Fig. 6.15) (Lobo et al. 2015). The margins of the southern Iberian Peninsula are mountainous, and the drainage basins are small and steep; in addition, rainfall events are torrential nature in the region; these conditions favour the generation of hyperpycnal flows. There is greater undulation development in prodeltaic settings off river basins with high maximum rainfalls; therefore, a genetic link between fluvial flow and undulation development has been proposed (Bárcenas et al. 2009). In this sense, a relationship is observed between undulation development and river basin parameters, such as river length and basin size (Bárcenas et al. 2009). The most detailed analysis has been conducted on the undulations off the Guadalfeo River, which could be classified as a moderately dirty river (Fig. 6.4a, b, d). There, morphometric differences between undulation fields suggest the occurrence of temporal changes in hyperpycnal flows. Higher undulations could be indicative of intensified river flow, whereas lower and more laterally extensive undulations could indicate their inactivity due to a change in the course of the river (Fernández-Salas et al. 2007; Lobo et al. 2015). On the other hand, the presence of prodeltaic channels and/or gullies would point to relatively high-energy hyperpycnal flows, suggesting a relationship between their development and fluvial flow (Figs. 6.5c, d and 6.15).

Current interpretations also assume that inner IPWs are moulded by relatively recent (i.e. Holocene stillstand) dynamic processes (Figs. 6.4a, c, e and 6.15). The original conceptual model highlighted the major influence of seaward sediment transport patterns induced by downwelling storm resuspension currents that trigger sediment avalanching onto a depositional slope below storm base levels (Fig. 6.15) (e.g. Hernández-Molina et al. 2000; Ercilla et al. 2010). More recent studies stress the additional influence of alongshore sediment transport, instead of downslope, on IPW development (Fig. 6.15) (Fernández-Salas et al. 2009), particularly on relatively straight coastlines with progradational coastal plains. There, IPW accretion parallel or oblique to the coastline is usually coupled to the progradational story of the adjacent coastal plains and seems to be favoured by significant alongshore currents. Major changes in development of IPWs would be caused by erosional events and/or by significant changes in the direction of prevailing winds, and then wind-forced currents, which ultimately affect littoral drift patterns (Fernández-Salas et al. 2009). In the particular case of the Carchuna IPW, sediment transport and IPW construction seem to be enhanced by the role played by the Carchuna Canyon head (Fig. 6.5a, b), which focuses wave energy during high-energy events and enhances coastline and shoreface erosion. As a consequence of the widespread erosion, sediments would be available in the coastal system for subsequent remobilisation, and these would be finally entrained by along-coast hydrodynamic processes (Ortega-Sánchez et al. 2014).

Sediment dynamics in those shelf areas where relict nearshore facies and wave-cut terraces are exposed (Figs. 6.13 and 6.14), point to domains (mainly on the outer continental shelf) with present-day low levels of sedimentation; in other words, they are shelf areas that do not receive sediment from fluvial sources or major coastal erosion. The ages obtained for the nearshore facies (from 21,610 ± 350 to 1249 ± 60 years) suggest that these facies were mainly formed during the last sea-level rise, as the sea-level was about 110 m (Mateu 1992) below its present position at about 18,000 years, and began to transgress the entire continental shelf. The successive coastline migration across the shelf would explain the fact these facies forms a widespread veneer over the entire continental shelf. This migration was pulsed and the stillstands would have favoured the formation of wave-cut terraces (Lobo et al. 2014). The occurrence of different types of bedforms, preferentially in outer continental shelf settings, where relict nearshore facies are exposed, on both the Iberian and African shelves, could be tentatively related to the activity of reworking processes during the course of the postglacial sea-level rise. Specifically, the dune fields reported on the shelf around Al-Hoceima Bay have been genetically linked with a sea-level stillstand at around 15,000 years, predating a major shelf flooding event (Lafosse et al. 2018).

6.6.2.2 Sediment Dynamics on the Distal Continental Margin

The distal margin is dominated by marine sedimentary processes, which mainly include the action of bottom currents and mass-movements.

Bottom Current Processes

Bottom current processes are responsible for the formation of contourite features, both depositional and erosional. The ubiquity of these features (Fig. 6.6a) makes bottom currents as the most important factor controlling sediment patterns in the deep-sea areas in the Alboran Sea (Figs. 6.6b and 6.15). The effect of bottom currents on sediments is twofold: they move sediments prior to and after deposition. In the first scenario (prior to deposition) sediment is transported and deposited by bottom currents favouring the formation of large-scale, plastered, and sheeted drifts, which contribute to the building of the open continental slope, base of slope, and the infilling of the basins (Fig. 6.6); in this scenario sediment deposition occurs far from the sources of continental sediments, i.e. rivers and streams, coastal erosion, and including Saharan aeolian input (e.g. Jiménez-Espejo et al. 2008; Moreno et al. 2002; López-Gonzalez et al. 2019). This activity has been occurring at least since the opening of the Strait of Gibraltar, at around 5.33 Ma (Ercilla et al. 2016; Juan et al. 2016). When sediment reaches the sea, the AW, LMW, and DMW drive the alongslope transport that provokes the dispersion and distribution of sediment (mostly the fine sediment) over large areas of the Alboran Sea (Fig. 6.15). In addition to this alongslope component of sediment transport, there is a downslope component, also exerted by the water masses, specifically by the water mass interfaces. These interfaces favour the occurrence of nepheloid layers with a relatively high content of fine sediments (e.g. McCave and Tucholke 1986) that move sediment downslope (Fig. 6.15). Deposition occurs when sediment motion velocity decays, producing the rapid settling of the suspended sediment, and thus drift formation. The sediment motion is related to large-scale velocity variations in the AW, LMW, and DMW pathways, which are themselves mostly governed by the interplay between the trend and morphology of the Iberian and African margins and basins (Fig. 6.1a), together with the Coriolis Force. The predominance of fine contourites in the sampled cores (Figs. 6.13 and 6.14) points to the fact they were deposited under generally low-energy conditions, at least in the case of the most recent (Holocene) contourite deposits. The vertical grain-size variations observed in those facies may be the result of changes in bottom current velocity (e.g. Toucanne et al. 2007; Stow and Faugères 2008) and sediment provenance (e.g. Brackenridge 2014; Rebesco et al. 2014).

When bottom currents move sediment after deposition, they contribute to reworking the seafloor. The effects of this reworking activity are seen clearly in erosive (moats, channels) and mixed (terrace) contourite features. Reworking occurs when the bottom current velocity increases enough to erode the seafloor (e.g. Nittrouer et al. 2007) (Figs. 6.6 and 6.15) and it occurs at two different scales in the Alboran Sea: (1) local; and (2) regional. Local accelerations of the DMW occur when this water mass is confined by the Alboran Trough and Al-Hoceima Valley (Fig. 6.1a). Along the Alboran Trough, the seafloor is mostly eroded, although channel-related drifts do form when the velocity decreases. Conversely, in the Al-Hoceima Valley there is only erosion, and the DMW transports the eroded sediment along the African margin, towards the Strait of Gibraltar. Locally, the LMW and DMW also accelerate when they interact with seamounts and steep scarps, producing seafloor reworking at the break of the steep slopes (Figs. 6.6 and 6.15). This reworking contributes to excavating erosive moats that constitute striking depressions at the feet of the seamounts (Palomino et al. 2011; Ercilla et al. 2016). This reworking/erosion contributes to the relatively high concentrations of suspended sediment at the benthic boundary layer that is deposited close to the moats, where the sediment motion velocities decay sharply, forming mounded, separated, and confined drifts (e.g. Stow et al. 2008; Rebesco et al. 2014).

Reworking at regional scale mainly occurs on the upper continental slope of the Iberian and African margins, where terraces have been mapped (Figs. 6.6 and 6.15). The reworking happens where the interfaces of the AW with LMW and DMW touch the continental slope seafloor. Turbulent motion characterises the interfaces due to the presence of internal waves that alter flow velocity with oscillations of up to 0.4 m/s, producing vertical displacement of water (50 m) above and below the mentioned interfaces (Fig. 6.15) (e.g. Sarnthein et al. 1982; Pomar et al. 2012; Shanmugam 2013a, b; Chen et al. 2014; Ercilla et al. 2016). Currently, internal waves are mostly formed within the Strait of Gibraltar (e.g. Armi and Farmer 1988; Bruno et al. 2002), and above striking variations in relief, such as the shelf break (e.g. Ercilla et al. 2016). The sediment cores have revealed the presence of wide areas of coarse sediments, free from fine sediments, on the seafloor at the proximal sites of the terrace (Fig. 6.14) (Ercilla et al. 1994), providing evidence for the action of this important turbulent motion. The position of the Atlantic and Mediterranean water mass interfaces would have varied during the past high frequency and high amplitude glacio-eustatic changes in sea level, caused by the three variables of the Earth's orbit (eccentricity/obliquity/precession) (e.g. Ercilla et al. 1994; Chiocci et al. 1997; Lobo et al. 2008). The horizontal displacements of interfaces during the sea-level changes would have favoured the reworking of extensive areas of the upper slope and enlargement of the terraces.

Additionally, the interplay between favourable bottom currents and climatic conditions could have influenced the complex CM development in different phases, possibly related to the last deglaciation (<5400 years) corresponding to the Late Holocene, as suggested by Fink et al. (2013) for the EMP mounds.

Mass-Movement Processes

Mass-movement processes are responsible for the formation of both the turbidite systems and the landslides. The morphology and deposits making up the architectural elements of *turbidite systems* indicate they are mainly formed by the action of channelized turbidity currents and related flows (mass flows), i.e. downslope density flows (Fig. 6.15). The U- and V-shapes of the canyons and related tributary gullies suggest those flows have a significant erosive capacity (Fig. 6.10e). Their energy is mainly related to sediment load characteristics and the relatively high seafloor gradients that directly influence the gravitational force (e.g. Ercilla et al. 1998; Pirmez et al. 2000; Ferry et al. 2005; McHargue et al. 2011). Sediment cores recovered from canyon floors indicate that turbidity and mass flows transport a great variety of grain sizes, from gravels to clay. Most of the canyons (except Torrenueva and Baños) were formed during the Messinian salinity crisis (Estrada et al. 2011; Ercilla et al. 2019), and their present-day morphosedimentary characteristics (Fig. 6.10a–e) are the result of gravitational flows that have been acting on them since that time. Pliocene and Quaternary sedimentary studies suggest that gravitational flows were active, eroding and enlarging the canyons, mainly during the glacial periods, when the sea-level and continental sediment sources were closer to or below the shelf-break. The occurrence of turbidity and mass flows decreased during interglacial highstand stages (e.g. Alonso and Maldonado 1992; Ercilla et al. 1992, 1994; Chiocci et al. 1997; Estrada et al. 1997; Alonso and Ercilla 2003). The U-shape of many canyons and the presence of sinuous talwegs on the seafloor (Fig. 6.10) suggest alternating deposition and erosion in recent times. The energy of the turbidity and mass flows decreases when they reach the gentle gradients at the base of the slope and in the adjacent basin, and their sediment charge deposits forming leveed channels and lobes, although erosion may continue along the main and distributary channel floors.

Recent studies have indicated that turbidity flow characteristics seem to be locally affected by the action of bottom currents running across the turbidite systems in the westernmost Alboran Sea (Ercilla et al. 2016, 2019). AW, LMW, and DMW contribute to the piracy of the finer sediment travelling in the upper part of the turbidity flows, making the turbidite systems sandier (La Linea and Guadiaro) closer to the Strait of Gibraltar. The action of the DMW also seems to have been more intense on the African margin, probably inhibiting the formation of leveed channels and lobes at the mouth of the Nekor and Ceuta canyons.

Respect to *landslides* shaping the seafloor of the Alboran Sea (Figs. 6.6, 6.11 and 6.15) the literature reveals that most of them formed during the Quaternary (Casas et al. 2011; Martínez-García et al. 2011; Alonso et al. 2014; Rodriguez et al. 2017; Galindo-Zaldívar et al. 2018). Their fresh morphologies indicate that their activity has continued into recent times. Slope sediment failure occurs when their metastable equilibrium is disturbed, causing the sediment to move downslope (e.g. Casas et al. 2011; Ercilla and Casas 2012). Although the causes of landslides are still not fully understood, several triggering factors, acting either individually or jointly, have been tentatively suggested for the Alboran Sea: over-steepening, seismicity, under consolidation due to overpressure by interstitial fluids, stratigraphy, and high sedimentation rates (e.g. Casas et al. 2011; Alonso et al. 2014; Rodriguez et al. 2017).

After failure, the sediment runs downslope, disintegrating, and remoulding as a consequence of the stress and incorporation of water during the movement (e.g. Locat and Lee 2000). Based on this process and the runout distance, the sediment remains as a coherent mass attached to or detached from the slide scar (Fig. 6.11). Detailed studies of the Baraza slide reveal that the type of movement may change through time. This landslide has been affected by two types of movement since its formation during the Upper Quaternary, firstly mass flow-type, followed by a more recent slump-type movement (Casas et al. 2011).

6.6.3 Geohazards in the Alboran Sea

The seafloor morphology offers interesting clues to help assess the main potential geological hazards. These hazards can be grouped into two major different categories, endogenic and exogenic. The endogenic are related to tectonic processes, and the exogenic are related to bottom current and mass-movement processes.

Hazards related to tectonic processes (1) are the most relevant in the Alboran Sea. They are related to its complex tectonic context (Fig. 6.1b) caused by the interaction between the Eurasian and African plates. This fact is evidenced by the numerous faults and folds affecting the seabed, in addition to the related seismicity. The central Alboran Sea presents the highest concentration of active tectonic structures (d'Acremont et al. 2014; Estrada et al. 2018; Galindo-Zaldívar et al. 2018) (Figs. 6.1b and 6.7). Historical records suggest that Spanish, Moroccan, and Algerian populations bordering the Alboran Sea have been affected by more than 50 destructive earthquakes in the last 2000 years (Martín-Lechado et al. 2005). The last was on January 25th, 2016, when there was an earthquake of magnitude $Mw = 6.3$ with its epicentre in the Alboran Sea (35.6° N, 3.81° W). This caused material damage in Melilla and other Moroccan cities.

Hazards related to bottom current processes (2) are mainly related to the erosive activity of the Atlantic and Mediterranean waters. This activity is revealed by the erosive contouritic features. Published literature on the present-day characteristics of oceanographic circulation points to the fact seafloor erosion could occur in the vicinity of the Strait of Gibraltar, on both the Iberian and African margins. In this area, the Atlantic and Mediterranean water masses accelerate (e.g. Kelling and Stanley 1972; La Violette 1984; Parrilla et al. 1986; Parrilla and Kinder 1987; Viúdez et al. 1996; Naranjo et al. 2012; Peliz et al. 2013; Sotillo et al. 2016). This results in two hazardous effects: the reworking of slope terrace sediments, rock outcropping, and the presence of a mobile seafloor at the entrance to the Strait of Gibraltar (Kelling and Stanley 1972; Ercilla et al. 2016). Here, sand waves and undefined sediment waves (metre-sized in relief, and a few to tens of metres in length) have been mapped (Heezen and Johnson 1969).

Hazards related to mass-movement processes (3) is revealed by the presence of landslides on the open slope and basins and on the steep walls of valley walls and seamounts (Fig. 6.6a). In spite of the active tectonic context of the Alboran Sea, the relationship between recent earthquake epicentres and submarine landslides is not readily apparent in this basin (Figs. 6.1b and 6.6a). The correlation is only clear on the northern side of the Francesc Pagès seamount and Alboran Ridge, where several landslides have been mapped along the 2016–2017 ENE-WSW seismicity alignment (Fig. 6.1b) (Ercilla et al. 2016; Galindo-Zaldívar et al. 2018). Most of these landslides are located on contourite deposits and the occurrence of alternating layers with different grain sizes and mechanical behaviour could induce slope failures under cyclic and/or static loading conditions. Slope instability may be also related to the presence of a high content of gas bubbles in the interstitial pore water that contributes reduced sediment shear strength. The gas content is mainly evidenced by the presence of pockmarks, as in the case of the Baraza Slide (Fig. 6.6a) (Casas et al. 2011). Many other predisposing factors contribute to the triggering of submarine landslides; for example the interaction of shallow canyon heads (e.g. Algeciras, Guadiaro and Carchuna canyons) (Figs. 6.3b and 6.10a, b) with coastal and fluvio-marine processes that undercut the canyon sidewalls, leading to a progressive slope over-steepening of the canyon heads. On the other hand, sedimentary processes related to the generation of hyperpycnal flows due to the torrential nature of the region and strong rainfall events may cause local erosion and mobile bedforms, as happens in many Iberian prodeltas (e.g. Bárcenas et al. 2009).

Hazards related to tectonics and slope instability can trigger destructive tsunamis (e.g. Fine et al. 2005; Gisler et al. 2006; Harbitz et al. 2014). The seismic-related risk of tsunamis in the Alboran Sea has not yet been quantified but is considerable. The various coastal regions of the basin have been affected by several tsunamis over the last seven centuries (Kaabouben et al. 2009). Accessible tsunami models, such as the Cornell Multi-grid Coupled Tsunami Model (COMCOT), enable us to assess the areas potentially affected in the Alboran Sea. The most-affected coastal area (involving sources in the south-central area of the Alboran Basin) is located between the cities of Marbella and Almería. In this area, wave elevations (locally exceeding 1 m in height) would reach the coast in less than 30 min (Álvarez-Gómez et al. 2011; Macías et al. 2015). Strike-slip faults like the Serrata-Carboneras and Yusuf faults could generate local tsunamis affecting the coastal infrastructure with a short (5 min) travel time (Álvarez-Gómez et al. 2011). Recently, the Averroes Fault has been suggested to be one of the most important potential tsunamigenic faults in the area (Estrada et al. 2018) (Fig. 6.7). Also, recent studies consider underwater mass-movements as a potential cause of tsunamis, and these have been numerically modelled in order to evaluate the affected areas (Macías et al. 2015; Rodriguez et al. 2017).

6.6.4 Contribution of Geology to Habitat Knowledge

Habitat mapping requires the integration of biological, geological, and oceanographic data. Surficial marine geology is a very important variable for habitat classification purposes and biodiversity studies. Marine geological mapping involves a range of acoustic and ground-truthing methods that provide crucial information for linking substrate characteristics (morphological and textural) with the existence of certain types of habitats. Furthermore, geology affects the environmental conditions of an ecosystem, for example changes in topography generated by slope movements govern the development, or not, of habitats. Also, major natural disasters, like earthquakes, tsunamis, and floods, are key factors affecting habitat settling. All these are specific topics in the study of marine geology.

In recent years, several research articles written from a geohabitat perspective have been published, mainly dealing with the northern margin of the Alboran Sea (Hebbeln et al. 2009; Palomino et al. 2011; Vázquez et al. 2015a; Gofas et al. 2014; Moya-Urbano et al. 2016; Sánchez-Guillamón et al. 2018). Most of these studies form part of the INDEMARES project, a European initiative to define Sites of Community Importance to be included in the Spanish marine Natura 2000 Network, and in which geological studies have played an important role.

In this sense, the studies undertaken to date in the Alboran Sea have focused on the following geomorphological units: prodeltas, bioconstructions, seamounts, and canyon heads. These geological studies have provided information on the depth, acoustic response, and textural characteristics of the sediment; the seafloor morphology, sediment dynamics, and the angle and orientation of the seafloor, which in combination with assemblages of habitat-forming species enables habitat identification and mapping. In many cases, the high diversity and patchiness of habitats can be explained by the high environmental variability resulting from the broad geomorphological diversity (De La Torriente et al. 2018). The geological contribution has been crucial for these studies, to allow the consistent identification and mapping of the habitats using benthic samples. These examples demonstrate the intrinsic association of geoscience and habitats, and it is from these associations that a better understanding of the total ecosystem can be made and ultimately managed (Barrie and Conway 2008).

6.7 Conclusions

This contribution summarises the geomorphology of the Alboran Sea, based on recent local and regional interdisciplinary studies, and the combined analysis of acoustic, seismic, sedimentological, and CTDs data. The geological and oceanographic characteristics of the Alboran Sea make this sea an ideal context in which to analyse geomorphology and sedimentary deposits from shallow to deep-sea areas.

Four major physiographic domains have been defined in the Alboran Sea: (1) continental shelf, (2) continental slope, (3) base of slope, and (4) intraslope and deep basins. The continental shelf is generally poorly developed, and the deep-sea areas are dominated by a highly irregular topography.

The proximal margin (continental shelf) comprises depositional (*prodeltas, infralittoral prograding wedges, and bedform fields*), erosive (*submarine valleys, wave-cut terraces*), *slides,* and *anthropogenic* features. The distal margins and adjacent sub-basins include features with a different genesis; these can be grouped as tectonic, seamount, fluid outflow, contourite, mass-movement, and biogenic structures. The main tectonic features with seafloor relevance are *folds* with dominant ENE-WSW strikes, and *faults* that can be grouped into two main sets of N25° E sinistral and N130° E dextral kinematics. Both predominantly affect the central and eastern seafloor of the Alboran Sea. Several *seamounts,* with different origins and varying sizes, are scattered along the continental slopes and in the sub-basins. Fluid outflow features include *mud diapirs*, *mud volcanoes*, *pockmark*s, and *authigenic carbonates patches*, which occur mainly in the Western Alboran Basin. A great variety of depositional (*drifts*), erosional (*moats, channels, and scarps*), and mixed (*terraces*) contourite features have been mapped from the shelf-break (>90 m water depth) to the basins. Mass-movement features comprise *turbidite systems* mapped on the Iberian margin; *canyons* mapped in the Iberian and African continental slopes and in the Alboran Ridge flanks; and *landslides* mostly situated on seamount walls and with a minor presence on the open continental slope. Finally, fields with *bioconstructions* have been identified on the Iberian and African continental slopes.

Folds and faults mapped affecting the seafloor accommodate the present-day convergence between the Eurasian and African plates. This convergence is oblique with NW-SE shortening and orthogonal extension, and the related faults have a high level of seismic activity that determines the NNE-SSW seismicity band crossing the Alboran Sea. Regional tectonics is considered a controlling factor on fluid flows are related to diapirs and mud volcanoes mapped in the WAB.

The morphosedimentary features reflect the way sediment has been transported and deposited. Their near surface sediments indicate that sedimentation is mainly siliciclastic with locally mixed sediments (terrigenous-carbonate) in the eastern Iberian sector (Almería margin). Five types of sedimentological facies have been identified in the Pleistocene-Holocene near surface record: nearshore, prodelta, contourites, turbidites, and mass-flow deposits. The proximal continental margin is dominated by coastal and fluvio-marine sedimentary processes that have been acting since the last glacial sea-level change. Features found on the outer continental margin (relict nearshore facies and wave-cut terraces) mainly formed during the last sea-level rise and today are relict. Modern features (prodeltas, IPWs, and bedforms) generally occur on the inner-middle shelf and have been deposited during the present-day highstand (6500 years BP to present). The distal continental margin is mainly dominated by marine sedimentary processes, with the action of alongslope bottom currents of the AW and MWs being responsible for the ubiquity of contourite sedimentation. On the other hand, channelised downslope turbidity flows and related flows responsible for building the turbidite systems, were dominant during the glacial periods when the sea-level and continental sediment sources were closer to, or below, the shelf-break. The occurrence of landslides is relatively more important on the active structural seamounts and seems to be the consequence of the interplay of several triggering factors, including over-steepening, seismicity, under consolidation due to overpressure by interstitial fluids, stratigraphy, and high sedimentation rates.

The seafloor morphology of the Alboran Sea facilitates an assessment of the main potential geological hazards. These hazards can be categorised into three main groups related to: (1) tectonic processes; (2) slope instability processes; and (3) bottom currents. The main potential hazards are a consequence of seismicity and landslides, which can also trigger destructive tsunamis. The Alboran Sea is an excellent area in which to demonstrate the association of geoscience and habitats, leading to a better understanding of the total ecosystem.

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Chapter 7
The Biogeochemical Context of Marine Planktonic Ecosystems

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7.1 Introduction

7.1.1 Biogeochemistry and Phytoplankton Productivity of the Alboran Sea

Although the Mediterranean Sea is considered in general an oligotrophic basin (Béthoux et al. 2002; D'Ortenzio and Ribera d'Alcalà 2009), it is able to sustain moderate levels of primary production. This fact is known as the "Mediterranean paradox" (Sournia 1973; Estrada 1996) which seems to be related to high levels of regenerated production and the existence of different fertilization mechanisms that inject nutrients into the euphotic layer. In fact, there are large differences in productivity between the different regions in the Mediterranean Sea, so that some areas are mesotrophic rather than oligotrophic (Stambler 2014). In these areas, primary production is considerably higher than the average for the whole Mediterranean basin (Bosc et al. 2004). In particular, the Alboran Sea is considered the most productive basin of the Mediterranean Sea (Bosc et al. 2004; Lazzari et al. 2012).

However, the Alboran Sea presents a high spatio-temporal variability in its hydrological and biogeochemical features as well as in its primary production. The enhanced productivity of the Alboran Sea, in comparison with other regions within

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the Mediterranean, is due to different periodic and recurrent fertilization mechanisms operating in the Strait of Gibraltar and also within the Alboran Sea, which are addressed and discussed in this chapter. These fertilization processes lead to the injection of new nutrients from subsurface waters into the euphotic layer supporting enhanced phytoplankton biomass and primary production, particularly in the North-western (NW) Alboran Sea (Minas et al. 1991; Garcia-Gorriz and Carr 2001; Bosc et al. 2004; Reul et al. 2005; Macías et al. 2007). However, the biogeochemical signatures of the upwelled waters at the Strait of Gibraltar and its proximities, and also those of Atlantic waters masses incursions, are progressively lost during the progress of these waters through the Alboran Sea. As the distance to the Strait increases the upper waters of the Alboran Sea become more oligotrophic (Bosc et al. 2004) due to the uptake of nutrients by phytoplankton and also to a lower number of fertilization mechanisms and to a higher variability in the eastern sector (Ramírez 2007; Renault et al. 2012; Oguz et al. 2014).

This chapter reviews the biogeochemical features of the different water masses found in the Alboran Sea, the different fertilization mechanisms (from upwelling events to incursions of nutrient-rich North Atlantic Deep Water NACW) which promote the injection of nutrient into the photic layer. The chapter also examines the nutrient dynamics in this basin and the potential limitation of phytoplankton by nutrients, as evidenced from the molar nitrate:phosphate (N:P) and nitrate:silicate (N:Si) ratios, and discusses the role of phytoplankton uptake in regulating nutrient concentrations and molar ratios in this basin. In addition, it also addresses the distribution patterns of chlorophyll-a (Chl-a) and primary production (PP) in relation to the hydrology and biogeochemical fields. The last section of this chapter analyses the effects of climate change and ocean acidification on the biogeochemistry and primary production in the Mediterranean and the Alboran Sea.

The average vertical profiles (annual climatologies) of nutrients and dissolved oxygen, as well as the average seasonal vertical profiles (seasonal climatologies) of Chl-a in the Alboran Sea (Manca et al. 2004) were plotted using data provided by OGS Istituto Nazionale di Oceanografia e Geofisica Sperimentale. Source: Data and metadata are provided by the Italian National Oceanographic Data Center of the OGS Istituto Nazionale di Oceanografia e Geofisica Sperimentale (NODC/OGS), acting within the International Oceanographic Data Exchange System of the UNESCO Intergovernmental Oceanographic Commission (IOC) since 27/6/2002.

In order to illustrate the singularities of the Alboran Sea, in comparison with the rest of the Mediterranean Sea, as well as to show the high spatial variability of nitrate concentration, N:P molar ratio, Chl-a and PP in this basin, average integrated values for these variables have been obtained. The data were "Generated using E.U. Copernicus Marine Service Information." Monthly mean data of Mediterranean Sea Biogeochemistry Reanalysis (Teruzzi et al. 2016) (Product: MEDSEA_REANALYSIS_BIO_006_008) (https://doi.org/10.25423/MEDSEA_REANALYSIS_BIO_006_008) were downloaded from the E.U. Copernicus Marine Environment Monitoring Service website (http://marine.copernicus.eu/services-portfolio/access-to-products) and processed to get the average integrated values (0–100 m) over the period 1999–2016 for those variables in the Mediterranean and the Alboran Sea. The processed data correspond to the month of May, one of the most productive months in the Alboran Sea (Lazzari et al. 2012).

On the other hand, the data on the nutrient distribution at 50 m depth in the Alboran Sea during the IctioAlboran 0793 survey (July 1993) were provided by Dr. Juan Pérez de Rubín (Instituto Español de Oceanografía, IEO).

7.2 Nutrients Dynamics: Coupling with Physical Processes

7.2.1 Nutrients and Water Masses in the Alboran Sea

Surface layers in the Alboran Sea are occupied by Surface Atlantic Water (SAW), known also as Modified Surface Atlantic Water (MSAW), which has its origin in the Gulf of Cadiz (see Chap. 5 of this book). Many studies have reported that the SAW entering the Alboran Sea is nutrient poor or even nutrient depleted (Minas et al. 1991; Béthoux et al. 1992; Turley 1999) due to the consumption by phytoplankton in the Gulf of Cadiz and the Strait of Gibraltar. However, the question of whether the Atlantic water entering into the Alboran Sea is depleted or not in nutrients has been matter of debate during the last decades (Béthoux et al. 1992; Dafner et al. 2003; Huertas et al. 2012). Much of these discrepancies could be due to the fact that in many studies nutrient concentrations have been reported for the Atlantic inflow entering into the Alboran Sea rather than for the SAW. At the Strait of Gibraltar, and due to intense mixing processes, the upwelling of subsurface rich nutrient Mediterranean waters into the Atlantic surface layer takes place. Other processes like incursions of NACW also occur (see below), thereby the nutrient load in the Atlantic inflow largely depends on these processes and also on the biological activity (Gómez et al. 2000). Moreover, mixing at the Strait is largely controlled by different physical factors (see Sect. 7.2.2). Therefore, nutrient levels in the Atlantic inflow can be rather variable. Nevertheless, the nutrient signatures of the SAW at the Strait have been obtained from the analysis of water masses (Minas et al. 1991; Gómez et al. 2000), where SAW is characterized by nitrate <2 μM, phosphate <0.01 μM, and silicate <1 μM (Gómez et al. 2000).

NACW has been detected by several studies in the upper layer of the Strait of Gibraltar and also in the Alboran Sea (Gascard and Richez 1985; Minas et al. 1991; Gómez et al. 2000; Ramírez et al. 2005; Ramírez-Romero et al. 2014). The entrance of this water mass into the Alboran Sea is strongly modulated by the tidal cycles at the Strait (see Sect. 7.2.2). NACW is a water mass rich in nutrients, with nitrate ~5–7 μM, phosphate ~0.35–0.45 μM, and silicate ~2–3 μM (Gómez et al. 2000). Although other studies have found lower phosphate concentrations (0.09 μM) associated to this water mass at the Strait of Gibraltar (Ramírez-Romero et al. 2014).

On the other hand, the intermediate and deep water masses found in the Alboran Sea are Winter Intermediate Water (WIW), Levantine Intermediate Water (LIW), and Western Mediterranean Deep Water (WMDW) (see Chap. 5 of this book). These water masses are characterized by different biogeochemical signatures due to their different origins and different residence times (Minas et al. 1991). During their progress from the Western Mediterranean towards the Alboran Sea, the biogeochemical properties of the intermediate and deep Mediterranean water masses are progressively modified by mixing with adjacent water masses, as well as by the accumulation of organic matter from the euphotic zone (by vertical flux or lateral advection) and bacterial activity (Minas et al. 1991).

The WIW is formed in winter in the NW Mediterranean (Salat and Font 1987; Millot 1999) and flows along the continental slope of the Iberian Peninsula (Vargas-Yáñez et al. 2012), reaching the Balearic Sea by spring (Pinot and Ganachaud 1999; Pinot et al. 2002) and the Alboran Sea by summer or beginning of autumn (Font 1987). Its recent origin, in comparison with other intermediate water masses, is reflected in its biogeochemical features. In the NW Mediterranean, its oxygen content is relatively high (Minas et al. 1991; Balbín et al. 2014) but it decreases progressively during its transit towards the Alboran Sea. In the Alboran Sea, there are very few data on the biogeochemical features of this water mass. Ramírez (2007) found a relative maximum of dissolved oxygen and a relative minimum of nutrient concentrations at 200 m depth, linked to a temperature minimum (θ) ranging from 13.09 °C to 13.20 °C at stations located at the border of the continental slope, where according to Parrilla and Kinder (1987) the WIW flows towards the Strait of Gibraltar. The presence of a temperature (θ) minimum was detected in summer and autumn at salinities ranging from ~37.90 to 38.30 (Ramírez 2007), while it was much less defined or even absent in winter and spring. At the θ minimum the dissolved oxygen concentration was on average 202.88 μM, while the mean nitrate, phosphate, and silicate concentrations were 6.55 μM, 0.25 μM, 3.75 μM, respectively. All these findings suggest the presence of WIW, but θ minimum values were higher than the typical θ minimum associated to the WIW in the Alboran Sea (Parrilla and Kinder 1987), indicating a warmer WIW. This could be due to the high variability observed in the formation of this water mass and to the variability of its circulation in the Western Mediterranean (Pinot et al. 2002; Vargas-Yáñez et al. 2012), which affect the mixing with other water masses.

The most important intermediate water mass in the Alboran Sea is the LIW (Parrilla et al. 1986; Parrilla and Kinder 1987; Minas et al. 1991). After reaching the NW Mediterranean, this water mass flows towards the Alboran Sea along the continental slope below the WIW (Font 1987; Millot 1999). It has been suggested that due to this seasonality the greater volume of LIW arrives to the Alboran Sea by summer-early autumn (Font 1987). The thermohaline and geochemical signatures of LIW remain clearly distinctive when they enter into the Alboran Sea. Nevertheless, during its journey towards the Alboran Sea, the LIW mixes with WIW and Mediterranean deep waters (Parrilla and Kinder 1987) modifying its levels of dissolved oxygen. These levels are also modified by microbial respiration in the core of LIW (Minas et al. 1991). Thus when the LIW arrives to the Alboran Sea it presents lower dissolved oxygen levels and higher nutrients concentrations than in the NW Mediterranean (Minas et al. 1991). Averaged dissolved oxygen values in the LIW for the whole Alboran Sea have been estimated to be 4.21 $\mathrm{ml \cdot l^{-1}}$ (Manca et al. 2004), although the lowest values are found in the Western Alboran basin (Minas et al.

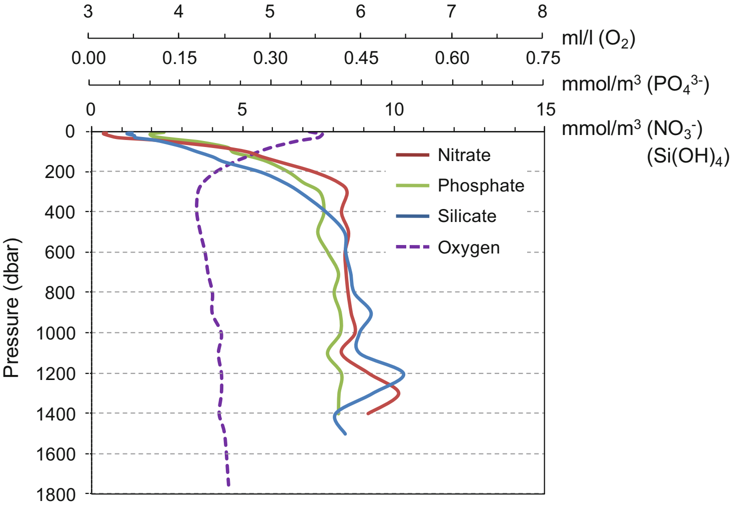


Fig. 7.1 Average vertical profiles (annual climatologies) of inorganic nutrients and dissolved oxygen in the Alboran Sea (Manca et al. 2004). Source: Data and metadata are provided by the Italian National Oceanographic Data Center of the OGS Istituto Nazionale di Oceanografia e Geofisica Sperimentale (NODC/OGS), acting within the International Oceanographic Data Exchange System of the UNESCO Intergovernmental Oceanographic Commission (IOC) since 27/6/2002

1991; Balbín et al. 2014; García-Martínez et al. 2019), with values ranging from ~3.2 to 3.9 ml·l^{-1} (Balbín et al. 2014; García-Martínez et al. 2019). Manca et al. (2004) reported averaged nutrient values in the LIW layer for the whole Alboran basin, with concentrations of nitrate 8.49 μM, phosphate 0.37 μM, and silicate 8.36 μM. Other studies have reported a maximum of nitrate and phosphate associated to the oxygen minimum in the Northern Alboran Sea (García-Martínez et al. 2019), which has been detected at depths ~300 m and 500 m in the Western and the Eastern Alboran Sea, respectively, coinciding with the depth level of the LIW. The average concentrations at the nitrate maximum range from ~9 μM to 11 μM, with lower values in autumn and higher in summer associated to the LIW in this sector of the Alboran (García-Martínez et al. 2019). However, former studies (Packard et al. 1988; Minas et al. 1991) did not found a nutrient maximum associated to the salinity maxima of the LIW (at ~400 m depth) in the Western Alboran Sea. The average vertical profiles for nitrate, phosphate, silicate, and dissolved oxygen for the Alboran Sea (annual climatologies) are shown in Fig. 7.1.

Below the LIW layer, denser less saline, and colder WMDW is found occupying the deepest part of the Alboran Sea basin (Parrilla and Kinder 1987; Minas et al. 1991; Manca et al. 2004). The WMDW is formed in winter in the Gulf of Lions (Millot 1999) and flows towards the Alboran Sea (see Chap. 5 of this book). Due to its recent origin, the WMDW is characterized by higher dissolved oxygen levels than the LIW (Minas et al. 1991). Thus in the NW Mediterranean Sea dissolved oxygen concentrations of this deep water mass are ~4.6–4.7 ml·l^{-1} (Minas et al. 1991).

According to its recent origin, the WMDW should also have lower nutrient concentrations than intermediate waters. In accordance Béthoux et al. (1998) reported a weak maximum for nitrate and phosphate in the Western Mediterranean associated to intermediate waters, with averaged salinity $\geq$38.492, and slightly lower nitrate and phosphate concentrations in deep waters. Similar profiles have been reported by other authors in the NW Mediterranean (e.g., Karafistan et al. 2002). In contrast silicate concentrations found in deep Mediterranean waters were slightly higher compared to intermediate waters, which has been attributed to the slower remineralization rates of silicate relative to nitrate and phosphate (Béthoux et al. 1998). However other studies have found that nutrient concentrations associated to deep Mediterranean waters in the NW Mediterranean, as well as in the Alboran Sea, are slightly higher than the concentrations found in the LIW (Manca et al. 2004). These abnormally high nutrient concentrations in the NW Mediterranean have been attributed to an increase of nutrient inputs from terrestrial and atmospheric sources (Manca et al. 2004). During its transit from the Gulf Lions towards the Alboran Sea the WMDW loses part of its biogeochemical signatures. In the Alboran Sea, the average dissolved oxygen concentration associated to this water mass is 4.50 $\text{ml}\cdot\text{l}^{-1}$ (Manca et al. 2004). This value is similar to values reported in earlier studies (Minas et al. 1991) in the Western Alboran Sea. The average nitrate and phosphate concentrations in the WMDW for the Alboran basin have been estimated to be 9.13 μM and 0.41 μM respectively (Manca et al. 2004), while the average silicate concentration associated to WMDW in the Alboran Sea was 8.38 μM (Manca et al. 2004) (i.e., similar to the value found by these authors for the LIW in this basin). In the Western Alboran Sea Minas et al. (1991) detected the higher silicate concentrations in the WMDW, with values ~10 μM on the African continental slope, due to the lifting of this deep water mass along the southern continental slope, while nitrate in deep waters was uniform with values ~9.0 μM.

7.2.2 Fertilization Mechanisms: Sources of New Nutrients to the Photic Layer

The most productive areas in the Alboran Sea are found in its NW sector, in particular on the Iberian continental margin between Europa Point and Marbella as well as in the proximities of the Strait of Gibraltar and the northern part of the Western Anticyclonic Gyre (WAG) (Minas et al. 1991; Baldacci et al. 2001; Reul et al. 2005). The enhanced productivity in this area, which is clearly distinguishable from satellite images (Garcia-Gorriz and Carr 1999, 2001), is caused by different fertilization mechanisms that induce the upwelling of colder subsurface nutrient-rich waters and promote phytoplankton blooms (Minas et al. 1991; Sarhan et al. 2000; Reul et al. 2005; Ramírez et al. 2005). The presence of cold surface waters in this area is almost permanent (Renault et al. 2012) and is favored by the bottom topography of the continental margin in the NW Alboran Sea, where the existence of submarine canyons could play a role in the exchange of waters between the continental shelf and deep waters (Parrilla et al. 1986; Lafuente et al. 1999; Sarhan et al. 2000). On the other hand, in the Alboran Sea, the intermediate Mediterranean waters flow following the geometry of the north continental shelf, banking against the slope (Parrilla et al. 1986) which facilitates its upwelling.

By far one of the most important fertilization mechanisms, due to its effect along all the northern continental shelf of the Alboran Sea (from Europa Point to further East of Cape Gata), is the upwelling induced by westerlies (Sarhan et al. 2000; Baldacci et al. 2001; Garcia-Gorriz and Carr 1999, 2001; Bakun and Agostini 2001; Mercado et al. 2012). Wind-driven upwelling is particularly important in coastal and continental shelf waters (Sarhan et al. 2000). This type of upwelling is more intense in spring coinciding with stronger westerlies (Garcia-Gorriz and Carr 1999, 2001; Ramírez et al. 2005). Thus the wind regime has important consequences on the Chl-a variability throughout the year. In the NW Alboran Sea, it has been reported that on average 70% of nitrate and 83% of silicate temporal variability (Ramírez 2007) was explained by the average seasonal zonal wind (E-W) component and seawater temperature, over 12 seasonal cruises, using multiple regression model. Under certain conditions, the upwelling can be attenuated or even inhibited by different factors. Thus the presence of the Atlantic jet close to the Spanish coast may hamper the upwelling of subsurface waters, caused by Ekman pumping due to westerlies (Sarhan et al. 2000). On the African continental shelf, westerlies induce downwelling of poor nutrient surface waters hampering phytoplankton growth (Bakun and Agostini 2001). On the other hand, easterlies cause convergence and downwelling of surface waters along the Spanish coast, while they produce upwelling along the African coast. During summer and autumn, when easterlies dominate the wind regime, downwelling occurs along the Spanish coast and upwelling takes place along the African coast (Bakun and Agostini 2001; Stanichny et al. 2005). The presence of a marked thermocline from July to September can also hamper the upwelling (Garcia-Gorriz and Carr 2001). Nevertheless, upwelling phenomena can occur even in summer under strong favorable winds, leading to occasional blooms (Ramírez 2007).

In addition to wind-driven upwelling, in this sector of the Alboran Sea, the path of Atlantic jet leads to the formation of an intense geostrophic front located at the northernmost limit of the WAG (Minas et al. 1991; Vargas-Yañez et al. 2002; Garcia-Gorriz and Carr 2001; Vélez-Belchí et al. 2005). The instabilities and vertical velocities associated to the agestrophic cross-fontal circulation promote the continuous vertical supply of nutrients to the photic zone (Tintoré et al. 1991; Gil and Gomis 1994; Sarhan et al. 2000). Another fertilization mechanism is linked to the variability of the Atlantic jet in the Western Alboran Sea. The position of the jet show fluctuations over time caused by variations in both the inflow of Atlantic water and the entrance angle of the Atlantic jet into the Alboran Sea (Sarhan et al. 2000; Vargas-Yañez et al. 2002). Thus the jet can shift southwards several km in short time periods (2–3 days) (Sarhan et al. 2000; Reul et al. 2005) leading to the upwelling of subsurface waters north of the jet. This upwelling mechanism seems only to occur during the southward shift of the jet, and its intensity is low compared to upwelling by westerlies (Sarhan et al. 2000).

Lateral advection of surface nutrient-rich waters by the main Atlantic current has also been described as an important fertilization mechanism in the Western Alboran Sea, as well as for other areas located at the center of the basin (Minas et al. 1991: Garcia-Gorriz and Carr 2001; Ruiz et al. 2001). These surface nutrients rich waters have their origin in upwelling events at the Strait of Gibraltar as well as in coastal upwelling occurring between Europa Point and Marbella (Minas et al. 1991; Garcia-Gorriz and Carr 2001; Baldacci et al. 2001; Oguz et al. 2014). Other studies have also pointed to the advection of phytoplankton rich waters from the Gulf of Cadiz towards the Alboran Sea as a source of phytoplankton biomass (Navarro et al. 2011; Ramírez-Romero et al. 2014). In the Alboran Sea, the surface waters are advected further east by the Atlantic jet following the main circulation pattern (Baldacci et al. 2001; Ruiz et al. 2001; Garcia-Gorriz and Carr 2001; Sánchez-Vidal et al. 2004), being an important source of nutrients and phytoplankton to the central and eastern part of the basin.

The upwelling Mediterranean waters at the Strait of Gibraltar is caused by different processes (Minas et al. 1991; Gómez et al. 2000; Echevarría et al. 2002) involving intense mixing and entrainment between nutrient-rich Mediterranean waters and Atlantic waters. These mixing processes are governed by the exchange of water masses at the Strait, which largely depend on the tidal cycles and the bottom topography (Echevarría et al. 2002). Dafner et al. (2003) calculated that ~16% of Mediterranean water outflow entrains with the Atlantic inflow and recirculates back into the Alboran Sea. Other studies have estimated that the mixing process during spring tides, alongside with injection of waters from coastal areas in the Gulf of Cadiz, would account for 31% of the total nitrate supply to the Alboran Sea through the Strait, while upwelling due to internal waves would account for 74% of the total entry of phosphate in the Alboran Sea (Ramírez-Romero et al. 2014). The upwelled waters at the Strait are advected towards the Alboran Sea by the Atlantic inflow. As indicated above, internal waves generated at the Camarinal Sill play a major role in the mixing processes at the Strait particularly during spring tides (Gascard and Richez 1985; Echevarría et al. 2002; Vázquez et al. 2008). In addition, it has been suggested that the trapping of internal waves at the Camarinal Sill could increase the mixing (Bruno et al. 2002). Once the train of waves enters into the Alboran Sea their path produces the intermittent lifting of subsurface waters (Vázquez et al. 2009; Van Haren 2014) leading to the pulsed injection of nutrients into the upper layer.

The nutrient enrichment of surface waters in the Western Alboran Sea is also caused by incursions of nutrient-rich NACW in the Atlantic inflow at the Strait of Gibraltar (Minas et al. 1991; Gómez et al. 2000, 2001; Ramírez-Romero et al. 2014), which are controlled by tidal cycles. The incursions of large amounts of NACW occur at spring tides, while at neap tides the incursions of NACW are discontinuous (Gómez et al. 2004; Ramírez-Romero et al. 2014). Once these incursions of NACW have reached the upper layers they are advected by the Atlantic inflow into the Alboran Sea and mixed with the surface waters (Minas et al. 1991; Echevarría et al. 2002), contributing to the fertilization of the euphotic layer in the western sector of this basin. During neap tides and in absence of internal waves the Atlantic inflow accounts for 69% of nitrate inputs to the Mediterranean from the Atlantic, mostly due to the contribution of NACW (Ramírez-Romero et al. 2014).

The presence of submesoscale cyclonic eddies in the North Alboran Sea (from Estepona to Cape Gata) has also been reported by a number of papers as a relevant source of new nutrients to the photic layer (Sarhan et al. 2000; Reul et al. 2005; Ramírez et al. 2005; García-Martínez et al. 2019). These eddies are formed from filaments detached from the main Atlantic current and they can persist for several days (Parrilla and Kinder 1987; Ramírez et al. 2005; Reul et al. 2005; García-Martínez et al. 2019). One of the most recurrent cyclonic cell is found off Estepona (e.g., Parrilla and Kinder 1987; Perkins et al. 1990; Cano and García Lafuente 1991; Baldacci et al. 2001) whose formation seems to be linked to the southward shift of the jet (Sarhan et al. 2000).

In the eastern sector of the Alboran Sea, the ageostrophic cross-frontal circulation associated to the presence of an almost permanent geostrophic front, caused by the path of the Atlantic jet, is one of the main fertilization mechanisms in this eastern sector. The front is known as the “Almeria-Oran front” and it separates the less saline and colder SAW in the Alboran basin from saltier and warmer Surface Mediterranean Waters (SMW) found in the Algero-Balear Basin (Tintoré et al. 1991; Prieur and Sournia 1994). The front exhibits a high variability linked to the high mesoscale instabilities in the general circulation pattern in the eastern basin compared to the western one (Millot 1999; Prieur and Sournia 1994; Renault et al. 2012). When the Eastern Anticyclonic Gyre (EAG) is well developed, usually in summer and autumn, the front is found at the easternmost boundary of this gyre (Prieur and Sournia 1994). However in winter the EAG is usually absent (Viúdez et al. 1996; Vargas-Yañez et al. 2002; Snaith et al. 2003) and the Atlantic jet shifts southwards and flows closer to the African coast (Claustre et al. 1994; Prieur and Sournia 1994; Renault et al. 2012).

7.2.3 *Distribution Patterns of Inorganic Nutrients (N, P, and Si)*

The dynamics of inorganic nutrients in the Alboran Sea presents a high spatial and temporal variability as a result of the high hydrodynamic variability and to the intense biological productivity in this basin. As a result, steeped nutrient gradients are observed both in the vertical and horizontal distribution (Figs. 7.1 and 7.2). The lowest nutrient concentrations in the Alboran Sea are usually found and the center of the WAG and the EAG (Fig. 7.2). Both gyres are downwelling zones where SAW, impoverished in nutrient due to the previous consumption by phytoplankton, converges, and sinks (Parrilla and Kinder 1987). Consequently, nutrient concentrations in the Alboran Sea central areas are particularly low during the stratification period, being frequently <0.25 μM for nitrate, <0.06 μM for phosphate, and <0.70 μM for

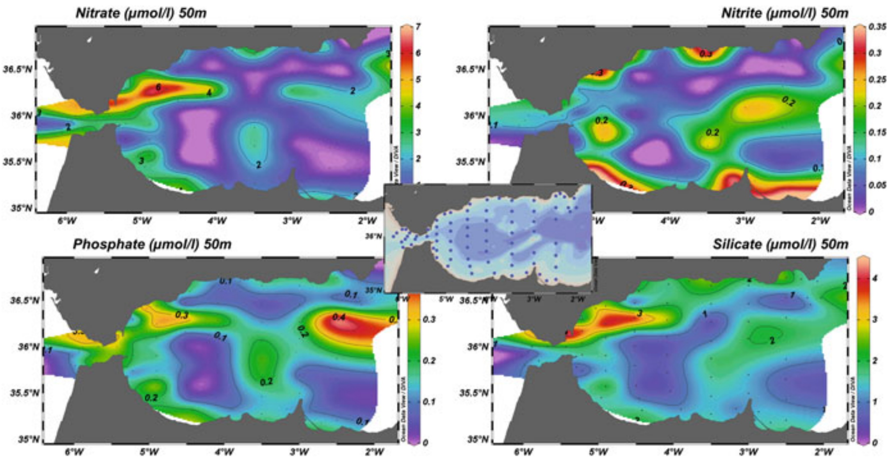


Fig. 7.2 Nitrate, nitrite, phosphate, and silicate concentration (μmol·l^{-1}) at 50 m depth during IctioAlboran93 survey conducted in July 1993 by IEO. The stations are shown in the map at the center of the figure [Source: Figure based on data provided by Dr. Juan Pérez de Rubín (IEO)]

silicate (Gil and Gomis 1994; Rubín et al. 1992, 1997; Cano et al. 1997). Other studies have reported also low concentrations in areas of the continental margin of the NW Alboran Sea during the stratification period, with nitrate and sometimes phosphate below their detection limit above the thermocline, while silicate concentrations remained above 0.8 μM (Ramírez et al. 2005; Ramírez 2007). Likewise, very low nutrient concentrations have also been found usually in adjacent areas north and east of the EAG due to the presence of warmer, saltier, and nutrient-poor MSW coming from the Algero-Balear basin. In the Mediterranean waters adjacent to the Almeria-Oran front phosphate concentrations in the upper 20 m are frequently below the detection limit (Jacquet et al. 2002; Leblanc et al. 2004), while nitrate and silicate are low but detectable with the lower concentrations around 0.03–0.06 μM and 0.8 μM, respectively (Leblanc et al. 2004). In contrast, the highest nutrient concentrations in the Alboran Sea are usually found at the vicinities of the Strait of Gibraltar and along the NW sector of the Spanish continental margin, where intense upwelling induced by different mechanisms takes place very frequently throughout the year (Minas et al. 1991; Baldacci et al. 2001; Renault et al. 2012). Thus, at the eastern side of the Strait of Gibraltar nitrate concentrations as high as ~5.0 μM have been found in the Atlantic waters, while phosphate concentration can reach values around ~0.30 μM and silicate up to ~3.0 μM (Gómez et al. 2000; Dafner et al. 2003; Huertas et al. 2012). Nevertheless, the variability at the Strait is very high and other authors have reported lower concentrations (e.g., Gómez et al. 2001; Echevarría et al. 2002; Ramírez-Romero et al. 2014). The variability of nutrients in this area depends on the tidal cycle, water exchange, stratification of the water column, the occurrence of mixing events, the incursions of NACW, and the wind forcing (Gómez et al. 2000; Echevarría et al. 2002). On the continental margin of the NW Alboran Sea, the highest nutrient concentrations are detected during intense coastal upwelling events (Gil and Gomis 1994; Prieto et al. 1999; Ramírez et al. 2005; Reul et al. 2005; Ramírez 2007; Macías et al. 2008; Mercado et al. 2012). Wind-driven upwelling events normally lead to nitrate concentrations around 2.0–3.0 μM in the upper 20 m of the water column on the continental margin, while phosphate and silicate concentrations are frequently around 0.15–0.20 μM and 1.5–2.0 μM, respectively (Ramírez et al. 2005; Reul et al. 2005; Mercado et al. 2014). Similar nutrient concentrations have also been found at the geostrophic front associated to the path of Atlantic jet in this area (Morán and Estrada 2001; Arin et al. 2002; Reul et al. 2005; Mercado et al. 2014). Wind-driven upwelling events frequently take place between November-March (Garcia-Gorriz and Carr 2001), but they may sporadically occur throughout all year, thereby similarly high nutrient concentrations in the upper layers have been occasionally reported in the NW Alboran Sea during late spring (June) and the stratification period (e.g., Rubín et al. 1999; Prieto et al. 1999; Ramírez 2007; Lazzari et al. 2012). Nevertheless, during the non-bloom period, which extends from May to September (Garcia-Gorriz and Carr 2001), coastal upwellings are less frequent and nutrient concentrations at the surface tend to decline. However, the fertilizing effect associated to the front persists even during the stratification period (Garcia-Gorriz and Carr 2001). Thus nitrate concentrations in the frontal area during the stratification period are >2.0 μM, while north and south of the jet they are <0.5 μM (Reul et al. 2005).

As a consequence of the contrasting oceanographic conditions between coastal and offshore waters, sharp costal-offshore nutrient gradients are frequently observed in the NW Alboran Sea (e.g., Gil and Gomis 1994; Rubín et al. 1997, 1999; Prieto et al. 1999; Garcia-Gorriz and Carr 2001; Mercado et al. 2014) (Fig. 7.2). In addition in the continental margin around 4.5° W there is usually a marked difference between the waters under the influence of the front associated to the Atlantic jet and the waters on the continental margin located north-northeast of the jet (Fig. 7.2), out of the influence of the jet. Thus, the general circulation pattern explains the relatively lower nutrient concentrations found in areas of the northern continental margin of the Alboran Sea located northeast of the jet, as observed in Fig. 7.2, in comparison with areas under the direct influence of the front associated to the Atlantic jet (Gil and Gomis 1994; Ramírez 2007).

Nevertheless, it has to be highlighted that the presence of circulation cells between Malaga and Motril is relatively frequent, with alternation of upwelling and downwelling (Gil and Gomis 1994). Thus, relatively high nutrient concentrations on the continental shelf in the area off Cape Sacatrif (close to Motril) are frequently found (Gil and Gomis 1994; García-Martínez et al. 2019), due to the recurrence in this area of a cyclonic eddy (Parrilla and Kinder 1987; Baldacci et al. 2001). On the other hand, several studies have reported an eastward decline of nutrients in the Alboran Sea (e.g., Denis-Karafistan et al. 1998; Karafistan et al. 2002). On the north continental margin, the lower concentrations have been observed in Cape Gata (García-Martínez et al. 2019). Nevertheless, nutrients in the frontal area of the Almería-Oran front are high compared to adjacent waters

(Fig. 7.2) (Bianchi et al. 1994; Claustre et al. 1994; Leblanc et al. 2004). Gil and Gomis (1994) detected very high nitrate concentration >6.5 μM at 50 m in offshore waters off the Almeria Bay, associated to a strong salinity gradient. Lower nitrate concentrations were found by Bianchi et al. (1994) at 50 m in the frontal area (~3 μM nitrate), while according to Leblanc et al. (2004) nitrate was ~1–2 μM at 50 m depth in the Almeria-Oran front area. Figure 7.3b shows the climatology of the depth-integrated nitrate concentration in the upper 100 m during the month of May (spring), one of the most productive months in the Alboran Sea (Lazzari et al. 2012). A marked north to south nitrate gradient in the Alboran Sea can be observed, with higher concentrations in the Northern Alboran coasts and the lower values observed in the Southern Alboran coasts (Fig. 7.3b). These marked differences are due to the convergence of nutrient-poor Atlantic waters in the southern part, while in the northern part the frequent upwellings lead to much higher concentrations.

In general, the vertical distribution of nutrients in the Alboran Sea follows a typical vertical pattern with low concentrations in surface waters and below a marked nutricline, that extends to depths around 250–300 m (Minas et al. 1991; Béthoux et al. 1992) (Fig. 7.1). The marked nutricline reflects the influence of Mediterranean waters below the nutrient-poor SAW layer (Minas et al. 1991). In the Western Alboran Sea, below the nutricline nitrate concentrations remains nearly constant (~9.0 μM) while phosphate concentration ranges between ~0.45 and 0.50 μM. In contrast, silicate concentration continues increasing more slowly below the nutricline, reaching its higher values (~10 μM) at the bottom of the basin in the Western Alboran Sea (Minas et al. 1991). However in areas close to the Strait of Gibraltar, where the presence of a oxygen extraminimum has been reported (Packard et al. 1988; Minas et al. 1991), the vertical profiles of nitrate and phosphate present a weak maximum at the lower limit of the nutricline (200–250 m), which is more conspicuous for nitrate (Minas et al. 1991). The maximum coincides with a dissolved oxygen extraminimum in the water column, where concentrations as low as 3.8 $\mathrm{ml \cdot l^{-1}}$ are reached (Packard et al. 1988; Minas et al. 1991). This extraminimum and the associated nitrate and phosphate maximum are the consequence of the intense export of organic matter from the nearby high productive areas in the NW Alboran Sea towards the center of the WAG, where the organic matter accumulates and sink promoting the growth of bacterial communities and the respiration of the accumulated organic matter, leading to the oxygen extraminimum and to the nutrient maxima (Minas et al. 1991).

At the center of the WAG and the EAG the subduction of SAW causes a pronounced deepening of the 37.5 isohaline, which is considered the interface between Atlantic and Mediterranean waters in this basin (Parrilla and Kinder 1987). As a result, a thick SAW layer (~150–200 m depth) is found at the center of both gyres (Lafuente et al. 1998; Leblanc et al. 2004). The downwelling of poor nutrient SAW at the center of both gyres is reflected in the nutricline, which reaches its deepest locations at the core of both anticyclonic gyres. Accordingly, the nitracline has been found at depths ranging from ~70 to 115 m at the center of the anticyclonic gyres (Leblanc et al. 2004; Morán and Estrada 2001; Mercado et al. 2014), and the phosphacline has been found a depths varying from ~ 50 to ~170 m

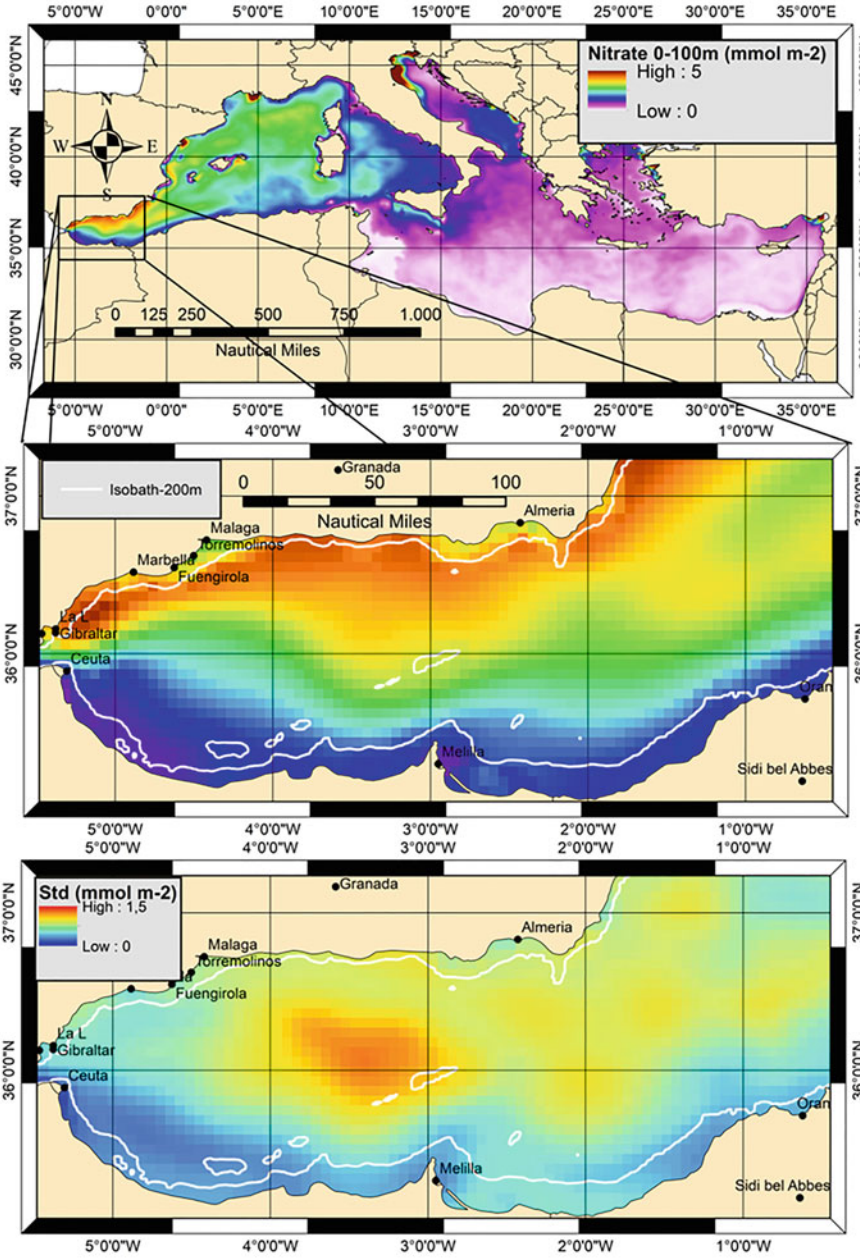


Fig. 7.3 Mean spring (May) depth-integrated (0–100 m) nitrate concentration (mmol·m^{-2}) over the period 1999–2016: (**a**) in the Mediterranean basin, (**b**) in the Alboran Sea and (**c**) standard deviation. Generated using E.U. Copernicus Marine Service Information. (Product: MEDSEA_REANALYSIS_BIO_006_008) (Teruzzi et al. 2016) (https://doi.org/10.25423/MEDSEA_REANALYSIS_BIO_006_008)

(Morán and Estrada 2001). As the distance to the center of the gyres increases the nutricline uplifts rapidly, becoming shallower in the frontal areas associated to the WAG and the EAG (Arin et al. 2002; Reul et al. 2005; Leblanc et al. 2004; Mercado et al. 2014), due to the cross-frontal ageostrophic currents associated to the frontal systems in the western and eastern Alboran basin (Tintore et al. 1988, 1991). In both frontal areas the nutricline is usually found at <15 m depth (Morán and Estrada 2001; Reul et al. 2005; Leblanc et al. 2004).

In the continental margin of the NW Alboran Sea, the nutricline is roughly found at similar depths for nitrate, phosphate, and silicate (Ramírez et al. 2005; Ramírez 2007) and it is notably shallower than in open waters of the Alboran Sea. The banking of intermediate Mediterranean waters, circulating close to the border of the continental shelf (Parrilla and Kinder 1987), and the remineralization process in the water column could have a major role in the development of a shallower nutricline in this sector. On the other hand, the nutricline in this area of the Alboran Sea shows seasonal variations, being generally weak in winter, probably due to the mixing in the water column and to the influence of low nutrient water masses at intermediate depths (Ramírez 2007). The nutricline becomes steeper during the course of the year as the water column stratification develops (Ramírez et al. 2005; Ramírez 2007). In general, the nutricline in the continental margin is well developed in summer and also in early autumn, when the vertical profiles of nitrate, phosphate, and silicate are characterized by a relative maximum located around 50–75 m (Ramírez et al. 2005; Ramírez 2007), while this nutrient maxima is absent in winter and spring. At those maxima nutrient concentrations reach values close to ~7.0 µM for nitrate, ~0.35–0.40 µM for phosphate and ~4.0 µM for silicate, coinciding with a relative minimum of dissolved oxygen (Ramírez 2007). These findings suggest the occurrence of intense remineralization processes in the water column at shallower depths on the continental margin compared to remineralization processes in deeper areas of the westernmost sector of the Alboran Sea (Minas et al. 1991). At 200–300 m depth nutrients also show a high variability (Ramírez 2007). Thus, on the continental margin at 300 m depth the average nutrient concentrations are about ~8.5–10.0 µM for nitrate, ~0.4–0.5 µM for phosphate, and ~5.0–6.5 µM for silicate (Ramírez 2007). Further offshore nitrate concentrations are higher, ~12 µM at 300 m depth (García-Martínez et al. 2019).

On the other hand the vertical distribution of nitrite in the Alboran Sea shows a conspicuous subsurface maximum (Bianchi et al. 1994; Ramírez et al. 2005; Ramírez 2007; García-Martínez et al. 2019). In the Alboran Sea the presence of nitrite maximum is frequently observed throughout the all year (Ramírez 2007; García-Martínez et al. 2019). The highest values are usually found during the stratification period, with an average nitrite concentration close to 0.3 µM (Ramírez et al. 2005; Ramírez 2007; García-Martínez et al. 2019). In the NW Alboran Sea this nitrite maximum is usually detected at depths ranging from 50 to 75 m (Fig. 7.2), frequently associated to the end of the nutricline (Ramírez et al. 2005; Ramírez 2007; García-Martínez et al. 2019). In the Almeria-Oran front area, the depth of the nitrite maximum have been found to range from ~40 to 110 m (Bianchi et al. 1994), with the highest concentrations (>0.5 µM) being found in the Atlantic waters adjacent to the front, while in the rest of the areas nitrite maximum values were around 0.2 μM (Bianchi et al. 1994). The nitrite maximum has been attributed to the oxidation of ammonium by nitrifying bacteria (Bianchi et al. 1994; Ramírez et al. 2005; Ramírez 2007), although the contribution from exudation by phytoplankton during the incomplete assimilatory reduction of nitrate cannot be disregarded (Ramírez 2007), since the nitrite maximum is frequently associated to the depth of the Chl-a maximum (Ramírez 2007; García-Martínez et al. 2019). However, it is noteworthy that the peak of nitrite is commonly found between the isohalines 37.0 and 37.5 (Ramírez et al. 2005; Ramírez 2007), which suggests that the Atlantic-Mediterranean interface could facilitate the accumulation of organic matter and the nitrification processes at this layer.

7.2.4 *Nutrient Molar Ratios: N or P Limitation?*

It is accepted as a general paradigm that the molar ratio of dissolved inorganic N and P in the global ocean follows the ratio N:P (16:1), which reflects the general elemental composition of marine plankton (Redfield et al. 1963). In addition, Brzezinski (1985) found that the N:Si ratio for diatoms growing under optimal conditions was ~1:1. Based on these findings, it is widely assumed that the optimal N:Si:P ratios for marine phytoplankton is 16:16:1. Deviations from this elemental ratio have been extensively used to infer the potential limitation of phytoplankton growth by nutrients (Howarth 1988; Nelson and Dortch 1996). Departures of the theoretical Redfield ratio have been reported by many studies in different marine regions, including the Mediterranean Sea which is characterized by the extremely high N:P ratios (Krom et al. 1991; Ribera d'Alcalà et al. 2003). Thus, the N:P ratio in the intermediate water layer in the Eastern Mediterranean usually varies from 24 to 51, while in the deep Mediterranean waters it ranges from 25 to 30 (Ribera d'Alcalà et al. 2003). In addition, the intermediate and deep Mediterranean waters are also characterized by low N:Si ratios compared to the ratio 1:1. The N:Si ratio is generally lower than 1:1 in the Eastern Mediterranean, with values around ~0.90 for intermediate waters and around ~0.5–0.6 for deep waters (Ribera d'Alcalà et al. 2003). In the surface waters of the Eastern Mediterranean, where PP is strongly limited by P (Thingstand et al. 2005), the N:P and N:Si ratios are very variable ranging between <5–60, and 1.7–18.2, respectively (Ribera d'Alcalà et al. 2003).

At difference from the Eastern Mediterranean, where P is the main limiting element for phytoplankton growth, the existing studies in the Alboran Sea and the Strait of Gibraltar suggest that N is the main limiting nutrient for phytoplankton growth in the surface layers (Dafner et al. 2003; Ramírez et al. 2005; Mercado et al. 2007, 2008; Ramírez 2007; Huertas et al. 2012). In the Gulf of Cadiz, the surface waters are characterized by N:P ratios <16:1, which suggests potential limitation of phytoplankton by N (Cravo et al. 2013). However, during its transits towards the Alboran Sea, the Atlantic waters coming from the Gulf of Cadiz are mixed and entrained with Mediterranean waters, while NACW cores are injected into the

Atlantic inflow. Due to these processes, as was well as to phytoplankton consumption (Gómez et al. 2000), the elemental composition of Atlantic waters is modified along the Strait of Gibraltar. Several studies have reported that the N:P molar ratio in the Atlantic inflow is close to the Redfield ratio (Béthoux et al. 2002), while other studies found that the N:P molar ratio in the Atlantic water inflow tends to be lower than the Redfield ratio (16:1). Accordingly, Huertas et al. (2012) observed that the N:P ratios in the Atlantic waters at the Strait of Gibraltar ranged from 11 to 12, while the mean N:P ratio for the Mediterranean outflow was 17.5. The lower N:P ratios in the Atlantic layer were attributed to a preferential consumption of nitrate by phytoplankton in the Strait of Gibraltar and adjacent waters. Nevertheless, nitrate and phosphate in the Atlantic water inflow were higher than the half-saturation constant for both nutrients, hence these waters cannot be considered nutrient depleted (Huertas et al. 2012). Other studies found that the N:P ratios in the Atlantic water layer were higher at the Mediterranean side of the Strait of Gibraltar (on average 23.6) than on the Atlantic side (on average 13.8) (Dafner et al. 2003).

For the N:Si ratio the opposite pattern has been observed, i.e., higher average values on the western side of the Strait (1.46) and lower values on the eastern side (0.81) (Dafner et al. 2003). These eastward changes across the Strait of Gibraltar in the N:P and N:Si ratios within the Atlantic water layer are accompanied by changes in the phytoplankton community, with dinoflagellates dominating in the Atlantic side and diatoms at the eastern side (Gómez et al. 2000; Dafner et al. 2003). Dafner et al. (2003) estimated that physical and biological processes at the Strait could account for ~16% and ~84%, respectively, of the changes observed in the N:Si:P ratio at the Strait of Gibraltar. These authors suggested that the increase of the N:Si ratio at the eastern side of Strait could be due to uptake of Si by diatoms, similarly, the low phosphate concentrations (<0.02 μM) at stations located at the eastern side of the Strait was also attributed an intense consumption of P by phytoplankton (Dafner et al. 2003). Nevertheless, the differences in the N:P values reported in the literature for the upper layers in the Strait of Gibraltar could also be due to the high spatio-temporal variability of hydrodynamic processes in this area (Gómez et al. 2000; Echevarría et al. 2002; Ramírez-Romero et al. 2014).

In the Alboran Sea, the nutrient molar ratios exhibit also high spatial and temporal variability in concordance with the high variability of nutrients. Figure 7.4 illustrates the spatial variability of the average integrated N:P ratio in the upper 100 m of the water column in the Mediterranean and the Alboran Sea in spring (May), reflecting a strong north-south gradient in the upper 100 m of the water column. However, as already mentioned different studies in the NW Alboran Sea have reported a deficiency of N relative to P in the surface layers when compared to the Redfield ratio (16:1) (Ramírez et al. 2005; Reul et al. 2005; Mercado et al. 2007). Thus, on the continental margin of NW Alboran Sea the average N:P ratio in the upper layer (0–20 m), i.e., at the depths where the Chl-a maximum is frequently found in this area (Ramírez et al. 2005; Ramírez 2007; García-Martínez et al. 2019), has been reported to range between ~2.0 and 14.0 (Ramírez et al. 2005; Ramírez 2007; Mercado et al. 2007). Reul et al. (2005) found N:P ratios lower than 16:1 above the nutricline and suggested a main role of N in regulating phytoplankton growth in

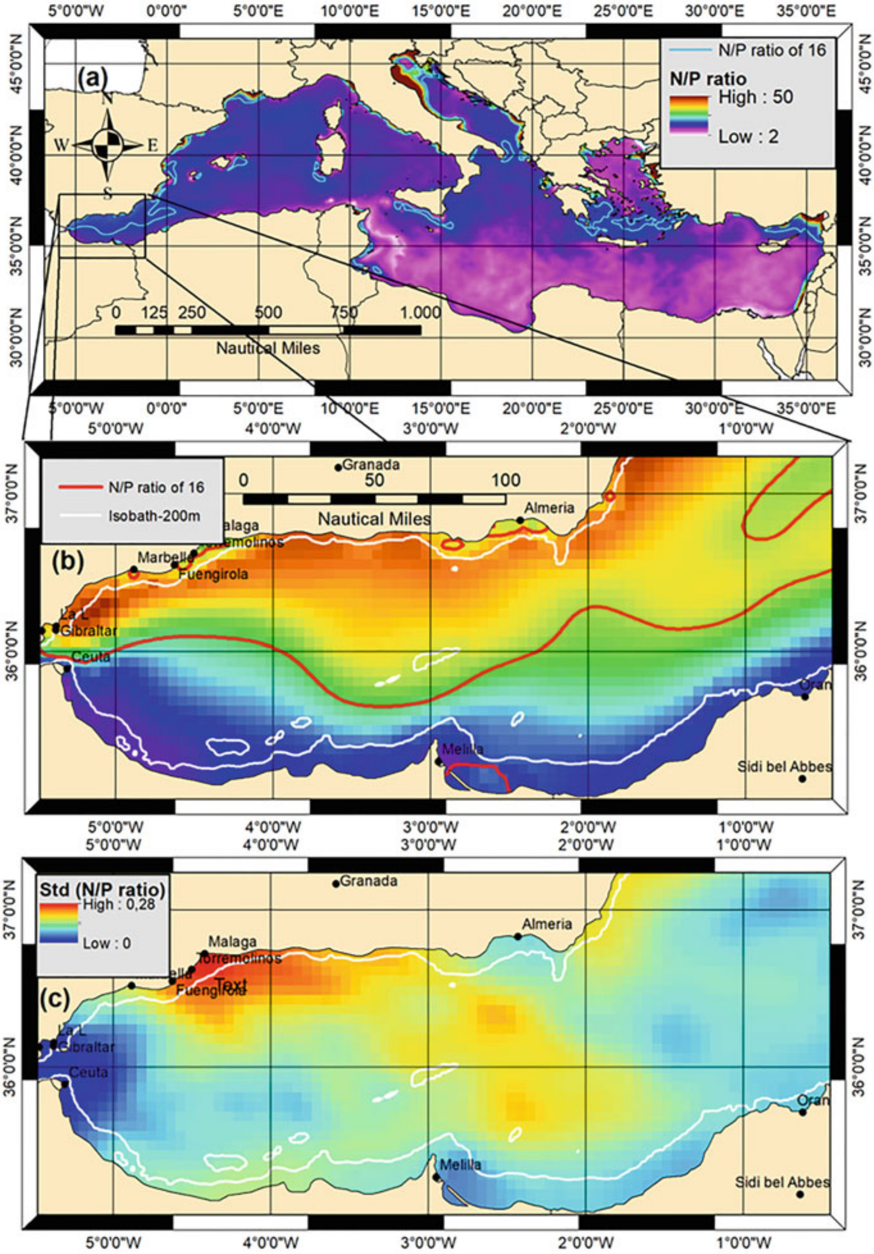


Fig. 7.4 Mean spring (May) depth-integrated (0–100 m) N:P ratio over the period 1999–2016: (**a**) in the Mediterranean basin, (**b**) in the Alboran Sea, and (**c**) standard deviation. Generated using E.U. Copernicus Marine Service Information. (Product: MEDSEA_REANALYSIS_BIO_006_008) (Teruzzi et al. 2016) (https://doi.org/10.25423/MEDSEA_REANALYSIS_BIO_006_008)

the NW Alboran Sea, while below the nutricline N:P ratios were usually above 16:1. Higher N:P ratios (integrated values over 0–75 m) have been found by García-Martínez et al. (2019) along the northern continental margin of the Alboran Sea, where the average N:P ratio ranged between 13 and 16, depending on the time of the year, with an overall mean value of 15. On the other hand, the N:Si ratio shows values < 1:1 in the upper 20 m of the water column (Ramírez et al. 2005; Ramírez 2007). Thus, the average values for the N:Si ratio in the upper layers (0–20 m) in the NW sector of the Alboran Sea vary between <0.5 and ~0.8, which are lower than the ratio 1:1 for diatom growing under optimal conditions (Brzezinski 1985). The lowest N:P an N:Si ratios are found during summer-early autumn, coinciding with an intense stratification of the water column, while the higher ratios are usually observed in winter, when the water column is mixed, as well as in those periods of the year when the incidence of wind-driven upwelling driven is higher, usually during spring (Ramírez et al. 2005; Ramírez 2007; Mercado et al. 2007; Macías et al. 2007).

These low N:P and N:Si ratios in the upper 20 m, together with the relatively low nitrate concentrations during most time of the year, suggests that N plays a major role limiting the phytoplankton growth in the upper layers of this basin during great part of the year (Reul et al. 2005; Ramírez et al. 2005; Ramírez 2007). In addition, nitrate concentrations found in upper layers of the Alboran Sea are generally lower than the half-saturation constant (Ks) (1 $\mu\text{mol}\cdot\text{l}^{-1}$) for nitrate uptake by phytoplankton in coastal zones (MacIsaac and Dugdale 1969). All these findings support the hypothesis that in the Alboran Sea nitrate is the main limiting nutrient for phytoplankton. Thus, nitrate would control phytoplankton growth in winter and autumn when the Chl-a maximum is usually located at 0–20 m depth (Ramírez et al. 2005; García-Martínez et al. 2019), and also in summer and autumn at those shallow depths. However, during the stratification period, the Chl-a maximum becomes deeper, particularly in areas out of the influence of upwellings, being usually found at 50–75 m depth, i.e., below the seasonal thermocline and close to the limit of the photic layer, coinciding with lower limit of the nutricline (Ramírez 2007). At those depths nutrients should not be a limiting factor for phytoplankton, however, limitation by light may occur (Mercado et al. 2008). The hypothesis of the N-limitation in the NW Alboran Sea has been contrasted by additional experiments (Ramírez 2007) and is also supported by other facts. Thus, based on a 3 years study Ramírez (2007) found that on average the seasonal mean of the zonal wind component and nitrate concentration jointly explained ~80% of the temporal variability of the average seasonal Chl-a values, while the relationship with phosphate was weak. Likewise, Reul et al. (2005) found a correlation between cell (>2 μm) abundance and nitrate, while they did not found a relationship with phosphate. Recent studies (Lazzari et al. 2016) also found that, at difference from the rest of the Mediterranean, N is the main limiting nutrient in the Alboran Sea.

During upwelling events, the N:P ratio in recent upwelled waters reaches values >16:1 in the surface layers (0–20 m) while nitrate concentrations are usually >3 μM, suggesting that there is no limitation by nitrate during the upwelling (Ramírez et al. 2005; Ramírez 2007). The intense upwellings in this area promote phytoplankton bloom and a notable increase of Chl-a which can reach values >5 μg·l^{-1} (Ramírez et al. 2005; Ramírez 2007). After cessation of westerlies a sharp decrease of nitrate has been reported, with concentrations dropping to undetectable levels at those stations with higher Chl-a concentration. This fast decline of nitrate is accompanied by a profound decrease of the N:P and N:Si ratios to values <2.0 and <0.2, respectively (Ramírez et al. 2005; Ramírez 2007). This suggests that nitrate is rapidly and preferentially removed by phytoplankton during intense phytoplankton blooms, causing a rapid decline of both ratios. At the Strait of Gibraltar and the NW Alboran Sea, a preferential uptake of nitrate has also been reported by other studies (Reul et al. 2005; Huertas et al. 2012). The fast and preferential uptake of nitrate would explain the low nitrate concentrations usually found in the upper layers (0–20 m) in this sector of the Alboran Sea during large part of the year, except when upwelling events take place. The limitation by nitrate in the upper layers (0–20 m) is intermittently overcome by the upwelling events in the continental margin (Ramírez et al. 2005; Reul et al. 2005) which lead to an temporal enhancement of the N:P ratio and nitrate concentrations in the surface waters (0–20 m). Paradoxically, the fast and preferential uptake of nitrate during the blooms would shift the system towards N-limitation in a few days after the cessation of the upwelling event (Ramírez et al. 2005; Ramírez 2007).

The notable increase of the N:P and N:Si ratios in the upper layers (0–20 m) observed during wind-driven upwelling events has its origin in the strong vertical gradients of the N:P and N:Si molar ratios (Ramírez et al. 2005; Reul et al. 2005). In this area the N:P and N:Si ratios show a sharp increase with depth down to 50–100 m. The vertical gradients of both molar ratios are more marked during the stratification period. In contrast, vertical gradients are usually less marked in winter and also during intense upwelling events (Ramírez et al. 2005; Ramírez 2007). At 50 m depth, the average N:P molar ratios vary between ~13 and 24, with most of the values above 15, while at 100 m depth the ratio increase to values ranging from ~19 to 26 (Ramírez 2007). Therefore, in the NW Alboran Sea subsurface waters become strongly deficient in phosphate at depths ~100 when compared to the Redfield ratio (16:1). At greater depths, the average N:P ratios continue increasing although more slowly, showing in general a weak maximum at 200 m where the average values ranged from ~20 to ~27. At 300 m depth, the N:P ratio decreases slightly with average ratios varying between ~19 and ~25 (Ramírez 2007), with most of these values above 21. It is noticeable that the N:P ratios found at 200 m in the NW Alboran Sea are higher than the values found in deep waters of the Algero-Balear and Tyrrhenian basin (Ribera d'Alcalà et al. 2003). The high N:P values at shallower depths in the NW Alboran Sea can be attributed to respiration processes (Minas et al. 1991; Ramírez et al. 2005, 2006) and to the upwelling of intermediate Mediterranean waters on the continental slope during their transit towards the Strait of Gibraltar.

Similarly, the N:Si ratio also shows remarkable vertical gradients in the NW Alboran Sea, reaching on average maximum values at depths ranging from 50 m to 100 m throughout the year (Ramírez et al. 2005; Ramírez 2007), with a peak frequently observed in summer at 50 m. At that depth, the water column becomes deficient in silicate in relation to nitrate, with the average N:Si ratio varying between

~1 and ~2. Below 100 m depth, the ratio tends to decrease slowly with depth. In the NW Alboran Sea, at 300 m depth the average N:Si values ranged from ~1.5 to ~1.8 (Ramírez et al. 2005; Ramírez 2007). Crombet et al. (2011) found integrated (0–100 m) N:Si ratios >1 at the Strait of Gibraltar and at the eastern border of the Alboran Sea, which is consistent with the Si deficiency detected at shallow depths in the NW Alboran Sea. The higher N:Si ratios found at ≥50 m in the NW Alboran Sea could be due to a fast remineralization of nitrate in the water column compared to the dissolution of biogenic silica, even if the latter is accelerated by bacterial colonization (Bidle and Azam 2001).

In the Almeria-Oran frontal area, Leblanc et al. (2004) observed a strong P limitation in the photic layers. They found very low phosphate concentrations and high integrated N:P ratios in the photic layer at the frontal zone, the jet, and the adjacent waters. Thus, N:P ratios values of 24:1 were detected in the Atlantic waters adjacent to the front, while the highest N:P ratio (90:1) was associated to Mediterranean waters adjacent to the front. These findings are consistent with observations in the Algero-Balear basin, where P is in general the main limiting nutrient (Thingstad et al. 1998; Moutin and Raimbault 2002). The N:Si values in the photic layer of the Almeria-Oran front ranged from 0.32 to 0.83, while below the photic zone they obtained N:Si values ranging from 1.4 to 2.0 (Leblanc et al. 2004).

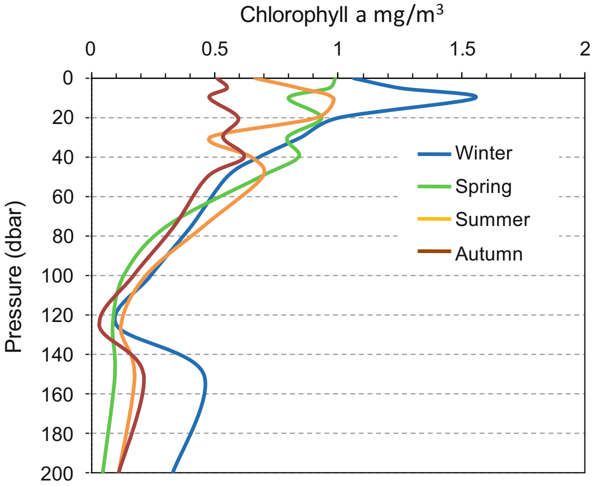
7.3 Phytoplankton Productivity: Coupling Between Physical, Biogeochemical, and Biological Features

7.3.1 Distribution Patterns of Chlorophyll-a and Primary Production from In Situ Data

The Alboran Sea is one of the most productive basins of the Mediterranean Sea. As previously discussed in this chapter, PP in the Alboran Sea is mainly related to wind-induced upwelling (particularly that forced by westerlies), mostly on the northern side of the WAG off the Spanish coast (Sarhan et al. 2000; Reul et al. 2005; Macías et al. 2007), and to the frontal ageostrophic circulation, associated to the path of the Atlantic jet, that induces upwelling at the periphery of the anticyclonic gyres (Sarhan et al. 2000; Garcia-Gorriz and Carr 1999, 2001). Therefore, any changes in the wind regime and the Atlantic jet characteristics may influence the dynamics and productivity of the Alboran Sea planktonic ecosystem (Garcia-Gorriz and Carr 2001; Ruiz et al. 2001; Macías et al. 2009; Oguz et al. 2014; Kersting 2016).

A number of studies have reported in situ data on Chl-a and/or PP distribution in the Alboran Sea (e.g., Morán and Estrada 2001; L'Helguen et al. 2002; Ramírez et al. 2005; Reul et al. 2005; Mercado et al. 2014; García-Martínez et al. 2019). Many of them have been conducted in the NW sector of the Alboran Sea, in particular in the area between Gibraltar and Marbella, as well as in the eastern side of the Strait of Gibraltar and the northern side of the WAG, since these are the most productive

Fig. 7.5 Average seasonal vertical profiles (seasonal climatologies) of chlorophyll-a in the Alboran Sea (Manca et al. 2004). Source: Data and metadata are provided by the Italian National Oceanographic Data Center of the OGS Istituto Nazionale di Oceanografia e Geofisica Sperimentale (NODC/OGS), acting within the International Oceanographic Data Exchange System of the UNESCO Intergovernmental Oceanographic Commission (IOC) since 27/6/2002



areas in the Alboran Sea (as result of the different upwelling events previously described). The high productivity in these areas is reflected in high Chl-a concentrations and high phytoplankton abundance, in comparison with adjacent areas of the Western Alboran Sea, as those of the center of the WAG (Rodríguez et al. 1998; Reul et al. 2005; Mercado et al. 2014). In the Eastern Alboran Sea, when the EAG is well developed, the most productive zones are found at the northern edge of the EAG (Leblanc et al. 2004). But when the EAG collapses, Chl-a is enhanced at the southern part (Claustre et al. 1994).

As a general pattern, the upwelling area in the NW Alboran Sea is characterized by Chl-a concentrations higher than 1 $\mu g \cdot l^{-1}$ and high PP, whereas lower Chl-a concentrations ($<1\ \mu g \cdot l^{-1}$) and low PP are found in the central WAG (Rodríguez et al. 1998; Reul et al. 2005: Morán and Estrada 2001; Mercado et al. 2014). The southern sector of the Alboran Sea, occupied by nutrient-poor Atlantic waters, is characterized by low Chl-a concentrations and low PP. On the temporal scale, Chl-a concentration reaches maximum values in winter-spring (Fig. 7.5), when the surface waters present higher nutrients concentrations, while it decreases in summer-early autumn, when the water column is strongly stratified, (Ramírez et al. 2005; Mercado et al. 2007; García-Martínez et al. 2019). However, changes in the fertilization mechanisms previously described, together with changes in the light regime, lead to temporal changes of this pattern and the development of phytoplankton blooms (Prieto et al. 1999; Ramírez 2007; Mercado et al. 2007, 2008; Macías et al. 2008; García-Martínez et al. 2019). Furthermore, wind-driven upwelling along the Spanish coast provides episodic increases of Chl-a along the Spanish coast (Reul et al. 2005; Ramírez et al. 2005; García-Martínez et al. 2019). In the water column, a deep Chl-a maximum (DCM) is usually observed in the Alboran Sea during the stratified season, at depths between 50 m and 75 m (Fig. 7.5) (Rodríguez et al. 1998; Ramírez et al. 2005; Ramírez 2007; García-Martínez et al. 2019). Nevertheless, the average profile of Chl-a in summer for the whole Alboran Sea presents also a shallower peak (Fig. 7.5), resembling the vertical profile in other areas of the Mediterranean (Lavigne et al. 2015). This shallower peak can be due to upwellings and advection of Chl-a patches. During the mixing period (late autumn to winter) the DCM is shallower or even disappear, with the higher Chl-a concentrations in the upper 20 m (Fig. 7.5) (Ramírez 2007; García-Martínez et al. 2019). In most of these cases, the Chl-a maximum is not properly a DCM, but a surface or subsurface maximum. In general, Chl-a concentration at the DCM in the Alboran Sea is commonly $>0.5\ \mu g{\cdot}l^{-1}$, although values $>1.0\ \mu g{\cdot}l^{-1}$ are often found in the NW margin, where values close to ~8 $\mu g{\cdot}l^{-1}$ can occasionally be found (Rodríguez et al. 1998; Ramírez et al. 2005; García-Martínez et al. 2019).

In the Alboran Sea PP decreases in general eastward, from the Strait of Gibraltar to Cape Gata. Although the existing in situ measurements of PP (^{14}C) in the NW Alboran Sea reveal that there is also a decrease of the integrated PP (PPint) following a coast-offshore gradient, with the highest average values in the frontal area (632 ± 184 mg·C $m^{-2}{\cdot}day^{-1}$) and the lowest average values in the center of the WAG (330 ± 149 mg·C $m^{-2}{\cdot}day^{-1}$) (Morán and Estrada 2001). On the other hand, Macías et al. (2009) found that PPint varied between 644 mg·C $m^{-2}{\cdot}day^{-1}$ at the frontal area and 6 mg·C $m^{-2}{\cdot}day^{-1}$ at the western side of the Strait of Gibraltar (off Europa Point). In the Almeria-Oran front (Eastern Alboran Sea), Semperé et al. (2003) estimated that the average PPint was around 242 mg·C $m^{-2}{\cdot}day^{-1}$ in the modified Atlantic jet area and the gyre, while it declined to 117 mg·C $m^{-2}{\cdot}day^{-1}$ in Mediterranean waters. Also in the Almería-Oran front and the Algerian Current the PP values at the frontal area ranged from 500 to 1300 mg·C $m^{-2}{\cdot}day^{-1}$ (with a mean value of 880 mg·C $m^{-2}{\cdot}day^{-1}$) (Lohrenz et al. 1988).

It has been hypothesized that in the absence of upwelling, the relatively low nitrate concentration found in the upper layers together with the low N:P and N:Si ratios, could favor the growth of a phytoplankton community of smaller cell size in NW Alboran Sea (Ramírez 2007), which are better adapted to grow in nutrient-deficient environments (Chisholm 1992) in comparison with other phytoplankton groups of larger cell size, such a diatoms. In fact several studies have reported that picoplankton and nanoplankton dominate the phytoplankton community in the surface layers of the Alboran Sea (Rodríguez et al. 1998; Arin et al. 2002; Reul et al. 2005). Moreover, temporal changes in the phytoplankton community at the continental margin of the NW Alboran Sea have been observed (Mercado et al. 2005, 2007). These changes, involving the shift of a phytoplankton community dominated by diatoms to a community dominated by coccolithophorids and small flagellates, were associated to changes in nitrate and the N:P the molar ratio. Moreover, taking into account that during great part of the year nitrate concentrations are low and that the N:P ratio is $<16{:}1$, it has been suggested that regenerated PP could be important in the NW Alboran Sea (Ramírez 2007). This is consistent with the low new PP values measured at the Almeria-Oran front (mean value 2.5 mmol· $m^{-2}{\cdot}day^{-1}$) compared to other oceanic and coastal areas (L'Helguen et al. 2002). Low nitrate uptake rates (up to 6.4 $nmol{\cdot}l^{-1}{\cdot}h^{-1}$) have been obtained in the frontal area, while maximum ammonium uptake rates were about

13 nmol·l^{-1}·h^{-1} (L'Helguen et al. 2002). The low new PP and nitrate uptake rates in the Almeria-Oran front could be caused by the low nitrate concentration in the photic layer and the relatively deep location of the nitracline (L'Helguen et al. 2002). In the NW Alboran Sea, the recurrence of intense upwelling events would temporarily overcome the limitation by nitrate, promoting phytoplankton blooms and a phytoplankton community dominated by diatoms (Gómez et al. 2000; Reul et al. 2005; Arin et al. 2002; Mercado et al. 2008, 2014). The rapid depletion of nitrate after the cessation of westerlies suggests that under the absence of upwelling, phytoplankton biomass and PP could be largely supported by regenerated forms of N. This is consistent with the findings of L'Helguen et al. (2002) who observed that PP in the Almeria-Oran front was initially nitrate-based, while regenerated production became gradually more important as nitrate was progressively consumed. In addition, average seasonal nitrate uptake rates in the upper layers of the NW Alboran Sea ranged from ~2 to ~70 nmol N l^{-1}·h^{-1}, although most values were $<$11 nmol N·l^{-1}·h^{-1} (Mercado et al. 2008), which are close those reported by L'Helguen et al. (2002) in the Almeria-Oran front. In contrast, ammonium uptake rates ranged between ~5 and 86 nmol·N l^{-1}·h^{-1} throughout the year (Mercado et al. 2008), with most of the mean seasonal values $<$30.6 nmol N·l^{-1}·h^{-1}. Higher uptake rates of both nitrate and ammonium were observed at the Chl-a maximum (Mercado et al. 2008).

However, most in situ measurements of Chla-a and PP have been carried out in particular areas of the Alboran Sea and did not cover either the whole Alboran basin or all the seasons. Over the last decades, several studies based on remote sensing data have analyzed the Chl-a and PP data in the whole Alboran Sea or in large parts of this basin, providing more comprehensive and synoptic information on the variability of phytoplankton biomass and PP in the Alboran Sea. This approach is discussed in the next section.

7.3.2 Distribution Patterns of Chlorophyll-a and Primary Production from Satellite Derived Data Models

7.3.2.1 Sea Surface Chlorophyll-a Concentration from Satellite Data

Surface Chl-a concentration as derived from satellite measurements allows detecting the main spatial and temporal patterns in the Mediterranean and the Alboran Sea (Morel and Andre 1991; Garcia-Gorriz and Carr 1999, 2001; Bosc et al. 2004; Macías et al. 2007). Based on Sea Surface Temperature (SST) and Chl-a concentration, Baldacci et al. (2001) defined two upwelling areas along the Spanish coast in the Alboran Sea: the first one is located between 5.5° W and 4.5° W, and the second one is located between 4.5° W and 2° W. The first area (A) is associated to the NW Alboran upwelling area and it stretches from the Strait of Gibraltar to Cape Pino (Malaga). The second upwelling area (B) extends from Cape Pino to Cape Gata (Almeria), the named Atlantic-Mediterranean Transition zone (Muñoz et al. 2017).

Both areas are characterized by the presence of waters upwelled by westerlies and/or cyclonic circulation cells (Baldacci et al. 2001), but they differ in their upwelling patterns throughout the year. Although the upwelling occurs simultaneously in both areas in spring and early autumn (October), higher Chl-a concentrations are found in area B in late autumn. In contrast in winter (January to March) and in summer higher Chl-a are found in area A.

In addition, the upwelling associated to the frontal area of the Atlantic jet is also a distinctive feature from Chl-a satellite data. The periphery of the WAG becomes richer in Chl-a as the jet travels through the Alboran Sea, due to the in situ growth of phytoplankton and also due to advection of Chl-a patches from nearby areas (Ruiz et al. 2001; Garcia-Gorriz and Carr 2001; Arin et al. 2002; Macías et al. 2007). On the other hand, according to Garcia-Gorriz and Carr (2001) the Chl-a annual cycle in the Alboran is in general characterized by a bloom period (November to March) and a non-bloom period (May to September), with transition periods between these two regimes. Other studies in the NW Alboran Sea based on satellite data have reported an intense bloom in March-April (Macías et al. 2007), declining the Chl-a values from June to September and increasing again from September to December. Lazzari et al. (2012), based on a 6 years study of satellite data for the whole Alboran basin, found the lower Chl-a values from June to September and higher values from November to May. Nevertheless, the interannual variability of Chl-a in the Alboran Sea is very high (Bosc et al. 2004) and its seasonal cycle, as derived from satellite data, is the most chaotic of the Mediterranean Sea (Bosc et al. 2004), with a minimum in summer (~0.20–0.25 μg Chl-a·l^{-1}).

While satellite images are limited to surface waters, 3D models allow integration of Chl-a and other variables in the water column (Lazzari et al. 2012). Figure 7.6 shows comparatively the mean integrated Chl-a values (1999–2016) during the month of May, one of the most productive months in the Alboran Sea according to the results of Lazzari et al. (2012), for the whole Mediterranean Sea and the Alboran Sea. Figure 7.6b shows a marked eastward gradient of Chl-a in the Alboran Sea with large differences between the western and the eastern basin. According to this Figure, in the western basin very high Chl-a concentrations are observed in spring in the NW sector off Malaga Bay, while very low values are found at the Strait of Gibraltar and in the westernmost part of the Alboran Sea. These low Chl-a values could be due to a time lag in the response of phytoplankton to the injection of nutrient into the euphotic layer. Some authors have argued that due to the high velocity of the Atlantic jet in the vicinities of the Strait, nutrients would have a quasi-conservative behavior (Minas et al. 1991). Thus the combined effect of the speed of the Atlantic jet and the time lapse for building phytoplankton biomass may result in low integrated Chl-a values at the vicinities of the Strait. Figure 7.6b also shows high Chl-a concentrations covering the entire eastern Alboran basin, probably due to the effect of wind-driven upwelling at this time of the year and the advection towards the center of the basin, although the values are slightly lower than those observed off the Malaga Bay. The higher variability is found between Marbella and Malaga due to intermittent upwelling processes (Fig. 7.6c).

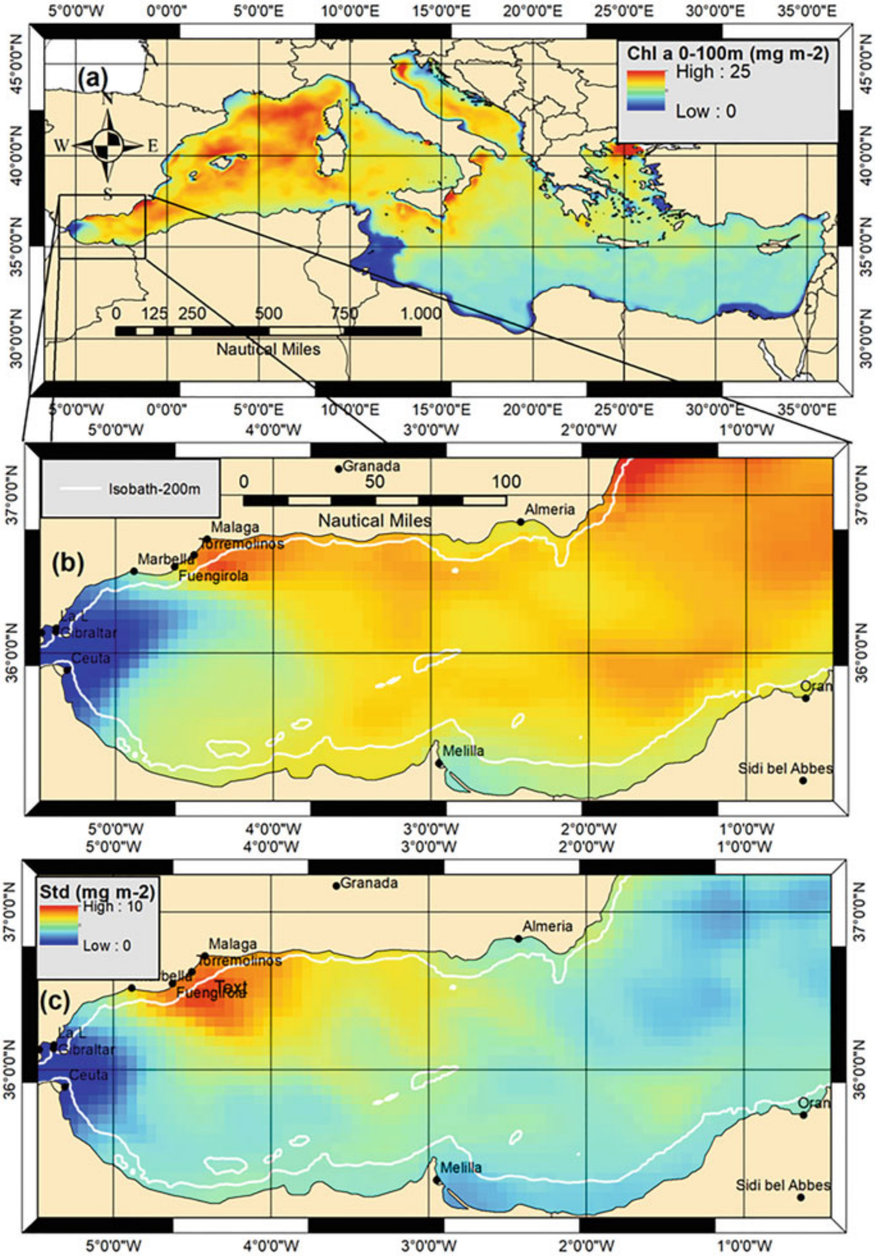


Fig. 7.6 Mean spring (May) depth-integrated (0–100 m) chlorophyll-a (mg·m^{-2}) over the period 1999–2016: (**a**) in the Mediterranean basin, (**b**) in the Alboran Sea and (**c**) standard deviation. Generated using E.U. Copernicus Marine Service Information. (Product: MEDSEA_REANALYSIS_BIO_006_008) (Teruzzi et al. 2016) (https://doi.org/10.25423/MEDSEA_REANALYSIS_BIO_006_008)

7.3.2.2 Primary Production from Satellite Data

According to Spalding et al. (2007), the Alboran Sea is an ecoregion included in the Mediterranean province, defined in general as a low productivity ecosystem (<150 g C·m^{-2}·year^{-1}) (Aquarone et al. 2009). However, at smaller regional scales within the Mediterranean, there is high spatial and temporal variability in PP. Thus, Bosc et al. (2004), analyzed 4 year mean PP values derived from satellite images for different Mediterranean Sea regions, and concluded that the Alboran Sea is the most productive region of the Mediterranean, with an average annual PP of 230 g C·m^{-2}·year^{-1}, being this value almost 100 g C·m^{-2}·year^{-1} higher than the overall mean for the Mediterranean basin. These values are in agreement with the results obtained by Antoine et al. (1995), who estimated a mean PP of 156 g C·m^{-2}·year^{-1} for the Mediterranean and 250 g C·m^{-2}·year^{-1} for the Alboran Sea. Based on a 3D-biogeochemical model (1999–2004) Lazzari et al. (2012), estimated for the Alboran Sea a net PP (NPP) of 274 ± 11 g C·m^{-2}·year^{-1} and classified this basin as mesotrophic (integrated NPP between 100 and 300 g C·m^{-2}·year^{-1}), showing the NPP a clear seasonal pattern with higher values between January and June and the highest peaks between February and May (Lazzari et al. 2012).

Figure 7.7 shows the spatial heterogeneity of PP in the upper 100 m in the Mediterranean and the Alboran Sea in spring (May), which according to the results of Lazzari et al. (2012) is one of the most productive months in the Alboran Sea. The depth-integrated (0–100 m) PP of the whole Mediterranean Sea depicts the Alboran Sea as the most productive region (Fig. 7.7a). In spite of being the region with the highest integrated NPP of the Mediterranean Sea, it is noteworthy to mention the existence of very strong spatial differences within the Alboran Sea, with zones where PPint values are extremely low and others with extremely high values (Fig. 7.7b). The areas with the highest PP (0.6 g C·m^{-2}·day^{-1}) are located in the northern part of the Alboran Sea (between Malaga and Motril) and the southern part of the eastern basin (off the eastern Moroccan coasts) (Fig. 7.7b). These values extrapolated to the whole year would result in a mean PP of 219 g C·m^{-2}·year^{-1}, which is similar to the value given by Lazzari et al. (2012). On overall, Fig. 7.7b illustrates the coexistence in the Alboran Sea of oligotrophic, poor Chl-a, and low productive areas, together with mesotrophic, rich Chl-a, and high productive areas.

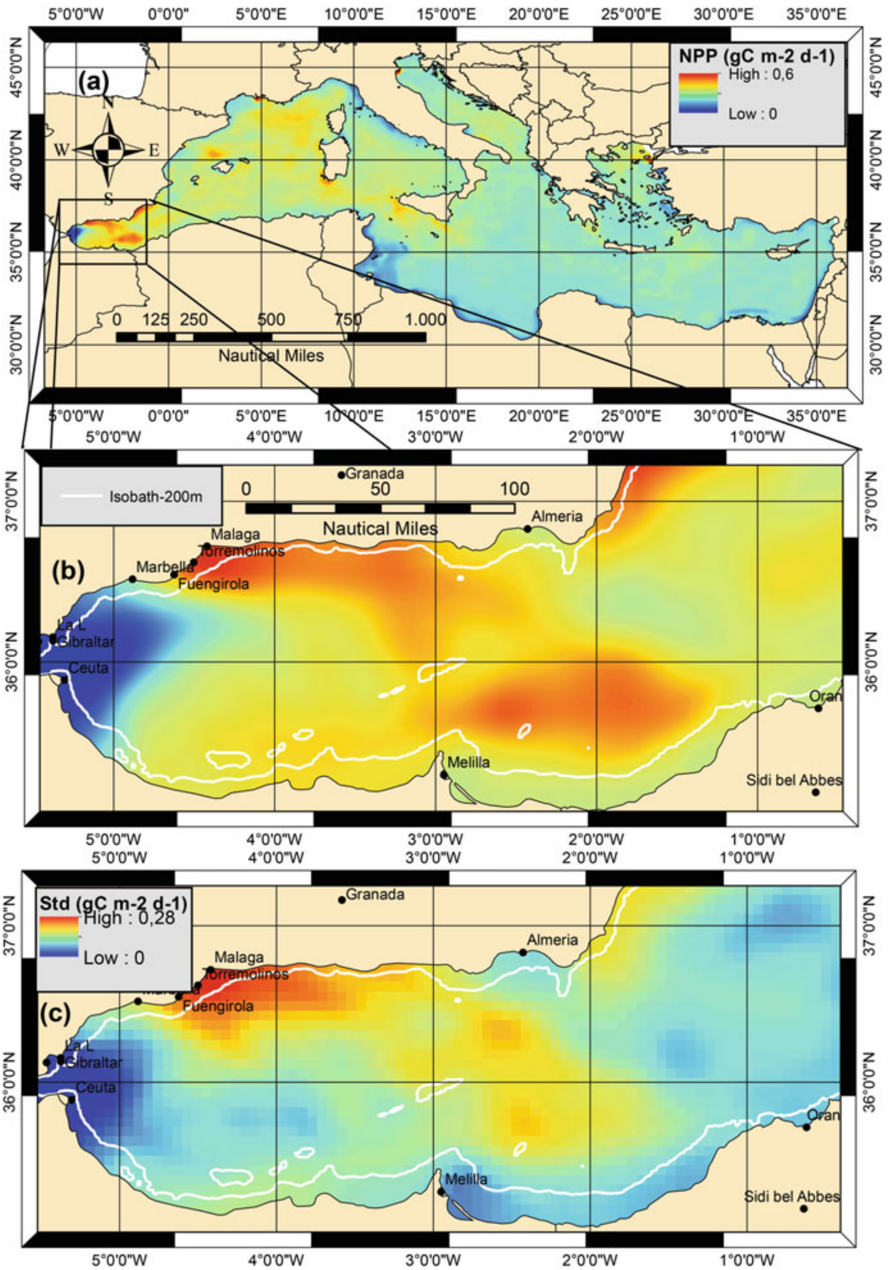


Fig. 7.7 Mean spring (May) depth-integrated (0–100 m) net primary production (g C·m^{-2}·day^{-1}) over the period 1999–2016: (**a**) in the Mediterranean basin, (**b**) in the Alboran Sea and (**c**) standard deviation. Generated using E.U. Copernicus Marine Service Information. (Product: MEDSEA_REANALYSIS_BIO_006_008) (Teruzzi et al. 2016) (https://doi.org/10.25423/MEDSEA_REANALYSIS_BIO_006_008)

7.4 Future Scenarios in the Framework of a Changing Climate

7.4.1 Analyzing the Possible Effects of Climate Change on Water Circulation, Nutrients, and Primary Productivity in the Mediterranean and the Alboran Sea

Climate change is expected not only to affect oceanic conditions worldwide (IPCC 2007, 2013; Reid et al. 2009) but also to induce changes in water mass properties and their associated circulation patterns. As result of changes in water temperature, stratification, vertical mixing, or in nutrient or light availability, water biochemistry, and marine ecosystems may be modified (Bopp et al. 2001; Boyd and Doney 2002; Sarmiento et al. 2004; Steinacher et al. 2010; Taucher and Oschlies 2011).

Due to its modest dimensions, Mediterranean Sea is very sensitive and may respond rapidly to environmental changes (atmospheric forcing and anthropogenic influences) (Béthoux and Gentili 1999; Lejeusne et al. 2010; Lionello et al. 2010; Schroeder et al. 2012, 2017). Expected future changes in the Mediterranean Sea include an increase in seawater temperature and salinity, reductions in freshwater inputs (precipitation and river inflow), changes in the ocean-atmosphere heat flux, and an increase in human pressure (Béthoux and Gentili 1999; Vargas-Yáñez et al. 2008; Sanchez-Gomez et al. 2011; Borghini et al. 2014; García-Martínez et al. 2017; Macías et al. 2018). All these factors play a crucial role in dense water formation and hence they determine the circulation in the Mediterranean Sea (Mediterranean Thermohaline Circulation—MTHC) (Béthoux and Gentili 1999). Changes in circulation can reduce the supply of nutrients, therefore geochemical cycles and PP (also affected through changes in temperature, pH, light availability, or in atmospheric and terrestrial inputs of nutrients) of the Mediterranean Sea will be altered (Sarmiento et al. 2004; Durrieu de Madron et al. 2011; IPCC 2013; Lazzari et al. 2014; Macías et al. 2014b).

Some studies have carried out a set of numerical experiments to quantify the sensitivity of the Mediterranean Sea to the twenty-first century climate change (Adloff et al. 2015). The projections of the possible effects of climate change on water circulation, nutrients, and primary productivity are studied by developing "scenarios" (the IPCC SRES, Nakicenovic and Swart 2000). A scenario is a description of a hypothetical future development of the Earth's societies and economies. The Intergovernmental Panel on Climate Change "Special Report on Emissions Scenarios" (SRES) explored pathways of future greenhouse gas emissions, derived from self-consistent sets of assumptions about energy use, population growth, economic development, and other factors. Considering the temperature rise by 2100, the "hottest" scenario is A1FI, followed by A2, A1B, B2, A1T; and B1 is the "coolest." However, in the A1B and A1T fossil CO_2 emissions are falling by 2100, whereas in A2 and B2 they are still rising, implying that climate impacts would be greater during the following century. In scenarios A1FI, B1, and B2, CO_2 emissions from land-use change drop below zero.

These scenarios are used to force models of different complexity and resolution (Lazzari et al. 2014). There are different types of models: General circulation models (GCM), higher resolution regional ocean models, or coupled atmosphere-ocean regional climate models (RCSM), but global models with low spatial resolution cannot sufficiently resolve the local and mesoscale processes that characterize the Mediterranean region (Jordá et al. 2011; Gomis et al. 2016; Akhtar et al. 2018), even less the Alboran Sea. The use of RCSM for future projections started recently with Somot et al. (2008) and Carillo et al. (2012) studies, followed by the European project CIRCE (Dubois et al. 2012; Gualdi et al. 2013) and actually in the Med-CORDEX initiative (Ruti et al. 2016). In this section, we present a detailed summary of different studies that have analyzed the projections obtained from models on the evolution of physical, chemical, and biological properties during the twenty-first century in the Mediterranean Sea.

The first attempt to predict the effect of ocean warming on the Mediterranean Sea circulation was the one by Thorpe and Bigg (2000). These authors used ocean and air-sea fluxes models with the low resolution which predicted a weakening of the MTHC in a scenario of $2\times$ CO_2. In the same way, Somot et al. (2006) using A2 scenario (IPCC SRES) obtained projections with higher resolution models that show an increase of sea surface temperature (SST) and salinity (SSS), and also a strong weakening of the MTHC and changes in the characteristics of the Mediterranean outflow. Somot et al. (2008) improved simulations by developing a global atmospheric model coupled with a high-resolution oceanic model of the Mediterranean Sea. Simulations for the period 1960–2099 performed in a SRES-A2 scenario showed once again an increase of the surface temperature in the Mediterranean basin.

Under the umbrella of the EU project SESAME (Lazzari et al. 2014), ecosystem models were developed to connect low and high trophic levels and basin scale models to execute scenario simulations (the IPCC SRES, A1B scenario) for the future (2070–2100). The results obtained for the twenty-first century simulations showed: (1) an upper layer warming that enhances photosynthesis and increase Gross Primary Productivity (higher in the Eastern Mediterranean Sea) and (2) an increase in the vertical stability of the water column which limits the nutrient vertical supply into the euphotic zone and therefore improves the microbial loop of the marine trophic web. The maximum increase of temperature is achieved in the Alboran Sea during wintertime and the primary productivity maps show a strong positive signal in the Alboran Sea.

The projections of models developed under the framework of the EU project CIRCE (Gualdi et al. 2013) show a decrease of the surface net heat loss during the twenty-first century. Dubois et al. (2012) study presented projections under A1B scenario for the period 1950–2050 and found a decrease in the heat loss and an increase in water loss, which may affect the Mediterranean water masses and the associated MTHC. Numerous studies have been carried out within the framework of the Med-CORDEX initiative, such as the study conducted by Harzallah et al. (2018), which evaluates the Mediterranean Sea heat budget components. Results for the period 1990–2010 show positive and significant trends in the temperature of the outflowing water through the Strait of Gibraltar. In addition, other projects such as VANIMEDAT-2 (Jordá et al. 2011) aimed at exploring the sea level variability under climate change scenarios for the twenty-first century.

NEMOMED oceanic models are regional versions of the NEMO model on the Mediterranean basin with different spatial resolutions: NEMOMED-12 (Waldman et al. 2017), NEMOMED-16 (Soto-Navarro et al. 2015) or NEMOMED-8. NEMOMED-8 model (Beuvier et al. 2010) has a horizontal resolution from 9 to 12 km (North to South). The circulation through the strait is simulated with realistic Atlantic Waters (AW). These models are used for coupled system regional climate system models (RCSMs) (Sevault et al. 2014; Adloff et al. 2015), which include a high-resolution and fully coupled representation of most of the physical components of the regional climate system (atmosphere, land surface, vegetation, hydrology, rivers, and ocean). Padorno et al. (2012) observed in their simulations for 140 years (1960–2099) with NEMOMED-8 that the main changes are warming and saltening waters, mean sea level increase, thermohaline circulation variations, and that deep water convection changes. Adloff et al. (2015) study the period 2001–2099 (NEMOMED-8), following different socio-economic scenarios (IPCC SRES). In most of the cases, they found an increase in the future Mediterranean SST and SSS and that MTHC tends to reach a situation similar to the Eastern Mediterranean Transient (EMT). The EMT, which took place in the Aegean Sea from 1988 to 1995, is considered the most relevant intermediate to deep Mediterranean overturning perturbation registered by instrumental records (Tsimplis et al. 2006; Roether et al. 2007, 2014; Lejeusne et al. 2010; Incarbona et al. 2016). In the 1990s, the Aegean Sea began to discharge unusually dense waters inducing the so-called EMT which was caused by the accumulation of high salinity waters in the Levantine and enhanced heat loss in the Aegean Sea, coupled with surface water freshening in the Sicily Channel.

Richon et al. (2018) used NEMOMED-8 coupled with biogeochemical model PISCES. In an A2 IPCC SRES scenario, projections for the twenty-first century indicate a warming, increased stratification, and changes in Atlantic and river inputs which can lead to an accumulation of nitrate (whereas no for phosphorus) in the Mediterranean Sea and a decrease in biological productivity. Most coupled climate–marine biogeochemical models also predict a decline in NPP in the coming decades as a response to global warming (Bopp et al. 2001, 2013; Steinacher et al. 2010).

Multi-model projections, such as the ones obtained from the World Climate Research Program Coupled Model Intercomparison Project Phase 3 (CMIP3) multi-model projections have been used to analyzed hydroclimatic changes in the Mediterranean over the twenty-first century (Mariotti et al. 2008). By 2070–2099, the CMIP3 multi-model projections predict an increase in the loss of freshwater over the Mediterranean Sea due to precipitation reduction and warming-enhanced evaporation. The decrease in river runoff from the surrounding land will further exacerbate the increase in the Mediterranean Sea freshwater deficit.

There are very few modeling studies about the effects of climate change on plankton community and productivity in the Mediterranean Sea. The MERMEX program aims to study the response of Mediterranean ecosystems to natural and anthropogenic pressures and combines integrated observation/experimentation/modeling approaches. Durrieu de Madron et al. (2011) reviewed the state of the current functioning and responses of Mediterranean marine biogeochemical cycles and ecosystems and concluded the need for international multi-disciplinary research coupling experiments, long-term observations, eco-regionalization, and modeling.

Herrmann et al. (2014) study represents one of the first attempts to model and assess the effects of the oceanic and atmospheric long-term evolution of the pelagic planktonic ecosystem, using a 3D coupled physical-biogeochemical model focusing only on the NW Mediterranean Sea. In Macías et al. (2018) a coupled model system is also used to explore potential changes in future scenarios (~2030) in the deep convection, in the euphotic layer fertilization, and the impact on phytoplankton and primary productivity in the NW Mediterranean Sea. Their results show an increase in the strength and duration of the annual deep convection event (which is the main trigger of the typical phytoplankton bloom of this area) and changes in the seasonal plankton cycles. On the other hand, Macías et al. (2015) present the results of a 3D hydrodynamic-biogeochemical coupled model (for the entire Mediterranean Sea). Simulations under two emission scenarios showed that the western basin becomes more oligotrophic due to a surface density decrease (increase stratification) because of the influence of the Atlantic waters that prevents surface salinity to increase.

Another important stressor is acidification and one of the EU initiatives that have addressed this issue in the Mediterranean is the MedSea project, which aimed at forecasting changes in the Mediterranean Sea driven by increases in CO_2 and other greenhouse gases, while focusing on the combined impacts of acidification and warming on the marine shell and skeletal building, productivity, and food webs. The combined effect of Mediterranean seawater acidification with warming on Mediterranean biogeochemistry, and ecosystems, through direct impacts on its highly adapted calcareous and non-calcareous organisms, may be larger than in other regions (http://medsea-project.eu/). The Mediterranean Sea is acidifying quickly (Goyet et al. 2016). Up to 30% of the anthropogenic CO_2 remains in the upper 200 m of the water column (Sabine et al. 2004). The acidification of the euphotic layer (Sabine et al. 2004; Orr et al. 2005) can affect physiological processes and the composition of the phytoplankton community (Reul et al. 2014). Current signals point to the reduction in the rate of calcification in phytoplankton (mainly coccolithophores), which could lead to changes both in marine ecosystems and in the carbon cycle. Nevertheless, there is no a consensus and different studies conjecture the widely varying responses under elevated pCO_2 (Beaufort et al. 2011; Álvarez et al. 2014; Meier et al. 2014; Dutkiewicz et al. 2015).

In general, climate projections tend to agree, with relatively high confidence, that the Mediterranean region will experience higher temperatures and reduced rainfall in the coming decades (IPCC 2013). In consequence, as climate model projections show, there will be increasing rates of evaporation and salinification of the Mediterranean Sea over the twenty-first century under anthropogenic greenhouse gas emission scenarios (Giorgi and Lionello 2008; Somot et al. 2008; Mariotti et al. 2008, 2015; Adloff et al. 2015). Mediterranean thermohaline circulation may significantly change by weakening in the western basin and a less certain response in the eastern basin (Somot et al. 2006; Adloff et al. 2015). Changes in thermohaline circulation can profoundly affect the biogeochemistry of the Mediterranean Sea (Powley et al. 2018) and through an increase of stratification (Herrmann et al. 2014; Adloff et al. 2015) may reduce the nutrient supply into the euphotic layer with consequences for phytoplankton blooms (D'Ortenzio and Ribera d'Alcalà 2009; Herrmann et al. 2013).

Potential effects of the climatic scenario have also been described for the Alboran Sea circulation (Macías et al. 2018), and for the upwelling in the NW of Alboran Sea, strongly influenced by the Atlantic water entering through the Strait of Gibraltar and that could be affected by a generalized slowdown of the thermohaline circulation (Macías et al. 2014a).

Mediterranean Sea phosphate and nitrate concentrations seem to be more dependent on atmospheric and terrestrial inputs than on the Atlantic influx across the Strait of Gibraltar (Béthoux et al. 1998; Ribera d'Alcalà et al. 2003; Durrieu de Madron et al. 2011). Since the beginning of the industrial era, there has been an overall increase in atmospheric deposition (Duce et al. 2008) that might be higher in the coming years. These changes coupled with the expected decrease in winter mixed layer depth, could result in changes in the relative availability of nutrients, and increase the relative importance of atmospheric inputs in the Mediterranean Sea. Expected consequences are an imbalance between nitrate and phosphate concentrations in surface waters, causing changes in the phytoplankton populations and in the entire food web (Pasqueron 2015).

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Chapter 8
Seaweeds and Seagrasses: The Marine Forests from the Alboran Sea

Antonio Flores-Moya, Diego Moreno, Julio De la Rosa, María Altamirano, and Elena Bañares-España

8.1 Seaweeds and Seagrasses: Taxonomical Approach and Ecological Role

While the term "seaweed" designates multicelled organisms from two different kingdoms distributed among three different phyla (Rhodophyta, red algae, around 4000 species; Heterokontophyta, brown algae, around 1500 species, included in the Kingdom Chromista; and Chlorophyta, green algae, around 700 species, included in the Kingdom Plantae), the term "seagrass" includes a paraphyletic group of marine angiosperms from the order Alismatales (Tracheophyta, Plantae; around 60 species). It must be highlighted that the three groups of seaweeds have no common ancestor and consequently they are considered as a polyphyletic group. In addition, some tuft-forming blue-green algae (Cyanobacteria) are sometimes regarded as seaweeds. Thus, "seaweed" and "seagrass" are not systematic terms, but they are extensively used in marine botany and ecology to designate the macroscopic photosynthetic organisms growing on marine substrates; they encompass the macroscopic, primary producers of the benthos.

Macroalgae are very diverse in their morphology, life habits, and functional diversity, and they shape the spatio-temporal physiognomy of the marine vegetation

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landscape on hard substrates. When these communities are well conserved and structured, up to four strata of vegetation (arboreal, shrub, caespitose, and basal or incrusting) similar to terrestrial forests can be differentiated. The seagrasses, with a significantly lower species richness and abundance, present a more uniform structural pattern. However, they constitute communities of great importance for the ecology and coastal sandy dynamics because seagrass meadows are habitats with high diversity, altering the geomorphology of seabottoms extensively and, interestingly, working as carbon sinks (especially, due to the biomass of rhizomes and roots).

In the marine environment, the presence of seaweeds and seagrass communities is restricted to the photic zone where irradiance levels allow photosynthesis to surpass respiration (Ros et al. 1989; Romero et al. 2004). Their distribution is also strongly conditioned by environmental factors that have an important vertical gradient, giving rise to distributions in more or less apparent horizontal bands, which may be characterized by the presence or absence of certain species. The amplitude of these bands is very variable and depends on the rate with which environmental factors vary. Close to the surface, the variations are very rapid, and therefore the bands are narrower and better defined. At greater depths, the transitions are more indistinct and may not appear completely clear, with frequent transition zones and mixed communities. The result of all these gradients and biological factors is a zonation of stripes at different levels. The phytal system (where seagrasses and seaweeds can proliferate) includes, from the surface to depths, the following levels: supralittoral, eulittoral, infralittoral, and circalittoral (Pérès 1982; Ros et al. 1989; Romero et al. 2004). The marine communities in which different species are grouped are named in reference to the type of substratum they colonize, hydrodynamism to which they are subjected, degree of illumination to which they are exposed, and the dominant species. However, it must be highlighted that in the Alboran Sea, an additional West-East (Atlantic-Mediterranean) gradient is superimposed due to the particular oceanographic conditions, as described in Sect. 8.3.

8.2 Origin and History of the Seaweeds and Seagrasses from the Alboran Sea

Four elements underlie the origin and diversity of the marine macrophyte flora of the Alboran Sea today: origin and geological history of the Mediterranean Sea as a whole, Atlantic influence due to its proximity to the Strait of Gibraltar, antiquity of the region, and the influence of recent human activities.

It can be considered that the flora of the Alboran Sea had its origin more than 100 million years ago during the Cretaceous, when the separation of the European and African plates allowed the connection of very different masses of waters from the Tethys Ocean and the primitive Indo-Pacific Ocean, approximately 120 million years ago. In this period, the Tethys was an ocean populated by numerous

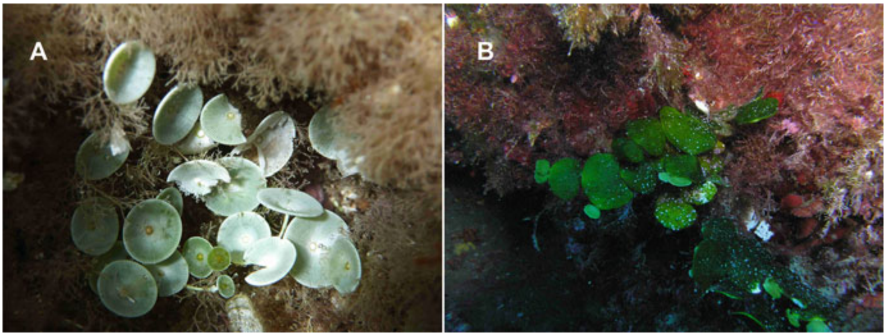

Fig. 8.1 *Acetabularia acetabulum* (**a**) and *Halimeda tuna* (**b**) are two floristic elements of a pantropical nature that appear in the easternmost part of the Alboran Sea. Photos: (**a**) María Altamirano; (**b**) Julio De la Rosa

warm-water species, some of which have survived multiple and drastic geological events associated with strong thermal changes that caused the extinction of the most of them. These surviving warm-water species, few in number, are considered nowadays the pantropical elements of the flora of the Alboran Sea. These species (current accepted taxa Guiry and Guiry 2020) have disjunct distributions in different warm and tropical water regions outside the Mediterranean. In the Alboran Sea, some of these pantropical elements are the infralittoral green algae species of the genera *Halimeda*, *Anadyomene*, *Acetabularia*, or *Flabellia* (Fig. 8.1) and other eulittorals such as *Valonia* or *Cladophora*, frequent in warmer waters of the easternmost of the Alboran Sea. More ancient species of Heterokontophyta originating in this period are, for example, *Sargassum vulgare*, very widespread on the coasts of Alboran, and also the infralittoral species *Zonaria tournefortii* and the rare *Hydroclathrus clathratus*. In this context, some of the most ancient red algae of the Alboran Sea are, for example, the species *Hypnea musciformis*, *Gracilaria bursa-pastoris*, *Laurencia papillosa*, *Liagora viscida*, *Amphiroa rigida*, and *Digenea simplex* (Augier 2007; Rodríguez-Prieto et al. 2013).

After the origin and long warm period of the Tethys Sea, a series of tectonic movements occurred during the Oligocene (30 million years ago) that reduced the surface area of the Tethys due to the convergence of the European and African plates and its warm influence in the region. To this must be added the closure of communication with the Indo-Pacific Ocean by the creation of the Isthmus of Suez during the Miocene (approximately 10 million years ago). Later, in the transition to the Pliocene, about 6 million years ago, the collision of the African plate with the Iberian microplate closed the Rif and Betic corridor of communication with the waters of the Atlantic Ocean. This complete isolation of the Tethys Sea lasted half a million years and not only prevented the entry of new pantropical elements but also greatly reduced the diversity of marine organisms including algae, due to repeated drying periods. During this period, known as the salinity crisis of the Messinian, only some euryhaline species could presumably survive, taking refuge in hypersaline shallow lagoons (Stanley 1990; Myers 1996). The surviving species of this period are considered paleoendemics, species that do not have a close relationship with other species from neighboring regions, such as the seagrass *Posidonia oceanica* or the red alga *Rissoella verruculosa*.

It was in the Pliocene that the waters of the ancient Tethys Sea were once again connected with the Atlantic Ocean, thanks to a series of orographic movements that created a huge waterfall 2000 m high and 30 km long, which for hundreds of years poured Atlantic waters into the newly originated Mediterranean Sea (Roveri et al. 2014). It is this moment, when the enrichment by species of Atlantic macrophytes begins, that distinguishes the Alboran Sea from the rest of the Mediterranean.

Subsequent successive glaciations that characterized the Quaternary period produced significant changes of sea level and seawater temperature to as much as 6 °C less in summer than at present (Thunell 1979). These thermal fluctuations produced successive migrations of boreal and subtropical species of Atlantic origin through the Strait of Gibraltar, which extended into much of the Mediterranean and which conferred the marked Atlantic character of much of the Alboran Sea today. During the glaciations, species from the North Atlantic were established in Alboran waters and the rest of the Mediterranean, such as *Halopithys incurva*, *Sphaerococcus coronopifolius*, *Porphyra umbilicalis*, *Gymnogongrus griffthsiae*, *Nemalion elminthoides*, *Chondracanthus acicularis*, *Pterocladiella capillacea*, *Cutleria multifida*, and *Ralfsia verrucosa*, the last with its southern distribution limit in these waters. To these it is necessary to add the marine seagrass *Zostera noltei*, presently extending to Atlantic Scandinavian coasts. Some of these species, originating in colder waters, are nowadays considered glacial relicts in the Mediterranean, and they remain in very localized locales of colder, often deep, waters, such as Alboran Island, where Laminariales and Tilopteridales (i.e., kelps and kelp-like species) can be found (Flores 2004; Flores-Moya 2012).

During the interglacial periods, species from the coasts of the tropical Atlantic could enter the Mediterranean through the Strait of Gibraltar. Some of them are still present in the Alboran Sea, such as *Dasycladus vermicularis* in Almeria and Karia Arkeman (open sea at the southeast end of the Sebkha Bou Areg of Nador, Morocco) and *Caulerpa prolifera*, abundant in the Bay of Algeciras and very abundant inside the Sebkha Bou Areg of Nador, forming mixed meadows with the seagrass *Cymodocea nodosa*. In the Alboran Sea, however, there are few Atlantic elements of tropical origin compared to other areas of the Mediterranean.

The Alboran Sea algae species from the quaternary are considered as neoendemics, boreal and subtropical species native to the Atlantic which evolved anatomical modifications that resulted in new species or varieties over time. Example of this is species of the genus *Cystoseira*, a genus that has intensive speciation, such as *C. tamariscifolia* and *C. usneoides* (Rodríguez-Prieto et al. 2013).

In the last 20 years, the flora has experienced important changes due to the unnatural migrations of species of Indo-Pacific origin. These changes are mediated by anthropogenic activities, perhaps in some cases linked in turn to changes in the surface temperature of the seawater. *Asparagopsis armata*, *A. taxiformis*, *Caulerpa cylindracea*, and very recently the brown alga *Rugulopteryx okamurae* (Fig. 8.2) have spread alarmingly on both shores of the Alboran Sea, probably favored at many

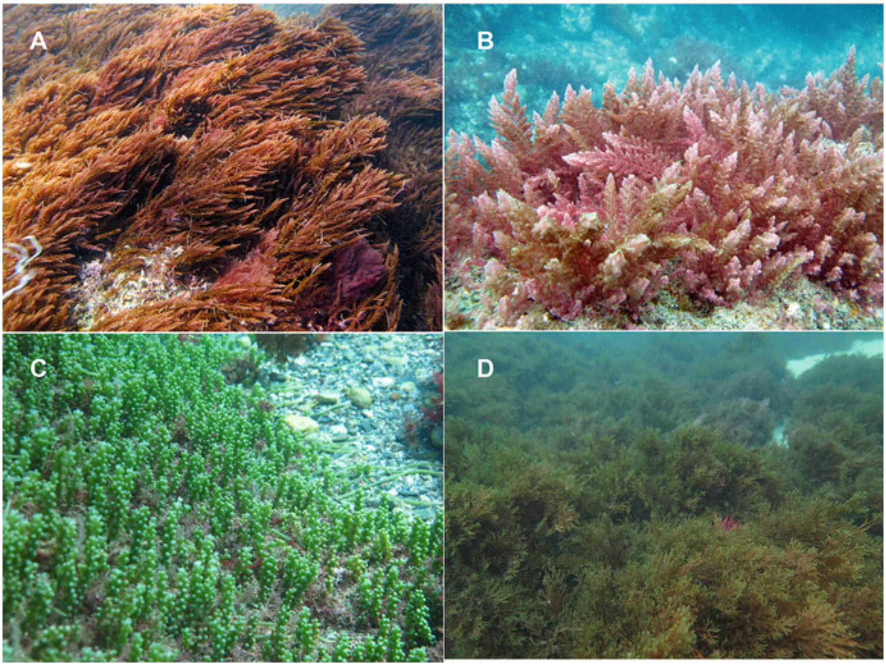

Fig. 8.2 Alochtonous and invasive seaweeds in Alboran Sea. *Asparagopsis armata* (**a**), *A. taxiformis* (**b**), *Caulerpa cylindracea* (**c**), and *Rugulopteryx okamurae* (**d**). Photos: (**a**)–(**c**), María Altamirano; (**d**) Julio De la Rosa

sites by an invasional meltdown phenomenon. These massive proliferations, in some cases identified as cryptic invasions, homogenize the Alboran underwater landscapes in many areas and may be considered as a marine representation of the new era identified as the Anthropocene.

8.3 Biodiversity of the Benthic Flora from the Alboran Sea: Present Knowledge

The flora of seaweeds of the north side of the Alboran Sea was compiled by Flores-Moya et al. (1995a, b) and Conde et al. (1996a), and several additions have been made since then (Conde et al. 1996b; Báez et al. 2001; Altamirano et al. 2006, 2008b; Invernón et al. 2009; Arjona et al. 2011; De la Rosa, 2016). The knowledge of marine macroalgal diversity of Moroccan Mediterranean shores has been referenced in several checklists (González-García and Conde-Poyales 1991, 1994; Benhissoune et al. 2001, 2002a, b, 2003). Recently, the combined research efforts of Moroccan phycologists have yielded an important number of new records of seaweeds from the Moroccan coasts of the Alboran Sea (Riadi et al. 2011, 2013;

Moussa et al. 2015; Hassoun et al. 2014, 2015, 2016a, b, 2018a, b; Salhi et al. 2016, 2018). The Chafarinas Islands are less than 3 km far from the Moroccan coast near the Argelian frontier. The first study of the seaweeds from the Chafarinas Islands was provided by Conde (1984), with additions by Navarro and Gallardo (1989), González and Conde (1994), Flores-Moya and Conde (1998), Altamirano (1999), and Altamirano et al. (2010). Recently González García et al. (2017) have published the first algal catalog of Spanish rocks on the Moroccan coast (Vélez de la Gomera and islets of Alhucemas).

The Alboran Island marine benthic flora was surveyed by Soto and Conde (1993), Rindi and Cinelli (1995), Conde et al. (1998), Conde and Flores-Moya (2000), and Ballesteros and Pinedo (2004) and compiled by Templado et al. (2006).

The early floristic studies in the Alboran Sea (especially, on the north shores) already showed the very remarkable presence of Atlantic taxa. This is due to special oceanographic conditions in the Alboran Sea. The negative water balance in the Mediterranean Sea (i.e., the loss of water by evaporation is higher than the inputs by precipitation and rivers) is compensated by a permanent current flowing from the Atlantic Ocean into the Mediterranean Sea through the Strait of Gibraltar. Thus, the salinity in the Mediterranean Sea is higher than that at the same latitude in the neighboring Atlantic Ocean, but it does not increase further because a high-salinity deep water current flows from the Mediterranean to the Atlantic. The surface current of Atlantic water flows close to the shores of the Iberian Peninsula and then turns around, like an anticyclone, in the Western Alboran Sea. Simultaneously, upwelling of cold, deep water close to the shores balances the offshore accumulation of water by the action of the anticyclone (Lacombe and Tchernia 1972). Qualitative and quantitative biogeographical studies focused on benthic marine flora have reinforced the hypothesis that the Alboran Sea is notably enriched with taxa from the Atlantic-boreal region (Conde 1984; Conde and Seoane 1982; González-García and Conde 1993; Báez et al. 2004a, b), and recently a biogeographical subregion (from the Strait of Gibraltar to Punta Calaburras) has been recognized based on the oceanographic conditions in the northern Mediterranean-Atlantic transition zone (Bermejo et al. 2015). Indications of this singularity are that the Alboran Sea is the distribution limit of the Atlantic-boreal *Fucus guiryi* and of Mediterranean species such as the seagrass *Posidonia oceanica* and the paleoendemic *Rissoella verruculosa* (Báez et al. 2004a, b). This Atlantic-Mediterranean boundary is located at the Punta de Calaburras on the Iberian Peninsula (Conde and Seoane 1982; Conde 1989) and at the Cabo de Tres Forcas on the Moroccan coast of the Alboran Sea (González-García and Conde 1993).

While the present knowledge of the flora could be considered to be almost complete on the north shores, more work is needed on the Moroccan coasts, such as the research carried out by Moroccan phycologists in the last decade. Another gap in our knowledge of the benthic marine flora from the Alboran Sea concerns functional aspects of populations and communities of seaweeds and seagrasses. A first synthetic approach focused on the main marine vegetation formations on Andalusia shores (including seagrasses, deep-water kelp forests, *Cystoseira* spp. and *Asparagopsis armata* forests, maerl bottoms, and *Caulerpa prolifera* beads) was compiled by Luque and Templado (2004). A synthesis of the dynamics and structure of deep-water kelp and kelp-like populations was provided by Flores-Moya (2012).

8.4 Seaweed and Seagrass Communities in the Alboran Sea

The peculiar biogeographical location of the Alboran Sea results in the confluence of three biogeographic regions: Atlantic-boreal, Mediterranean, and Macaronesian (Lüning 1990). In addition, the physical nature of its coasts presents a great variety of substrata and habitats, allowing the development of a great diversity of marine communities, some of which are of great importance and constitute areas of exceptional biodiversity. Moreover, the mixture of Atlantic and Mediterranean waters together with the outcrops in deep waters is probably a determining factor for the particular biota inhabiting the sea bottoms from the Alboran Sea (Cebrián and Ballesteros 2004).

Plant communities are characterized by the presence of one or more dominant species with narrow ecological niches, which possess a greater "ecological value," together with others (subordinate species) with broader niches. Some species present a wide margin of tolerance to certain environmental conditions, so they present a wider bathymetric amplitude and can be observed as common species in different communities. In certain areas, these communities can be marked by the presence of particular elements such as the presence of pantropical species in the eastern Alboran Sea (*Halimeda tuna*, *Acetabularia acetabulum*; Fig. 8.1) or Atlantic species in the westernmost part (*Lichina pygmaea*, *Fucus guiryi*).

8.4.1 Supralittoral Zone

The supralittoral zone is located above the wave-swept area of the water, so plant development depends exclusively on hydration provided by the water splashed from waves. The upper limit is wet only occasionally, during days of heavy weather, whereas the lower horizon is subjected to continuous splash. This dependence on the waves causes the vertical extension of this level to vary with the degree of exposure and inclination of the substrate and the frequency and strength of the waves. The adverse conditions imposed by the limited exposure to water and the high temperatures and salinity make plant life very difficult in this zone, where only lichens and cyanobacteria (both endo- and epilithic) can develop. The supralittoral biocenis is generally uniform on a global scale, with low abundance and diversity of species (Pérès 1982). Among the lichens are species of *Verrucaria* (*V. amphibia* and *V. maura*) that form scattered very dark, almost black, spots. At certain sites in the western area of the Alboran Sea and in contact with the next lower zone, *Lichina pygmaea*, a dark-colored lichen with the appearance of a minute tree, is frequent. The cyanobacteria (epilithic microphytobenthos) develop black crusts, well attached

Fig. 8.3 In the supralittoral horizon, cyanobacteria are the most representative elements of the flora of the coast. The mats developed by these species can present a different consistency and degree of development depending on factors such as exposure and degree of hydration. Photo: Julio De la Rosa

to the substrate, especially after winter storms and in spring due to increased water availability, and can develop considerable surface coverage (Fig. 8.3). The most colorful crust development usually corresponds to species such as *Staneria sublitoralis*, *Chroococcidiopsis fissuratum*, *Entophysalis deusta*, and *E. granulosa* (De la Rosa 2012). Where relatively continuous water flow occurs, dense mats of filamentous cyanobacteria such as *Lyngbya confervoides* or species of *Phormidium*, *Microcoleus*, or *Calothrix* can develop.

After windy episodes and storms, the cavities and crevices of the substrate are filled with water and form the so-called supralittoral pools. These pools are very ephemeral and are subject to sporadic renewal of their water. They have very particular environmental conditions with high salinity and temperature, low concentrations of oxygen, and sometimes high levels of eutrophication. In these harsh conditions, there are few organisms capable of developing, and they may be very inconspicuous. Sometimes important microscopic communities with *Tetraselmis* spp., *Chlamydomonas* spp., or diatoms impart a green or brown color to the water. Among the few macrophytobenthos adapted to these conditions are cyanobacteria (*Lyngbya* spp.) and green filamentous algae such as *Chaetomorpha aerea* and *Ulva compressa*.

8.4.2 Eulittoral Zone

This zone extends between the tidal limits, which in the Alboran Sea oscillate around 30–50 cm. Desiccation during periods of emersion (low tide) and hydrodynamism are the main factors that affect the development of plant communities in this zone. The main adaptations involve the shape of thalli, the most frequent biotypes being crusts, elastic thalli, and thalli with incrustations of calcium carbonate. In this zone, two subsidiary zones can be differentiated (Fig. 8.4a). The upper zone generally appears less populated, whereas in the lower zone, the longer immersion time favors more stable environmental conditions and the presence of species with well-developed thalli. Although the environmental conditions are not optimal for their development, the eulittoral communities constitute the first belt of macroscopic algae that we can observe on the coast.

In the upper zone, red algae are the main and most striking floristic component due to the elastic nature of their thalli. In this first belt of algae, there are species such as *Rissoella verruculosa* (Fig. 8.4b) forming striking bands. This species was considered a Mediterranean endemic, but it is now known in the Canary Islands (Haroun et al. 2003). It develops preferentially on siliceous and dolomitic substrates, so it is absent at Alboran Island (Templado et al. 2006) and in other large areas of the Alboran Sea. Other species characteristics of this community are *Nemalion helminthoides* (Fig. 8.4b), *Rivularia bullata*, *R. atra*, *Ralfsia verrucosa*, *Mesospora macrocarpa*, and several ephemeral and seasonal species such as *Bangia atropurpurea* and *Pyropia leucosticta*. At this level, in areas such as harbors or breakwaters with more unfavorable conditions generally linked to eutrophication, an uncompacted dark brown and very dense belt of *Huismaniella nigrescens* is developed, associated with other opportunistic species such as *Cladophora laetevirens* or *Ulva* spp.

The eulittoral communities of the lower zone present a long list of species with a very characteristic morphology, clearly different from that of the upper zone: a colorful, soft, very compact turf of small algae (Fig. 8.4c). Calcareous algae form the base of this vegetation, sometimes standing out above the rest of the species, depending on the greater or less hydrodynamism. In sheltered environments, a very dense cespitose biotype community develops, where it is difficult to distinguish all the constituents at first sight. Among the most frequent and easily recognizable species are *Huismaniella nigrescens*, *Gelidium latifolium*, *G. pusillum*, *Chondracanthus acicularis*, *Caulacanthus ustulatus*, *Osmundea pinnatifida*, *Hypnea musciformis*, *Ellisolandia elongata*, *Colpomenia sinuosa*, *Champia parvula*, *Cladophora pellucida*, *Chaetomorpha linum*, *Ulva lactuca*, and *U. rigida*, as well as various species of *Polysiphonia* and *Ceramium*. As the intensity of the hydrodynamism increases, they begin to dominate rather than the calcareous algae, while the cespitose vegetation is masked or even disappears on the highly exposed vertical surfaces, where *E. elongata* clearly dominates. In addition to these species, *Lithophyllum incrustans* and *Mesophyllum alternans* frequently occur. At the westernmost extent of the coast of the Iberian Peninsula and on the African coast,

Fig. 8.4 In the eulittoral zone, it is possible to differentiate clearly up to two subsidiary zones characterized by different species (**a**). *Rissoella verruculosa* (below) and *Nemalion helminthoides* (center) are two of the most characteristic species of the first level of the eulittoral zone; *R. verruculosa* appears restricted to non-calcareous substrates (**b**). A macroalgae community of caespitose biotype with a great diversity of species develops in the lower zone of the eulittoral (**c**). Photos: Julio De la Rosa

Fucus guiryi (Fig. 8.5a) and *Lithophyllum byssoides* (Fig. 8.5b) are characteristic species. It must be highlighted that *F. guiryi* reaches its limit of distribution on the European coast of the Alboran Sea at Punta de Calaburras (Mijas, Málaga) and on

Fig. 8.5 *Fucus guiryi* and *Lichina pygmaea* (**a**) are two species restricted to the western basin of the Alboran Sea. *Fucus guiryi* characterizes the infralittoral zone, whereas *L. pygmaea* is a lichen that lives in the supralittoral zone and can also extend to the upper zones of the eulittoral. *Lithophyllum byssoides* (**b**) is a rare species in the Alboran Sea but has a good development on the western African coast of this sea. This species is included in *The Spanish and Andalusian List of Wild Species in Special Protection Regime*. Photos: Julio De la Rosa

the African coast at the western base of the Tres Forcas cape (Punta Negri) and its populations fluctuate under the influence of the North-Atlantic Oscillation (Bañares-España et al. 2017; Melero-Jiménez et al. 2017). On the other hand, although *L. byssoides* has an extensive distribution in the Mediterranean, it is rare in the Alboran Sea except for good development on the western African coast. This species is included in *The Spanish and Andalusian List of Wild Species in Special Protection Regime* (Spanish Royal Decree 139/2011 and Andalusian Decree 23/2012), and it is very sensitive to pollution and trampling. In shaded areas such as cracks or fissures of rocks, sciaphilous species appear, such as *Hildenbrandia rubra*, *Pterocladiella capillacea*, *Gymnogongrus patens*, diverse species of *Peyssonnelia*, *Codium adhaerens*, *Bryopsis muscosa*, and *Valonia utricularis* (Fig. 8.6a).

In the eulittoral zone, there is frequent development of pools that can develop algal communities of high richness and diversity, typical of the upper infralittoral. The kind of communities that develop depends basically on the size and frequency of water renewal in the pool. In those located at a higher level, with relatively extreme conditions of salinity and temperature, masses of filamentous (*Chaetomorpha aerea*) or tubular (*Ulva* spp.; Fig. 8.6b) green algae are frequent. In larger pools that remain filled with water, the vegetation is much more diverse, extending the cover of the infralittoral vegetation. Species such as *Halopteris scoparia*, *Padina pavonica*, *Dictyota dichotoma*, *Plocamium coccineum*, *Gelidium* spp., and *Ellisolandia elongata* may appear, sometimes with even larger species such as *Cystoseira compressa*, *C. tamariscifolia* (Fig. 8.6c), *Sargassum vulgare*, *Asparagopsis armata*, and *A. taxiformis*.

When the eulittoral communities are affected by various eutrophicating pollutants, there is a considerable decrease in their biodiversity. The more usual species are replaced at first by more opportunistic and eutrophication-tolerant species such as *Bangia atropurpurea*, *Pyropia leucosticta*, and *Ulva* spp. With extreme

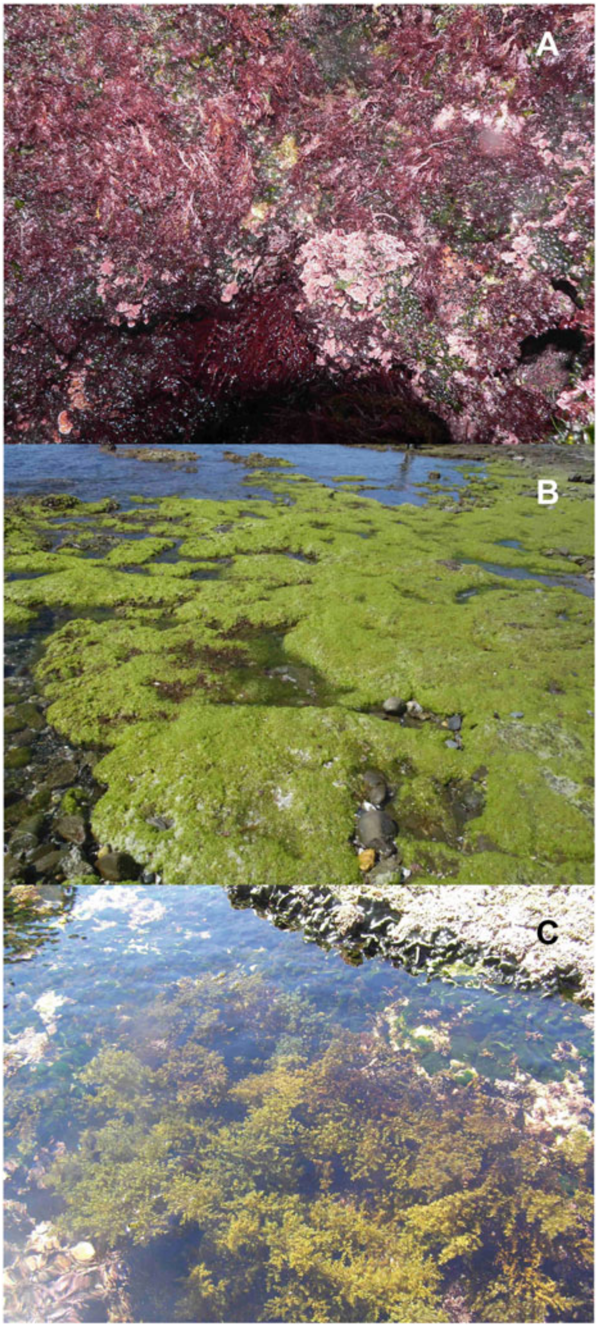

Fig. 8.6 Sciaphilic environment and strong hydrodynamism with *Pterocladiella capillacea*, *Ellisonlandia elongata*, and *Valonia macrophysa* in the eulittoral zone (**a**). Development of Ulva compressa populations in the eulittoral zone (**b**). Eulittoral pools with *Cystoseira tamariscifolia* and other large algae (**c**). Photos: Julio De la Rosa

eutrophication, the eulittoral becomes dominated by cyanobacteria (Templado et al. 2012) or other fast-growing filamentous algae.

8.4.3 Infralittoral Zone

The infralittoral zone is permanently submerged. Its upper limit is defined by the absence of species that cannot tolerate emersion, and the lower limit is delimited by the disappearance of seagrasses and photophilic algae. In this zone, water is not a limiting factor, hydrodynamism becomes less pronounced, and salinity is almost constant. The type of substrate and the light gradient are the main factors that influence the development of different communities. It is a habitat of enormous complexity and heterogeneity that shelters a great diversity of biological communities. Rocky substrates with strong irradiance support communities of photophilic algae. It has very diverse communities rich in species, and under optimum conditions, up to four strata can be distinguished depending on the biotypes of its components.

Depending on the degree of hydrodynamism, it is possible to differentiate between communities of exposed or sheltered areas. The former are established in the upper levels at shallow depths where wave action is important. In the Alboran Sea, this community is represented by *Cystoseira tamariscifolia* forests (Fig. 8.7a). Except on Alboran Island (Templado et al. 2006) and the Chafarinas Islands, it does not usually form a continuous belt; instead scattered, small forests are restricted to areas with strong hydrodynamism. According to the degree of coverage, the basal layer of the incrusting *C. tamariscifolia* communities is usually formed by *Mesophyllum alternans* or *Lithophyllum incrustans* (Gofas et al. 2014). In addition, other species such as *Ellisolandia elongata*, *Jania rubens*, *Hypnea musciformis*, *Osmundea pinnatifida*, *Laurencia* spp., *Gelidium* spp., or *Valonia utricularis* are present. On Alboran Island, in areas more protected from the action of the waves, *Cystoseira tamariscifolia* is replaced by species such as *Cystoseira compressa* and *Gelidium latifolium*, sometimes accompanied by *Cystoseira balearica*, *C. sauvageauana*, *C. elegans*, or *C. foeniculacea* (Gofas et al. 2014). When the availability of light is reduced, a cover of sciaphilous algae develops, such as *Hildenbrandia crouaniorum*, *Plocamium coccineum*, *Pterocladiella capillacea*, *Peyssonnelia rubra*, *Cladophora pellucida*, *Bryopsis plumosa*, *B. cupressina*, *Valonia utricularis*, and *Codium* spp.

In sheltered areas, a very diverse community of photophilic algae develops. This community covers a large part of the rocky surfaces of the Alboran Sea coastline and constitutes one of the most easily observed landscape units. This biocenosis would correspond to a forest dominated by Fucales, with various species of *Cystoseira* as characteristic and dominant elements, and in certain environments also by *Sargassum vulgare* (Gofas et al. 2014). On Alboran Island, *Cystoseira tamariscifolia* is replaced by *C. nodicaulis*. The latter species appears between 3 and 4 m depth and extends to something more than 10 m. However, these communities dominated by

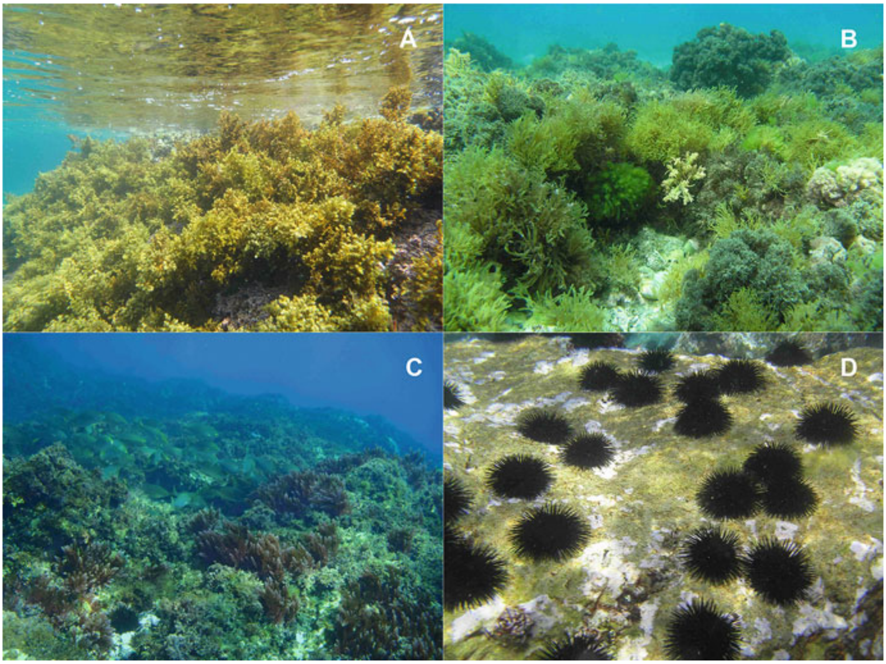

Fig. 8.7 *Cystoseira tamariscifolia* characterizes the first level of the infralittoral zone. It develops small forests that harbor a large amount of associated flora and fauna. Corallinaceous algae such as *Ellisolandia elongata* form the basal stratum (**a**). Photophilic algae in sheltered areas with absence of Fucales and with Sphacelariales (*Halopteris scoparia*, *Cladostephus spongiosus*) and Dictyotales (*Dictyota* spp.) as more prominent elements (**b**). Photophilic algae in sheltered areas with *Asparagopsis taxiformis* (**c**). Biocenosis of encrusting red algae with the sea urchin *Arbacia lixula*. The excessive grazing of this species causes the disappearance of larger algae, and only those with calcified and encrusting thalli such as *Lithophyllum incrustans* can survive (**d**). Photos: Julio De la Rosa

Fucales are clearly declining along much of the coastline of the Alboran Sea (Ballesteros and Pinedo 2004; Templado et al. 2012; Gofas et al. 2014). Their presence is currently restricted to certain areas such as Alboran Island, the Chafarinas Islands, or sites on the North African coast (Templado et al. 2006; Gofas et al. 2014). They have practically disappeared from the northern coasts of the Alboran Sea. Among the factors that may have caused this decline is pollution, because *Cystoseira* spp. are very sensitive to eutrophication. Other factors are overgrazing by sea urchins and competition with exotic species of marked invasive nature such as *Asparagopsis* spp. (Ballesteros and Pinedo 2004). The result is that this community is replaced by a shrubby biotype dominated mainly by the brown algae *Cladostephus spongiosus* and *Halopteris scoparia,* accompanied by many others, such as *Halopithys incurvus*, *Jania rubens*, *Haliptilon virgatum*, *Amphiroa rigida*, *Liagora viscida*, *Colpomenia sinuosa*, Dictyotales such as *Padina pavonica*, *Dictyota dichotoma*, *D. cyanoloma*, *Taonia atomaria* or *Dilophus spiralis*, *Sargassum vulgare*, or the relict tropical species *Dasycladus vermicularis* and *Acetabularia acetabulum*, both restricted to the most eastern area of the Alboran Sea (Fig. 8.7b). *Asparagopsis armata* and *A. taxiformis* are very characteristic elements and in many cases are the dominant species of the underwater landscape of this biocenosis (Fig. 8.7c).

A community widespread at this level, and which characterizes large areas of the rocky underwater landscape of the Alboran Sea, is the so-called community of encrusting red seaweed and sea urchins. This community derives from the community of photophilic algae, in which excessive grazing by sea urchins (*Paracentrotus lividus* and *Arbacia lixula*) causes the total disappearance of the erect algal component. Such overgrazing leaves only the calcareous encrusting thalli of species of red algae, the most usual being *Lithophyllum incrustans*, recognizable by its characteristic white-pink color (Fig. 8.7d).

In areas with a significant limitation of light, either by depth or by the contours of the substrate, the community of hemisciophilous algae, so-called precoralligenous community, is developed. This community is a transition between the infralittoral and circalittoral zones. In these shaded environments, some species of algae are adapted to these low-light conditions. *Cystoseira usneoides*, a larger species, forms important forests in certain areas of the Alboran Sea (Fig. 8.8a). As was the case in the previous community, the typical *Cystoseira* species of this community are also usually absent, with *Asparagopsis* spp. being the most important and abundant elements. At Alboran Island, this community maintains high levels of coverage and development, even though the population of the sea urchin *Sphaerechinus granularis* is also very high, so the absence of these communities in the rest of the Alboran Sea coast may be more related to pollution or competition with *Asparagopsis* spp. than with excessive grazing by sea urchins. Among the species appearing with *C. usneoides* are *Halopteris filicina*, *Dictyopteris polypodioides*, *Zonaria tournefortii*, *Sphaerococcus coronopifolius*, *Plocamiun cartilagineum*, *Codium bursa*, *C. vermilara*, *C. effusum*, *Flabellia petiolata*, *Valonia macrophysa*, *Bryopsis plumosa*, *B. cupressina*, *Lithophyllum stictaeforme*, *Peyssonnelia* spp., *Mesophyllum alternans* (which forms large calcareous concretions), or *Halimeda tuna* (present in the easternmost part of the Alboran Sea). In these populations of *Cystoseira usneoides*, frequently species of Laminariales have better development in zones at greater depths.

At greater depths than in the communities of *C. usneoides*, forests of the large kelps *Laminaria ochroleuca* and *Saccorhiza polyschides* develop (Fig. 8.8b). The underwater landscape dominated by these large algae forms a well-structured and stratified community with a high associated biodiversity that can penetrate into the circalittoral zone. Under the canopy of these large kelps proliferate the small kelps *Phyllariopsis purpurascens* and *P. brevipes*, together with *C. usneoides*. Other species associated with these communities are in general the same ones found in the previous mentioned *C. usneoides* formations, together with other species such as *Fauchea repens*, *Halymenia floresia*, *Gelidium* spp., *Kallymenia* spp. and *Sebdenia* spp. The species of *Phyllariopsis* can form their own communities at deeper levels

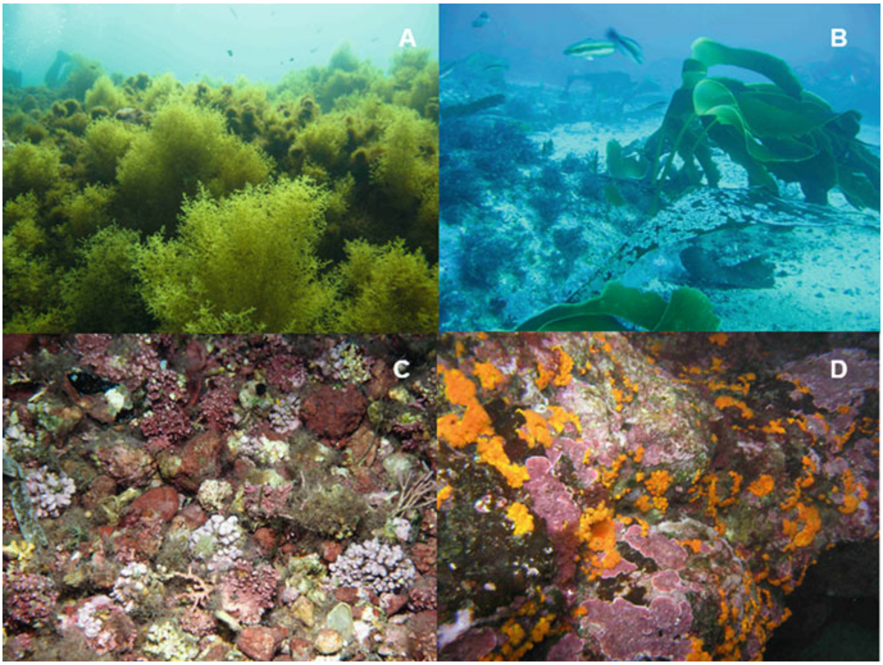

Fig. 8.8 Significant forests of *Cystoseira usneoides* develop in certain areas of the Alboran Sea, such as Alboran Island and the African coast of this sea, and on the western end of the Iberian Peninsula coast, between Estepona (Málaga) and the Strait of Gibraltar (**a**). Forests of *Laminaria ochroleuca* with *Saccorhiza polyschides*. These formations are very rare in the Alboran Sea, but they develop at the Strait of Gibraltar and Alboran Island (**b**). Maerl bed with high diversity of corallinaceans (**c**). Community of sciaphilic algae in the circalittoral zone with *Lithophyllum stictaeforme*, *Plocamiun coccineum*, and *Peyssonnelia rubra* (**d**). Photos: (**a**, **b** and **d**) Julio De la Rosa; (**c**) Diego Moreno/Sustainable Marine Environment Management Program/Andalusia Government

associated with red corallinaceous algae and other red algae with laminar thalli typical of the circalittoral zone.

Infralittoral soft substrates are commonly formed from residual rhizome mats of marine seagrasses or, in some cases, by the green alga *Caulerpa* spp. which develop a structural pattern that resembles that of seagrass, and they can develop on this more unstable type of substratum. In the Alboran Sea, two *Caulerpa* species develop such meadows. *C. prolifera* is native in this sea, although it has become increasingly rare and is currently restricted to localized areas, in many cases associated with marine seagrasses. *C. cylindracea* (Fig. 8.2c) is an invasive exotic species that has also colonized other infralittoral habitats such as hard substrates, seagrass meadows, or maerl beds.

Invasive alien species stand out among the factors that cause loss of native biodiversity in marine communities. Some of the communities in the Alboran Sea have been drastically affected by the arrival of some of these species. As previously mentioned, *Asparagopsis armata* (Fig. 8.2a) and *A. taxiformis* (Fig. 8.2b) are two very characteristic elements and in many cases are the dominant ones of infralittoral communities, both in photophilic and hemisciaphilous environments. *Caulerpa cylindracea* is an exotic species of Australian origin that has spread over much of the bottoms of Alboran Sea, both on the African coast and on the Iberian Peninsula, invading habitats as diverse as eulittoral pools, seagrass meadows, infralittoral hard and soft bottoms, maerl, and coralligenous substrates. The arrival of *Rugulopteryx okamurae* (Fig. 8.2d) is especially dramatic. Although its presence in the Alboran Sea is currently restricted to the westernmost area (both shores of the Strait of Gibraltar) and isolated sites on the coast of Málaga (Altamirano et al. 2016; García Gómez et al. 2018), Granada and Almería its development has drastically transformed the underwater landscape, especially the infralittoral hard bottoms. This species is the main, and at times almost unique, representative of these "new communities," with coverage close to 100% in many cases and with very high biomass values.

The Alboran Sea has the particularity of coverage on some sandy bottoms of the infralittoral meadows of all four species of seagrasses found in Europe (*Posidonia oceanica*, *Cymodocea nodosa*, *Zostera marina*, and *Z. noltei*), sometimes coexisting in relatively restricted areas. A good example is Roquetas de Mar in Almería, where at the end of the twentieth century, the four species were present together in a very restricted area (Moreno and Guirado 2003). The coexistence of the four species is very rare in other parts of the Mediterranean, such as at Cala Jonquet on the Costa Brava (Cebrián et al. 1997). Regrettably, *Z. marina* has practically disappeared in recent years from the Alboran Sea (Arroyo et al. 2015) and other localities in the Mediterranean such as Catalonia (Romero et al. 2015) for various reasons, so it is no longer possible to find all four species in the same area.

The presence of seagrasses substantially modifies the soft substrates on which they attach, constituting a new habitat that in many ways is intermediate between sediments and rocky bottoms. This effect is very noticeable, especially in the meadows of *P. oceanica*, which is the largest species and whose presence most extensively transforms the characteristics of the seabed. The new marine habitat formed by the meadows consists almost entirely of seagrasses, since the great majority of the macroalgae do not have the capacity to attach to soft substrates.

The meadows of *P. oceanica* constitute one of the main climax stages of Mediterranean coastal ecosystems (Díaz-Almela and Duarte 2008). The meadows are heterogeneous, with many species of hard bottoms found among the rhizomes of the seagrasses, while organisms typical of soft substrates can also be found in them, mainly in sediment-filled channels. Many species live preferentially in these meadows, and some are exclusive to them, mainly those that live in the foliar stratum between the leaves. We must not forget that the meadows serve as the home for many species of commercial interest for their whole lives, or else one phase of the life cycle, such as the juveniles of many pelagic species (Urra et al. 2013; Rueda et al. 2015).

The flora that seagrass meadows host is similar to that of the nearby hard substrates, but there are many organisms in the foliar stratum, where algae are the most important component of the epiphytes that cover the leaves. Among the seaweeds that colonize the leaves of *P. oceanica* are small coralline algae such as *Pneophyllum fragile*, *Hydrolithon farinosum*, and *Titanoderma pustulatum* (Templado et al. 2004). These algae are pioneers in the colonization of the leaves and can become dominant, covering more than 40% of the surface. The erect seaweeds colonize the leaves later and are dominant in the late phases until the excess of epiphytes causes the loss of the leaves. Among these algae are *Giraudya sphacelarioides*, *Cladosiphon cylindricus*, *Sphacelaria cirrosa*, *Dictyota linearis*, *Ectocarpus siliculosus*, *Acrochaetium daviesii*, *Stylonema alsidii*, *Ceramium flaccidum*, *Dasya corymbifera*, and *Cladophora albida* (Templado et al. 2004). In the stratum of rhizomes, a shadier environment, there are very abundant species of the genus *Peyssonnelia*, especially *P. rubra* and *P. squamaria*, and other species such as *Jania rubens*, *Valonia utricularis*, and *Flabellia petiolata*, among many others. However, the most important alga in the rhizomes is *Mesophyllum alternans* (in the literature often as *M. lichenoides*), a red alga that forms concretions of about 40 cm in diameter and that can reach up to 80 cm and that are very characteristics of the meadows of *P. oceanica* from the Alboran Sea (Junta de Andalucía 2012). These concretions are very interesting because they provide shelter to an abundant microfauna of mollusks and crustaceans and support other rhodophytes such as *Amphiroa rigida*, *Jania rubens*, *Peyssonnelia* spp., etc. (Hergueta et al. 2004).

8.4.4 Circalittoral Zone

The progressive attenuation of solar irradiance determines the lower limit of the upper zone. It is a gradual attenuation, so changes do not occur abruptly and a clear boundary with the infralittoral is not always present. Different biological indicators are considered to establish the border between both areas, such as the distribution limit of seagrasses, the substitution of photophilic species for sciaphilous ones (e.g., *Halopteris scoparia* for *Halopteris filicina*), or the presence of populations of deep-water species such as *Cystoseira zosteroides*.

The community of hard bottoms in the circalittoral zone is called the coralligenous community. The depth at which it is found provides great stability in terms of hydrodynamism and temperature. The coralligenous community is structured in several strata, but the floristic component is restricted to the basal layer and is composed of species of red calcareous algae. These algae have a structural role of great importance as generators of microhabitats that make possible the complexity and diversity of this community (Ballesteros 2006). The coralligenous is a very heterogeneous community and is considered among those that host the greatest biodiversity in the Mediterranean, next to the *Posidonia oceanica* meadows (Gofas et al. 2014). Among the corallinaceous species are *Mesophyllum alternans*, *Lithophyllum incrustans* or *L. stictaeforme*, several species of *Peyssonnelia*, and other algae with soft and small thalli such as *Phyllophora crispa*, *Flabellia petiolata*, *Codium* spp., *Valonia macrophysa*, *Zonaria tournefortii*, *Halopteris filicina*, *Dictyopteris polypodioides*, *Arthocladia villosa*, and *Sporochnus pedunculatus*, among many others. As previously mentioned, they can also include *Phyllariopsis purpurascens* and *P. brevipes*.

At this level, as well as on infralittoral bottoms, the community of maerl is developed. This community consists of red calcareous algae forming rhodoliths (also known as rhodolithic bottoms), whose thalli grow three-dimensionally into spheroids that facilitate both their movement along the bottom and the maximum use of the scant incident light. These communities are restricted to certain areas close to capes, usually with intense currents. Smaller rhodoliths are found on shallower bottoms, whereas the larger ones tend to occur at greater depths. In Alboran Sea, the smaller rhodoliths appear from 20 m depth, whereas those of average size and larger are found at 30–40 m (Gofas et al. 2014). The typical maerl-forming species are *Lithothamnion coralloides* and *Phymatolithon calcareum*, which are accompanied by *Peyssonnelia* spp (Fig. 8.8c). Other characteristic species of these maerl bottoms are *Zanardinia prototypus*, *Bonnemaisonia asparagoides*, *Fauchea repens*, *Phyllophora crispa*, *Botryocladia botryoides*, *Kallymenia* spp., *Sebdenia* spp., *Scinaia* spp., *Flabellia petiolata*, and *Codium* spp. The composition of the community associated with maerl beds of Alboran Island presents remarkable variations depending on the depth. In the shallowest part, macroalgae such as *Ulva rigida* or the kelp *Laminaria ochroleuca* are often fixed to rhodoliths. Here the specific composition of the calcareous algae can vary, and the coverage of non-calcified algae decreases (Gofas et al. 2014). The growth of the rhodoliths requires very particular environmental conditions, which is why these bottoms are relatively rare and confined to small areas in the Alboran Sea (Ramos Esplá and Luque 2004). These communities are very structured, harboring a great diversity in both species and functional richness.

Semi-dark caves and the entrances of caves and tunnels can occur at any bathymetric level of the infralittoral zone. In these permanently submerged environments, the light conditions are very similar to those described for the circalittoral horizon, so the species that develop are the same as in the coralligenous community. The intensity of hydrodynamism determines the presence or absence of certain species. Among those that can be observed are encrusting red algae such as *Lithophyllum stictaeforme* or *Mesophyllum lichenoides* and others such as *Hildenbrandia* spp. or various species of *Peyssonnelia* (Fig. 8.8d).

In the infralittoral and circalittoral on detritic sedimentary bottoms, on which materials of terrigenous and biogenic origin are mixed, a community is developed in which the algal cover consists small species whose attachment systems allow them to develop on the limited surfaces offered by this type of substrate. Many of these algae are also present in the maerl bottoms, and some of them can be found together with corallinaceans already mentioned before such as *Scinaia furcellata*, *Peyssonnelia rosa-marina*, *P. rubra*, *Phyllophora crispa*, *Halopteris filicina*, *Zanardinia prototypus*, *Arthrocladia villosa*, *Sporochnus pedunculatus*, *Phyllariopsis brevipes*, *Flabellia petiolata*, *Valonia utricularis*, and *Codium* spp. among others.

8.5 Critical Locations for Marine Vegetation Biodiversity and Conservation in the Alboran Sea

This section presents a selection of areas of exceptional interest (Fig. 8.9) due to the high biodiversity and healthy condition of the benthic macroalgae or seagrass communities. Most of these locations are in protected areas, and they are accessible for direct observation by snorkel or scuba diving.

To observe the different seaweed and seagrass communities, it is important to take into account the seasonality of many of the organisms. Some species have a seasonal development (annual species), while others are perennial species. In general, the period between spring and early summer is the best time to see most of them in their well-developed state. Others, such as those formed by encrusting red seaweeds, maerl beds, or seagrass meadows, can be seen at any time of the year, although the biodiversity associated with them may vary during the year.

Most of the areas discussed below are included in the Natura 2000 network. It is necessary to keep in mind that, in order to access an area for recreational or scientific activities, permission is required from the area management administration, which is why prior consultation is recommended. Detailed information for a large part of

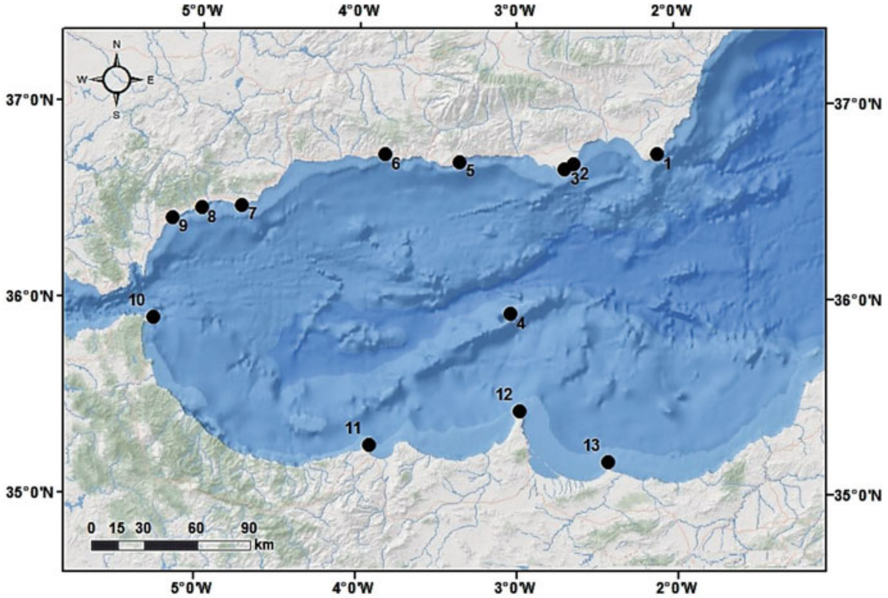

Fig. 8.9 Locations with especial interest for marine vegetation biodiversity and conservation in the Alboran Sea. 1, Cabo de Gata; 2, Roquetas de Mar; 3, Punta Entinas-Sabinar; 4, Alboran Island; 5, Acantilados y Fondos Marinos de Calahonda-Castell de Ferro; 6, Acantilados de Maro-Cerro; 7, Calahonda; 8, Placer de las Bóvedas; 9, Estepona; 10, Ceuta; 11, Al Hoceima; 12, Cape Tres Forcas; 13, Chafarinas Islands

these areas also can be obtained on the web site of the relevant environmental administration.

1. *Cabo de Gata*. Located at the eastern limit of the north shore of the Alboran Sea, in the Natural Park Cabo de Gata-Níjar (province of Almería). It features extensive meadows of *P. oceanica* (Fig. 8.10a) and *C. nodosa* (García Raso et al. 1992), and for this reason, this site was selected for the installation of an artificial reef in order to preserve the meadows (Moreno et al. 2005, 2006). The important natural values of the area allow it to be declared, as well as marine-terrestrial Natural Park, Marine Reserve, Specially Protected Areas of Mediterranean Importance (SPAMI) area, Geopark, and Biosphere Reserve.
2. *Roquetas de Mar*. Located in the southeast of the Iberian Peninsula (province of Almería). The importance of this marine area lies in the presence of *Posidonia oceanica* seagrass meadows that form a unique barrier reef of great interest. It is one of the few *P. oceanica* reefs that survive on the Mediterranean coast and is unique on the coast of the Alboran Sea. In 2001 it was designated as *Posidonia* Barrier Reef Natural Monument (Fig. 8.10b, c) and in 2016 as a Special Area of Conservation (SAC). *Cymodocea nodosa* and *Zostera noltei* occur in addition to *P. oceanica*. Among the algae, the invasive species *Asparagopsis taxiformis* and *Caulerpa cylindracea*, which have recently spread widely, are conspicuous.
3. *Punta Entinas-Sabinar*. Located in front of the localities of El Ejido and Roquetas de Mar (province of Almería). The presence of various habitats of community interest (Directive 92/43/EEC) led to its designation as SAC Fondos Marinos de Punta Entinas-Sabinar. It is heterogeneous, with alternating sandy areas and rocky outcrops, ranging 5–30 m in depth. On the deepest bottoms, there are detrital sediments with maerl. The main attraction is the extensive *P. oceanica* meadow, which constitutes a habitat of community interest as the largest known western meadow of the Mediterranean coast, reaching 25 m deep. There are also *Cymodocea nodosa* meadows, but these are of smaller extent. Within these meadows, stands of *Zostera noltei* appear on muddy sand bottoms. Outside the meadows of *P. oceanica*, there are detritic bottoms with areas of maerl, with corallinaceans and a rich associated flora. On the rocky substrates, a very diverse community of algae proliferates.
4. *Alboran Island*. Located in the center of the Alboran Sea, the entire perimeter of the island consists of cliffs with heights around 10 m, with small caves and an extensive rocky platform. Next the island, to the NE, is the islet of Nubes. The bottoms around the island host a large number of marine species in a magnificent state of conservation; however, seagrasses are not present (Templado et al. 2006) as the bottoms are mainly rocky and with high hydrodynamism. The high biodiversity on the island is also proof of its good conservation, which has contributed to its designation as both a Marine and Fishing Reserve and as a Natural Place. It is also a site included in the list of SPAMI. In the Alboran Sea, large kelps such as *Laminaria ochroleuca* and *Saccorhiza polyschides* and the small kelps *Phyllariopsis brevipes* and *P. purpurascens* are scarce, but here their presence between 40 and 60 m depth is noteworthy, although they can also be

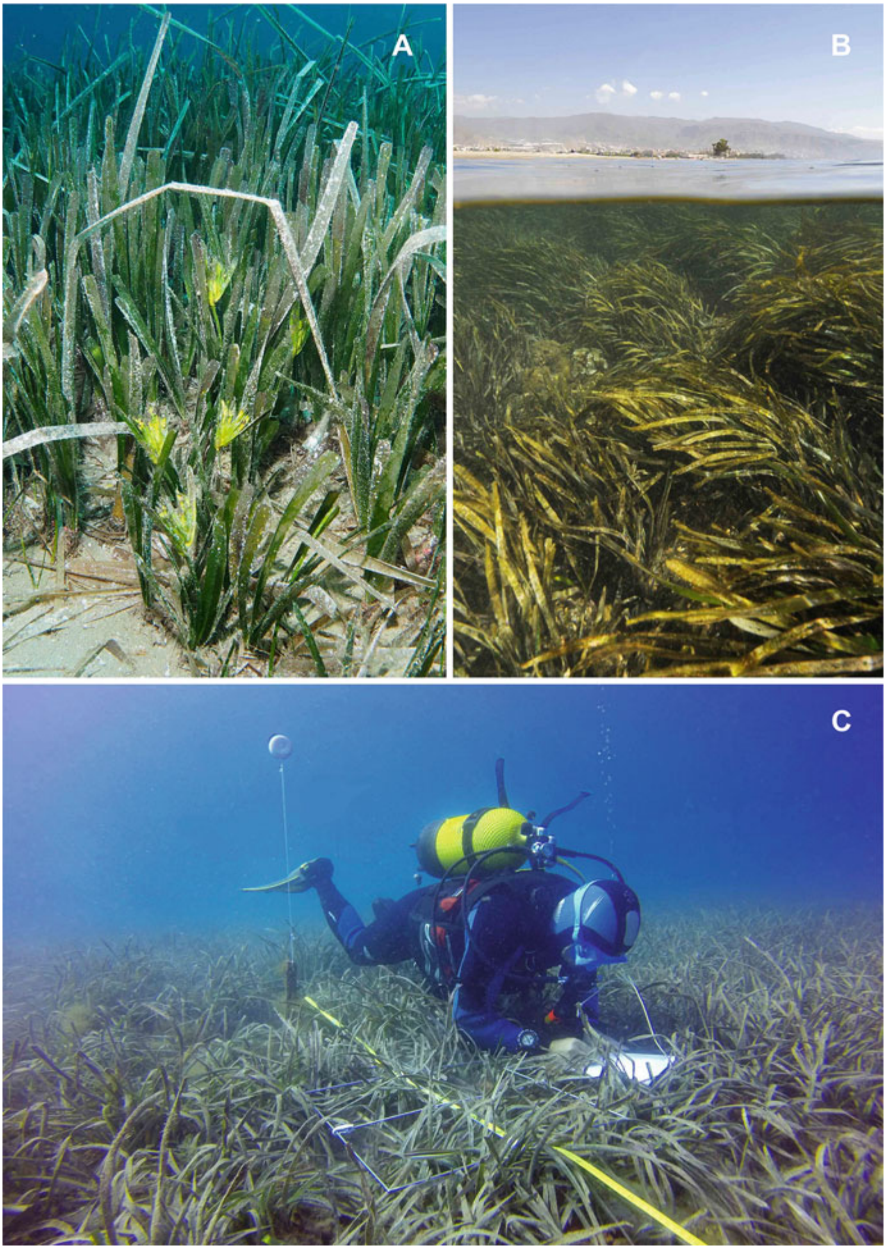

Fig. 8.10 Abundant flowering of *Posidonia oceanica* observed at −12 m in Agua Amarga, Cabo de Gata-Níjar Natural Park (Almería, Andalusia), in November 2017 (**a**). The seagrass that arrives at surface in the Barrier Reef of Posidonia, located in Roquetas de Mar, Almería (Andalusia), is considered as a Natural Monument within the Network of Natural Protected Natural Areas of Andalusia (**b**). Monitoring of a *Posidonia oceanica* fixed station within the POSIMED network by technical and voluntary divers, obtaining density and coverage among other parameters. Roquetas de Bajos, Almería (Andalucía), at 11 m (**c**). Photos: Diego Moreno/Sustainable Marine Environment Management Program/Andalusia Government

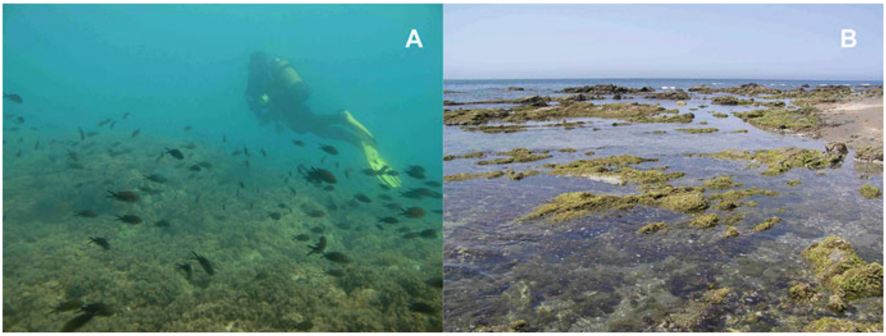

Fig. 8.11 Community of *Halopteris scoparia* on the cliffs of Calahonda-Castell de Ferro (**a**). Potholes in the eulittoral where a rich and varied flora of algae develops. These habitats are very well represented in the SAC of Calahonda (**b**). Photos: Julio De la Rosa

observed from 25 to 30 m depth. Of particular interest are the photophilic and hemisciaphilous algae forests of the different species of *Cystoseira* (*C. tamariscifolia*, *C. nodicaulis*, *C. usneoides*) and the maerl beds with a rich flora of corallinaceae and non-calcareous species. Details of the studies on the algal flora from Alboran Island are presented in Sect. 8.1 of this chapter.

5. *Acantilados de Calahonda-Castell de Ferro*. This stretch of cliff coast is located between the localities of the same name in the province of Granada. This coastline extends approximately 9 km, with several coves or inlets. The SAC of the Acantilados y Fondos Marinos de Calahonda-Castell de Ferro and other nearby areas such as the SAC de Acantilados y Fondos Marinos de la Punta de la Mona are hotspots for the conservation of marine biodiversity on the north shores of the Alboran Sea (Fig. 8.11a). This area presents a very good state of conservation with a great variety of habitats such as large cracks, semi-submerged and submerged caves, islets, and large blocks of stone. In the eulittoral zone, important populations of *Rissoella verruculosa* and *Cystoseira tamariscifolia* can be observed. In the infralittoral zone, photophilic algae communities develop in both exposed and sheltered environments. The formations of *Mesophyllum lichenoides* acquire a spectacular development in certain areas at this site, almost unique in the littoral of the province of Granada. From 18 to 20 m depth at the base of the cliffs, precoralligenous communities develop. The abundance of large cracks, cavities, overhangs, and very shallow caves allows the observation of communities of red corallinaceous algae.
6. *Acantilados de Maro-Cerro Gordo*. Located between the provinces of Granada and Malaga. It is a coastal strip of about 12 km, with a cliff face along which beaches and small coves are interspersed. The great diversity and biological richness of this area, both marine and terrestrial, have inspired several protection measures on the part of the regional and European environmental administrations. In 1989 it was declared a Natural Place and in 2015 as a special conservation area. It is also an area included in the SPAMI list. The marine portion is home to an important and rich natural heritage, highlighted by the presence of

P. oceanica and communities of sciaphilous algae in the various caves and large cavities present on its bottoms. The eulittoral communities are also of great interest, where important developments of *Rissoella verruculosa* can be observed, being one of the main enclaves of the Alboran Sea where this species develops. The bottom reaches a maximum depth of around 25 m in the Punta de Cerro Gordo, although the plant communities of greatest interest in this area are between 0 and 12 m. Eulittoral pools and populations of *Cystoseira tamariscifolia* are well developed in this area. *Mesophyllum lichenoides* also shows significant development in certain areas.

7. *Calahonda*. Located on the western coast of the province of Malaga (not to be confused with the Acantilados y Fondos Marinos de Calahonda-Castell de Ferro, detailed in #4; these two Andalusian localities have similar names). The presence of natural habitats compiled in Directive 92/43/EEC justified the designation of this area as a SAC. It is a terrestrial and maritime area located on the continental shelf, which includes a small strip of land along the shore, formed by sandy beaches and rocky outcrops. The SAC of Calahonda is an area of relevance for its biological diversity and has one of the richest faunal and floristic heritages of Europe (García Raso et al. 2010). The rocky platforms and eulittoral pools have a rich flora, even including the seagrass *Cymodocea nodosa*. In the eulittoral appears *Fucus guiryi*, a species that here reaches its eastern limit of distribution on the coasts of the Iberian Peninsula. In the infralittoral, the presence of the seagrasses *Posidonia oceanica* and *Cymodocea nodosa* accompanied by a varied flora of algae stands out. There are large shallow areas of dead *P. oceanica* that probably constituted barrier reefs until a few decades ago.
8. *Placer de las Bóvedas*. The Placer de las Bóvedas is one of the few circalittoral rocky bottoms located off the coast of the province of Malaga, and it is in an excellent state of conservation, constituting an area of extraordinary biodiversity. It is located about 9 km southwest of San Pedro de Alcántara, between Estepona and Marbella. It is a set of underwater elevations, the shallowest at 25 m depth. The marine flora proliferates down to 40 m depth, characterized by encrusting coralline formations and maerl beds. This area was included in the proposed Special Area Conservation El Saladillo-Punta de Baños in 2016 (the final status must be recognized by the EC, but at the time of writing, it is still pending).
9. *Estepona*. At the eastern end of the bay of Estepona (Málaga) lies the SAC Fondos Marinos de la Bahía de Estepona. Here *Posidonia oceanica* meadows do not exceed 4 m in depth (included in a proposed enlargement to the Special Area Conservation in 2016). These sites are very near the western limit of distribution of this species, at Punta Chullera. In deeper areas, rocky substrates host *Cystoseira usneoides* formations, red corallinaceous algae such as *Lithophyllum stictaeforme* or *Mesophyllum lichenoides*, and extensive communities of the small kelp *Phyllariopsis purpurascens*.
10. *Ceuta*. Ceuta has 21 km of coastline, influenced by Atlantic and Mediterranean waters. Along this coastal strip, cliff areas alternate with coves and beaches.

Large rock formations and sand areas mark the orography of the sea bottoms. In the north bay, there are rocky platforms and reefs with the lichen *Lichina pygmaea*, *Lithophyllum byssoides*, and *Fucus guiryi* as well as a rich flora of cyanophyceans. There are also abundant eulittoral pools with an abundant and rich flora of algae, including *Caulerpa cylindracea*. The infralittoral landscape is completely dominated by *Rugulopteryx okamurae*, although it is possible to see residual nuclei of the native vegetation such as *Cystoseira tamariscifolia* and *C. usneoides* forests, which can be observed in better condition in areas of the southern bay where the colonization by *Rugulopteryx okamurae* is not yet in an advanced state. Typical circalittoral environments exhibit precoralligenous formations with *Mesophyllum lichenoides* and other corallinaceans and a good development of maerl beds, as well as *Laminaria ochroleuca* and *Saccorhiza polyschides* forests.

11. *Al Hoceima*. The National Park of Al Hoceima, to the west of the city of Al Hoceima, includes the coastal cliff face and a good stretch of seabed. Among the algal communities, the forests of *Saccorhiza polyschides* and *Cystoseira usneoides* stand out. Shallow seaweed communities and littoral pools present significant species richness. Submerged caves and tunnels are other elements of interest.
12. *Cape Tres Forcas*. The Cape Tres Forcas is the most outstanding peninsula on the Mediterranean coast of Morocco, designated by Morocco as a site of biological interest in 2005. It has a spectacular coastal environment and has been generally little explored. In the shallower bottoms, important communities of photophilic algae are found such as *Sargassum vulgare* and *Cystoseira tamariscifolia*; in the eastern shore, occasionally *Acetabularia acetabulum*; and in deeper waters, *Saccorhiza polyschides*.
13. *Chafarinas Islands*. The archipelago is composed of three islands of volcanic origin: Congress, Isabel II, and Rey. It is located 2 miles north of the Moroccan village of Ras El Ma. Designated recently as SAC, it is one of the last nearly virgin refuges of the Mediterranean. Access to the islands is restricted exclusively to military or scientific personnel, and diving activities are prohibited except for scientific purposes.

    Its rocky and steep coasts provide an ideal refuge for many species. On the south side of the three islands, on sandy substrate and at shallow depth, extensive meadows of *Posidonia oceanica* extend and to a lesser extent *Cymodocea nodosa*. The shallow platforms host an important flora where one can observe species such as *Rissoella verruculosa* and communities of different species of *Cystoseira*. The abundance of *Sargassum furcatum*, a species especially abundant in both the photophilic and the hemisciophilous communities, is noteworthy, as well as the presence of some tropical species such as *Acetabularia acetabulum*.

8.6 Future Directions in Management and Conservation Biology of Seaweeds and Seagrasses in the Alboran Sea

Marine macrophyte management in Spain began indirectly late in the twentieth century through the designation of several protected areas, mainly on those islands and coastal localities with lesser human influence. After that, the conservation of these habitats was implemented by the enactment of laws, international agreements, and standards. One of the first was the European Council (EC) Regulation 1626/1994, later replaced by the Regulation 1967/2006, most widely known as the "Mediterranean Regulation." This Regulation prohibits fishing with bottom-trawl nets over the *Posidonia oceanica* meadows in the Mediterranean and promotes the installation of artificial reefs. This has reduced the decline of the meadows, at least on the eastern coasts. However, the most relevant regulations for seagrass conservation were the Habitats Directive 92/43 EC and the Council Directive 97/62/EC, adapting the previous directive to technical and scientific progress. Seagrasses are represented in the succeeding designated priority habitats (*Posidonia* beds, 1120, and Coastal lagoons, 1150). Three other community interest habitats may also include seagrass meadows of several species: sandbanks that are covered by shallow seawater all the time (1110), mudflats and sandflats not covered by seawater at low tide (1140), and large shallow inlets and bays (1160).

The setting up of the Natura 2000 network implied the establishment of Sites of Community Interest (SCI) in the marine environment, which in turn the Habitats Directive foresees its final designation as a Special Areas of Conservation (SAC). The final reckoning is that 75% of Spanish seagrass meadows are included within one of the existing marine protected areas. This percentage varies among communities on the Mediterranean coast, ranging from 62 to 96% for the Valencia and Murcia regions, respectively (Guillén and Otero 2015). Nevertheless, this protection is worthless without the approval of the currently developing management plans and the final designation of these areas as Special Areas of Conservation. Moreover, the fostering and improvement of the supervisory and surveillance monitoring, application of the law, and enforcement against infringements must be seriously considered.

The Water Framework Directive (2000/60/EC) includes monitoring of the ecological status of some marine angiosperms to assess the quality of Mediterranean waters. Furthermore, the Marine Strategy Framework Directive (2008/56/EC) also includes marine angiosperms as environmental quality bioindicators complementing the Water Framework Directive assessment in several parameters. The application of both directives may result in stricter control of the harmful human activities affecting these seagrasses.

The Spanish Law of Natural Heritage and Biodiversity (Ley 42/2007) aims to conserve Spanish biodiversity, understood as habitat, species, and genetic biodiversity. For this purpose, an inventory of habitats and marine species was developed (Inventario Español de Hábitats y Especies Marinos, IEHEM) according to the Real Decreto 556/2011. This inventory supplies information to the Spanish catalogue of endangered habitats (Catálogo Español de Hábitat en Peligro de Desaparición, CEHPD) and to the List of Wild Species under Special Protection Regime (Listado de Especies Silvestres en Régimen de Protección Especial, LESPE, Spanish Royal Decree 139/2011 and Orden AAA/75/2012). Concurrently, the Community of Andalusia (Andalusian Decree 23/2012) also compiles the Andalusian List of Wild Species under Special Protection Regime (Listado Andaluz de Especies Silvestres en Régimen de Protección Especial, LAESPE) and the Catalogue of Threatened Marine Species (Catálogo Andaluz de Especies Amenazadas). Both lists (LESPE and LAESPE) include the seagrasses found in the Alboran Sea (*Posidonia oceanica*, *Cymodocea nodosa*, *Zostera noltei*, and *Zostera marina*) and up to 16 algal species, due to their importance for the Mediterranean. For instance, *Cystoseira* is one of the most important genera due to its Mediterranean species diversity and ecological niche, and for this reason, all Spanish Mediterranean species of *Cystoseira* are included, except *C. compressa*. Afterward, the Recovery and Conservation Plan for Threatened Invertebrates and Phanerogams of the Marine Environment was approved by the Andalusian administration in 2017.

The pressure on seagrasses is progressively increasing, although significant progress has been made in public awareness and participation and in the valuation of meadows and their conservation, thanks to the Life+*Posidonia* Andalucía Project (2011–2016) (del Castillo and Díaz-Almela 2014; Mendoza et al. 2014; Mendoza and Alarcón 2014). In addition to the advances in cartography, a network of fixed stations has been established (currently with 35 sites along the Andalusian coast) that support development of a data series of *Posidonia* meadows, demographic data, and flowering records, to date very scarce (Junta de Andalucía 2017). Regarding coastal protection, it is worth highlighting the effort in the declaration of numerous protected areas (at least on the north coast of the Alboran Sea), many of which defined by the presence of marine angiosperm meadows (Aranda and Otero 2014). Proof of this is that almost 95% of the *P. oceanica* meadows in Andalusia are included in the Marine Protected Areas, according to the integrated cartography of the Life Blue Natura (2015–2019, so still in progress), which guarantees their conservation. This integrated cartography is available in the Environmental Information Network of Andalusia REDIAM (Junta de Andalucía 2017).

In addition, in 2017 the "Plan for the Recovery and Conservation of Threatened Invertebrates and Phanerogams of the Marine Environment" was approved in Andalusia (Junta de Andalucía 2017, 2018 and 2019) which includes the four angiosperm species present in the Alboran Sea, identifies pressures and threats, and contemplates concrete action measures. There are many possible lines of improvement and action, as in the case of the management of coastal resources in areas with *P. oceanica* meadows, which require effort in coordination among administrations (national, regional, and local), to achieve effective governance (Guillén and Otero 2015; Otero et al. 2018).

Finally, much progress has been made in facing the threats to the littoral, its species, and its habitats, with the recent approval of the Climate Change Law of Andalusia (Law 8/2018 on measures against Climate Change) that contemplates new management and conservation tools, such as those aimed at conserving the blue carbon stock stored in the centuries-old meadows of *P. oceanica* and other

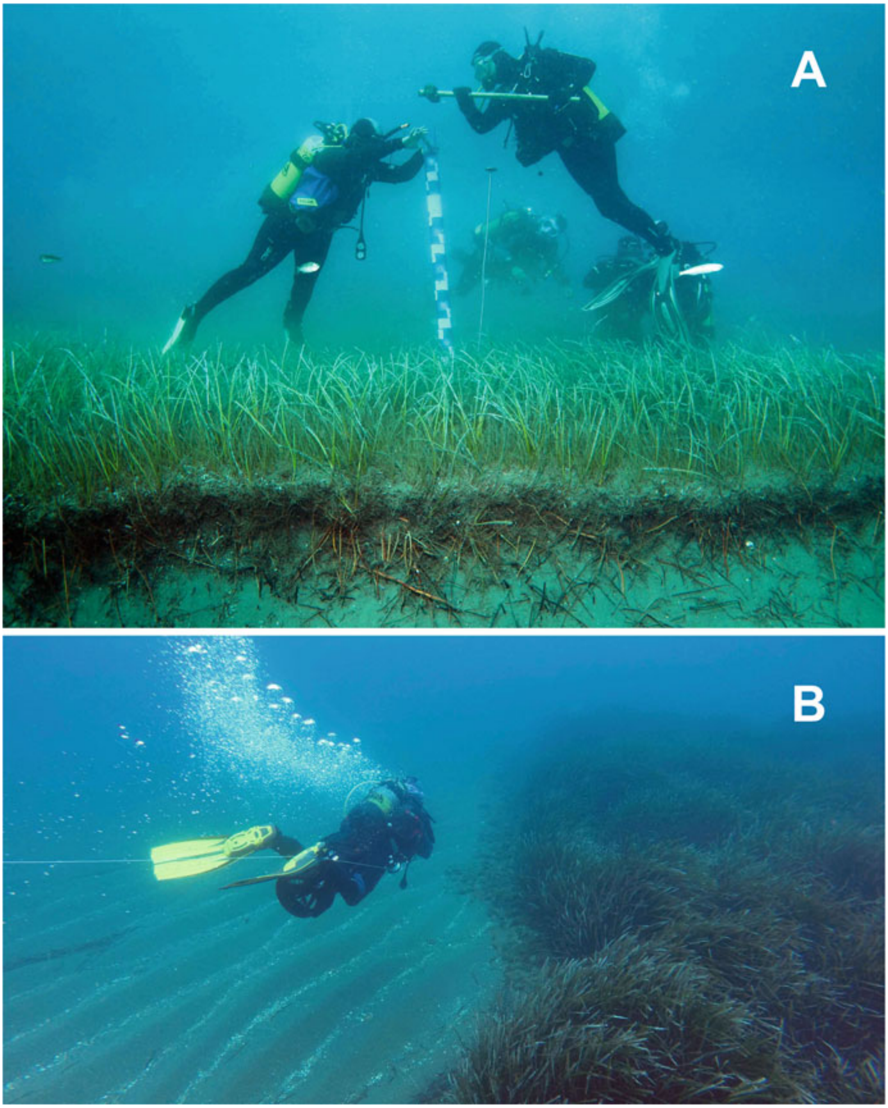

Fig. 8.12 Obtaining a corer by diving in a meadow of *Cymodocea nodosa* at −7 m in the bay of Almeria (Andalusia) to know the carbon stock. CSIC campaign for Life Blue Natura, in October 2016 (**a**). Bordering a *Posidonia oceanica* meadow at −10 m, with a submarine scooter and GPS on the surface buoy, to perform a detailed cartography for the Life Blue Natura. Bay of Almería (Andalusia), July 2016 (**b**). Photos: Diego Moreno/Sustainable Marine Environment Management Program/Andalusia Government

seagrasses (Mateo et al. 2018). In the final phase of the Life Blue Natura, the objective was to know the magnitude of this carbon stock (Figs. 8.12 and 8.13) and how to maintain it over time through conservation and regeneration projects in

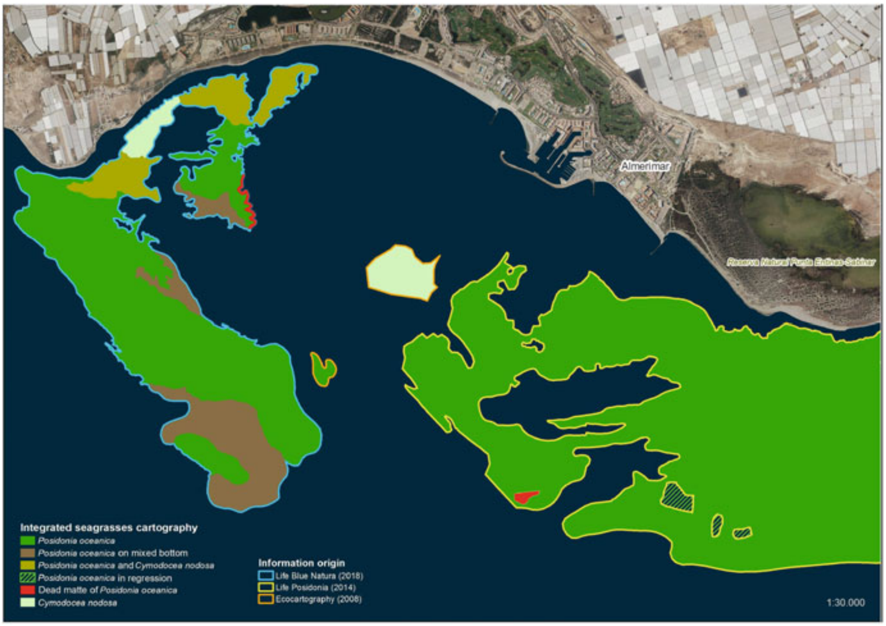

Fig. 8.13 Detail of the integrated cartography obtained for the Life Blue Natura from different sources. Bay of Almerimar in Almería (Andalusia). Map and photo: María Teresa Carreto/Sustainable Marine Environment Management Program/Andalusia Government

marine angiosperm meadows and to define a quality standard for these projects. There have been some attempts at restoration by transplanting plantlets of *Posidonia oceanica* and *Cymodocea nodosa*, but success was limited and transplants did not survive more than 2 years. The limited growth of *Posidonia oceanica* and its substrate requirements probably constrain the possibilities of its use as primary restoration species. Even so, transplantations using the more rapidly growing species *C. nodosa* were also useless (Guillén and Otero 2015). The noticeable regression of *Zostera marina* populations along the Andalusian coasts (Arroyo et al. 2015) represents an important diversity loss in the Alboran Sea. Moreover, because these populations supported a higher diversity of faunistic communities, as is found in eelgrass beds in Europe (Rueda et al. 2009), their regression entails a detriment to ecosystem services. Moreover, the persistent lack of recovery could be the result of a change in the feedback mechanisms, which now keeps the degraded ecosystem in a new stable state, hindering recovery (reviewed by Maxwell et al. 2016). Therefore, although there are successful eelgrass restoration examples in several countries where this practice has been used for decades, the time elapsed since the disappearance of the species also complicates its recovery (Moksnes et al. 2018). So, more emphasis is needed on obtaining high-quality and more accurate information about characterization of the habitat and, hence, the species requirements. Unfortunately, this information is still deficient compared to terrestrial ecosystems. Moreover, not only the specific ecological requirements but also information about different methodologies to perform efficient species conservation, such us in vitro propagation, seed germination, planting techniques, and so on, are still sparse. All this information could be used to perform mathematical modeling to assess highly favorable sites for various species. Careful site selection for restoration is essential for transplantation to succeed, even though the marine ecosystem represents a highly complex environment presenting many variables that escape control by the researcher. Once a site is selected as a function of environmental conditions, then natural storms, currents, and grazers are the most common factors that have to be considered. Future management models necessarily must incorporate the authorities' goal of enhancing the investment by promoting high-quality research focusing on marine restoration. Moreover, marine ecosystem restoration should not be only focused on angiosperm species but also on endemic and/or key ecological species such as canopy-forming algae species.

Climatic change, pollution, overfishing, and recurrent invasions of non-native species in the Mediterranean constitute the major threats for these species at present. In this sense, prevention of non-native species invasions, early-warning systems, and the maintenance of a good ecological marine status may be crucial for seaweed and seagrass conservation in the Alboran Sea.

8.7 Main Threat to the Benthic Flora of the Alboran Sea

The Alboran Sea is not immune from the loss of biodiversity that is occurring on a global scale, without any signs of deceleration. Pressures on the environment in general, and the sea in particular, have increased in recent decades, and efforts to control this loss of biodiversity have been inappropriate in most cases. Some authors have not hesitated to call this Anthropocene event the "sixth extinction." In the case of marine plant communities, this loss of biodiversity translates not only into the loss of species but also drastic changes that affect the relationships among them and the structural and functional simplification of the community. The result is the development of very homogenous communities with a low structural and functional organization. The marine macroalgae and angiosperms, and the communities to which they give rise, have an important bioindicator characteristic (Sánchez Castillo 2006; Templado et al. 2012), which makes these plant formations of special relevance as a management tool for marine natural spaces. The conservation of these communities is essential.

Among the different threats to which the marine communities are subjected, the destruction of habitats is undoubtedly the first cause of biodiversity loss. This loss of habitats has various origins such as coastal installations (ports, dams, breakwaters, roads, wastewater outfalls) or illegal trawler fishing, which is the main cause of regression of seagrass meadows. Special mention is deserved in this section to the work of regeneration of beaches, so common at certain sites of the European littoral of the Alboran Sea. These activities cause a very significant increase in the turbidity of the water that affects the vegetation communities, as well as sedimentation of particles that results in burying benthic species in the affected areas. Seagrasses are especially sensitive to increases in sedimentation rates.

The generalized eutrophication suffered throughout the Mediterranean is felt in a special way in the Alboran Sea. Numerous uncontrolled spills of various kinds, poorly treated wastewater, and discharges from activities related to agriculture result in the entry into the sea of a significant amount of nutrients and chemicals that result in a significant loss of biodiversity and deterioration of marine biocenoses. The eulittoral zone is the first to suffer these consequences, with increasingly frequent opportunistic algae populations growing rapidly, occupying a large part of the rocky substrates to the detriment of the species typical of these environments in pristine conditions.

An increase in surface water temperature is the most obvious manifestation of climate change, and although it has not yet been demonstrated that this has a direct effect on the marine plant communities of the Alboran Sea, it may have a close relationship with a series of phenomena that are causing the loss of biological diversity and homogenization of these communities, as supported by ample evidence in other regions (Thibaut et al. 2005; Wernberg et al. 2011, 2013; Araujo et al. 2016; Krumhansl et al. 2016; Casado et al. 2019). Algae are organisms whose basic biological processes are thermo-dependent, especially reproductive processes, which are constrained to very narrow temperature ranges and on which the maintenance of populations depends (Breeman 1988; Lüning 1990). The distribution of many species of the Alboran Sea can therefore be constrained by both episodic and prolonged increases in sea temperature. Particularly sensitive to this threat are species in their native range of distribution, such as many species of *Cystoseira*, the red alga *Rissoella verruculosa*, or the marine phanerogam *Posidonia oceanica*.

Meanwhile the increase in temperature, while negatively affecting native species, may be favoring the establishment and dispersion of allochthonous species from more temperate waters, which can occupy the niches left by native species and so act as invasive species. The number of allochthonous species introduced into the Alboran Sea is unknown, but it is known with certainty that in the last 20 years, this region has suffered the invasion of four species of invasive macroalgae of Indo-Pacific origin, the four currently homogenizing important extensions of its coastline. In order of chronological appearance, these four species are the red algae *Asparagopsis armata* (Seoane 1965) and *Asparagopsis taxiformis* (Altamirano 1999; Altamirano et al. 2008a; Zanolla et al. 2018), the green alga *Caulerpa cylindracea* (Altamirano et al. 2014), and, since 2016, the brown alga *Rugulopteryx okamurae* (Altamirano et al. 2016, 2017; García-Gómez et al. 2019).

This cascade of invasions reveals an invasional meltdown phenomenon in the waters of the Alboran Sea, which is leading to an alarming loss of biological diversity in many coastal areas, especially in the Strait of Gibraltar. Thus, the recent introduction of *R. okamurae* has led to the disappearance of important forests of Fucales in Ceuta and Laminariales on the Mediterranean coast of Cadiz, as well as other smaller photophilic algae species, such as prairies of *Halopteris* spp. and *Dictyota* spp. (García-Gómez et al. 2019). The north bay of Ceuta has suffered an important alteration of its marine plant communities. Formerly it was rich in Mediterranean and Atlantic elements (Figueroa et al. 2014), but since the appearance of *C. cylindracea* and its coexistence with the two species of *Asparagopsis*, until the recent introduction of *R. okamurae*, now they barely meet. The frequency of these invasive events highlights the sensitivity of the region to the threat of invasive species and the lack of administrative measures to prevent it, for example, those related to the management of ballast water. Without them, the Alboran Sea may end up as a giant aquarium of Indo-Pacific species, as if it were reborn into its ancestral era of the ancient Tethys Ocean.

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Chapter 9

Benthic Fauna of Littoral and Deep-Sea Habitats of the Alboran Sea: A Hotspot of Biodiversity

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9.1 Historical Exploration of Habitats and Their Associated Benthic Communities in the Alboran Sea

The Alboran Sea and the Strait of Gibraltar represent an area of strategic and scientific interest from many points of view and have been the subject of numerous geological, hydrological and fishery resources studies. A detailed knowledge of their benthic marine biota came rather late, mostly starting in the late twentieth century. Early reports include a short note on Alboran Island by Richard and Neuville (1897), recording there for the first time the occurrence of the North Atlantic gastropod *Littorina saxatilis*, the first record of the limpet *Patella ferruginea* in Chafarinas Islands by Pallary (1920) and lists of decapods from the coasts of Melilla and Málaga by Miranda and Rivera (1919, 1921) and of fishes from Mediterranean coasts of Morocco by de Buen (1912).

At present, a large amount of information of extraordinary biogeographical interest has been secured on the marine biota, but it is scattered in many publications, reports or doctoral thesis, usually focused on specific taxonomic groups or particular areas. It would be tedious to detail all of them, but hereafter we provide some hints on the major efforts and sources.

9.1.1 Ship-Based Exploration

The great deep-sea explorations of the nineteenth century completely ignored the Alboran Sea. Closest came HMS "Porcupine" (1870) that sampled in detail western Portugal and the Ibero-Moroccan Gulf and then sailed East to explore the Sicilian Channel and the French research vessel "Talisman" (1883), which made a very thorough survey along the Atlantic coasts of Portugal, Spain and Morocco but did not enter the Mediterranean.

In the mid-twentieth century, Jacques Cousteau's celebrated ship "Calypso" was repeatedly chartered by the French government for scientific cruises, one of them in the Ibero-Moroccan Gulf and the Alboran Sea in 1958. Few results were published (e.g. Pérès 1959 for Tunicates and Bellan 1959 for Polychaetes), but this was the occasion for divers to make the first encounter with the *Laminaria* forests (Cousteau and Dugan 1963).

The French cruise "Polymede II" (April–May 1972) collected 15 benthic samples along the Alboran Sea, at depths between 80 and 1000 m, and some of this material

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was studied (e.g. amphipods, Bellan-Santini 1983, 1985; caudofoveates, Salvini-Plawen 1977; bryozoans, d'Hondt 1977; cephalopods, Mangold-Wirz 1973; echinoderms, Sibuet 1974).

The starting point for our knowledge of the deep-sea benthos on each side of the Strait of Gibraltar is really the BALGIM expedition, organized in May–June 1984 by the Muséum National d'Histoire Naturelle of Paris. Samples were taken with beam trawl, epibenthic sled and rock dredge at depths between 160 and 1700 m, and an impressive set of results was published for almost all important taxonomic groups except gastropods and polychaetes: sponges (Boury-Esnault et al. 1994), octocorals and antipatharians (Grasshoff 1989), hydrozoans (Ramil and Vervoort 1993), bryozoans (Harmelin and d'Hondt 1992a, b, 1993), decapods (García Raso 1996), barnacles (Foster and Buckeridge 1995), cumaceans (Ledoyer 1987; López-González et al. 1996), pycnogonids (Stock 1987), bivalves (Salas 1996), echinoids (David 1989), chaetognaths (Casanova 1987) and tunicates (Monniot and Monniot 1988, 1990; Turón 1988).

In 1985 and 1986, the Instituto Español de Oceanografía assessed the bottoms exploited for red coral (*Corallium rubrum*), between 75 and 130 m depth, mostly on the platform surrounding the Alboran Island. Templado et al. (1986) summarized general data and preliminary results regarding the fauna, and later some reports were published on particular taxonomic groups, such as sponges (Maldonado 1992, 1993) and decapods (García Raso 1989).

The impressive 1000-m high cliff on the south face of the Alboran Ridge was filmed from the French submersible "Cyana" during the "CyanAlboran" cruise in September–October 1994. Sadly, the underwater images were never made available to biologists, and virtually no results have been published.

Another major breakthrough came with the research project "Fauna Ibérica" coordinated by the Museo Nacional de Ciencias Naturales (CSIC, Spain), aimed to updating taxonomy and distribution data for all faunal groups and to issue authoritative monographs in due course. In this context, the FAUNA I cruise (Fig. 9.1) sampled the Ibero-Moroccan Gulf and the Alboran Sea in July 1989, followed years later by Fauna IV (July 1996) where particular attention was given to sampling around the Alboran platform by diving in 0–60 m and trawling down to 450 m. Preliminary results of the first cruise were published by Templado et al. (1993). Study of the material collected in both cruises resulted in numerous publications on particular taxonomic groups and the description of species new to science. A general monograph on the benthic fauna and flora surrounding the island was issued by Templado et al. (2006).

Since 1994, the MEDITS annual surveys provide information on demersal and epibenthic species of trawlable grounds of the northern part of the Alboran Sea. Although the main objective of these surveys is to carry out the assessment of exploited demersal resources by direct methods, information on presence, abundance and biomass of epibenthic species and habitat-forming species caught with the otter trawl have been recorded during the last decades, published in papers for specific groups (e.g. molluscs, decapods) and used in the initial evaluation of the Marine Strategy Framework Directive (DIR 2008/56/EC) (Abelló et al. 2002; IEO-MAGRAMA 2012; Ciércoles et al. 2018).

Fig. 9.1 Sorting a haul with rhodoliths on board R/V "García del Cid" during FAUNA I cruise [Diego Moreno/Fauna Ibérica project-MNCN-CSIC]

In 2008, a Training-Through Research Cruise funded by the UNESCO, under the framework of the EU project HERMES, explored coral mounds and cold seeps in the West Alboran Sea. These investigations confirmed the presence of large coral buildups comparable by their dimensions to carbonate mud mounds of the NE Atlantic Ocean. This was the first and very important documentation of large-scale cold-water coral reefs in the Alboran basin. Detailed investigations of mud volcanoes revealed strong gas emissions (mainly in Carmen mud volcano), which fuelled abundant chemosymbiotic organisms, including frenulate polychaetes and bivalves (Comas and Suzyumov 2009).

Further exploration was carried out on the little known Djibouti Banks, located in international waters of the northern part of Alboran Sea, on board R/V "Cornide de Saavedra" of the Instituto Español de Oceanografía, in March–April 2009. Molluscs from the Djibouti Banks were reported on by Gofas et al. (2014b).

At the same time, the German cruise POSEIDON POS 385 in May–June 2009 investigated the distribution and faunal composition of cold-water coral ecosystems in the Alboran Sea (Hebbeln et al. 2009). By means of a "remotely operated vehicle" (ROV), they targeted the Málaga mounds, Al Idrissi Bank in the Djibouti group, the East Melilla area including Banc des Provençaux, the Alboran and Adra ridges and the Seco de los Olivos (also known as Chella Bank). The video-based investigations were completed by fauna and sediment sampling from the ROV or by standard sampling methods (gravity corer, box corer). A remarkable finding was the occurrence of some living deep-sea oysters (*Neopycnodonte zibrowii*) that colonized a steep cliff at 490 m water depth.

As part of the INDEMARES "Inventory and designation of the Natura 2000 network in marine areas of the Spanish state" project, a LIFE+ project aimed at documenting by identifying areas of value to the Natura 2000 network in Spanish offshore areas, research was carried out around the Alboran Island with R/V "Isla de Alborán" in 2011 and 2012 and around Seco de los Olivos by OCEANA on board their catamaran "OCEANA Ranger". Results were summarized in two INDEMARES monographs (Gofas et al. 2014a; De la Torriente et al. 2014) and further elaborated by de la Torriente et al. (2018). OCEANA also explored other parts of the Alboran Sea using ROV-mediated imaging, in places such as Banc des Cabliers, the Djibouti Banks (El Algarrobo/Avempace) and Banco Sabinar (Avenzoar) (Pardo et al. 2011). The images obtained during those cruises have notably contributed to our understanding of the in situ composition and aspect of benthic communities on these bottoms.

9.1.2 Shore-Based Studies

Data on the coastal biodiversity of the Alboran Sea started to be collected when the Biological-Marine Station of Málaga, now a centre of Instituto Español de Oceanografía, was created in 1911 by Odón de Buen, but his work and that of his sons Fernando and Rafael were mainly focused on the ichtyofauna (O. de Buen 1912; F. de Buen 1926). With the outbreak of the Spanish Civil War, de Buen was on the losing side and was exiled; any progress was hardly made during the following decades.

The spectacular renaissance of taxonomy and natural history in Spain in the last decades of the twentieth century featured, among others, the beginning of significant shore-based studies in the Alboran Sea and the Strait of Gibraltar. Early work includes several doctoral theses on some taxonomic groups in an area which was then very poorly known: J. Enrique García Raso on decapods (1981), Carmen Salas Casanova on bivalves (1984), José Carlos García Gómez on opisthobranch molluscs (1984), Ángel A. Luque del Villar on shelled gastropods (1984) and Manuel Maldonado Barahona (1993) on sponges.

Starting in 1982, a group of researchers from the universities Autónoma de Madrid and Barcelona and the Museo Nacional de Ciencias Naturales of Madrid studied the marine gastropods of the Almería coast, publishing a first inventory in 1986 (Ballesteros et al. 1986). In 1983, the University of Málaga (UMA) explored the Alboran Island, resulting in a general description of the marine habitats and biota (García Raso and Salas 1984) and lists of decapod crustaceans (García Raso 1984) and marine molluscs (Salas and Luque 1986).

Further research involving the universities of Málaga and Autónoma de Madrid and the Museo Nacional de Ciencias Naturales studied between 1985 and 1990 the marine biota around Cabo de Gata with institutional funding from the Consejería de Medio Ambiente of the Andalusian government. These projects led to the declaration of the "Parque Natural Cabo de Gata-Níjar" in January 1988, to the first conservation measures of its Marine Reserve and to the publication of a monograph on its marine biota (García Raso et al. 1992). Later on (1995–1996), the same authority funded a project that produced the first detailed maps of seagrass meadows in Almería and a further project (2001–2003) on the Andalusian marine macrophyte grounds that resulted in a collective monograph on the seagrass meadows and other marine vegetation of the Andalusian coasts (southern Spain) (Luque and Templado 2004).

The exploration of the Strait of Gibraltar also started in the 1980s. In May, 1986, an intensive sampling around Ceuta, at the eastern entrance of the Strait, was organized as a joint venture of the Muséum National d'Histoire Naturelle of Paris and the University of Seville. This was mainly targeted to molluscs, and, although no synthetic report was ever published, the material collected there was the basis for the description or revision of many species (Gofas 1987, 1992, 1993; García-Gómez and Ortea 1988; García-Gómez et al. 1989; Salvini-Plawen 2003). Mostly based on this material, Gofas (1998) stated the enormous interest of the Strait because of the presence of several short-range endemics, unusual on a mainland shoreline. In the Strait of Gibraltar and surroundings, intensive studies of the fauna and the benthic communities followed under the impulse of José Carlos García Gómez, at the University of Seville. He created there the Marine Biology Laboratory, supervised many doctoral theses on the benthos of the area (J. Lucas Cervera Currado on opisthobranch gastropods, 1988; Carlos M. López Fé de la Cuadra on bryozoans, 1990; Pablo López-González on anthozoans, 1993; José Luis Carballo on sponges, 1994; Santiago A. Naranjo Lozano on tunicates, 1995; Mª Dolores Medel Soteras on hydrozoans, 1996; Juan E. Sánchez Moyano on the epifauna of photophilous algae, 1996, among others) and carried on many projects which eventually culminated with mapping the nearshore communities and with the creation of the "Parque Natural del Estrecho" in January 2003 (see García Gómez et al. 2003).

For the purpose of conservation and sustainable development, the regional authority launched in 2004 the Sustainable Management of the Andalusian Marine Environment Program (Junta de Andalucía 2008–2019). A highly specialized technical team, distributed throughout the Andalusian coast with the intention of gathering homogeneous information, supports the annual surveys. Through this programme, more than 2500 records of the 87 threatened species of marine invertebrates were collected in the *Red Book of the Invertebrates of Andalusia* (Barea-Azcón et al. 2008); hundreds of hectares of seagrass meadows of the four species of marine angiosperms present in the Andalusian coast were mapped, and more than 1000 sightings of cetaceans were made. In total, the biodiversity inventory comprises more than 900 species on the coasts and the Andalusian marine environment.

The Museo del Mar Ceuta foundation, established in 2006, opened a further basis of operation where bionomic studies were carried out, particularly on the extraordinarily diverse sea bottoms surrounding Ceuta's Monte Hacho and Benzú, which were declared as Sites of Community Importance in July 2006. The results of this series of surveys are summarized in a book by Ocaña et al. (2009).

Somewhat later, at the beginning of this century, exploration of the coast of Granada was initiated by the late Amelia Ocaña, of the University of Granada. The

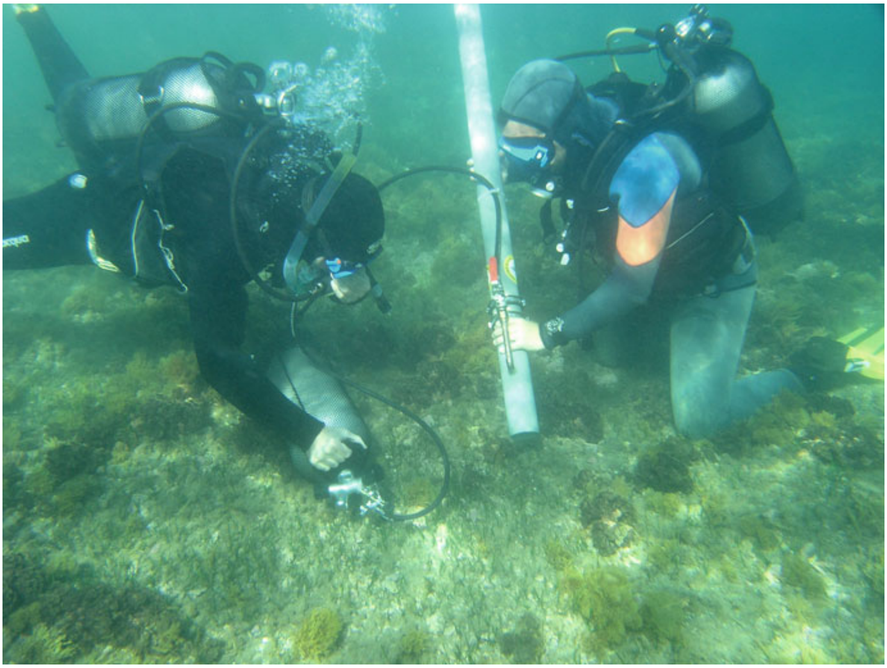

Fig. 9.2 Sampling the infralittoral in the Calahonda Special Area of Conservation (Málaga), using the air-lift pump, a noninvasive sampling device, on the photophilous algal community [José Luis Rueda]

results, mainly obtained by scuba diving, are presented in a profusely illustrated guide (Sánchez Tocino and Ocaña 2003). After her premature death in 2007, work was continued there by Luis Sánchez Tocino who also set up a web site dedicated to the benthic fauna of the Granada coast and co-supervised the doctoral thesis of Carlos Navarro-Barranco (2015) on benthic fauna of marine caves from Granada and Málaga coasts. In parallel, data on the benthic communities of the Granada coast were also provided by Cebrián et al. (2000) and Cebrián and Ballesteros (2004).

The marine zoology group at the University of Málaga extended research to other areas, including the outstanding site of Calahonda (Málaga) which was surveyed in 2006 and declared as a Special Area of Conservation in the Natura 2000 network in August 2015 (Fig. 9.2). This research again involved several doctoral theses: José Luis Rueda on the molluscs associated with seagrasses (2007), Javier Urra on the molluscs of different habitats of the Calahonda Special Area of Conservation (2012) and J. Enrique García Muñoz and Ángel Mateo Ramírez (both in 2016) on the decapods of the same area. A summary of the investigations in Calahonda is given in García Raso et al. (2010), and other data are also included in the above mentioned monograph on seagrass and other vegetated bottoms of Andalusia (Luque and Templado 2004).

Much less is known of the southern part of the Alboran Sea. The fauna and flora of the Spanish city of Melilla have been mostly ignored in the scientific literature, but some general features were presented by Bueno del Campo and González García (1996). One exception is the Chafarinas Islands, which have staged numerous scientific projects dedicated to their marine biota, mostly involving scientists from the universities of Málaga, Valencia and Autónoma de Madrid and, more recently, of Granada and Centro de Estudios Avanzados de Blanes (CSIC), resulting in several doctoral theses: Eduardo López and Francisco J. Torres Gavilá on annelids (1995 and 2007, respectively), Álvaro L. Peña Cantero on hydrozoans (1995), Jordi Silvestre on decapod crustaceans (2000), Santiago Villora-Moreno on meiofauna (1993), Amparo Martí-Gil on amphipods (1997) and many articles on different animal groups such as decapods, sponges and molluscs (e.g. García Raso 1988; Maldonado et al. 2013; Oliver et al. 2015). An overview was provided by Guallart and Afán (2013) and Maldonado et al. (2013). A prominent feature of this insular setting is the survey over many years of the endangered limpet *Patella ferruginea*, which has there its most important populations (Guallart and Templado 2016). Another exception is the Mar Chica near Nador, the sole coastal lagoon of the Alboran Sea and a very important element in the socioeconomic context of Northern Morocco (Guelorget et al. 1984; Dakki 2003; Zine 2003). In the proximity of Nador, the doctoral thesis by Mohamed Menioui (1988) provided interesting information on the benthic communities associated with macroalgae. Important bionomic research is going on in the Moroccan and Algerian parts, involving in many cases the Regional Activity Centre for Specially Protected Areas in the Mediterranean, and some results have been published (Ben Haj et al. 2009; Bazairi et al. 2013; Dauvin et al. 2013 among others). It is expected that the gap will be filled in due course.

9.2 Supralittoral and Intertidal Communities

Along the sea-land interface, animal and vegetal communities are subject to high stress; therefore it is the home of few, highly specialized species. This is a very hostile environment, where the substrate is subject to strong insolation, sudden changes in temperature and splashing, intense evaporation and rainfall (Templado et al. 2012). In the Alboran Sea, contrary to the Atlantic where the tidal range can span several metres, the intertidal zone is a very narrow strip due to a tidal range usually less than 1 m. In addition, it is very exposed to human impacts due to the intense tourist pressure and high coastal population density.

Very few studies have tackled the intertidal communities, and they basically regard the western area (e.g. Conradi and López-González 1999; Krapp-Schickel et al. 2011 on peracarid crustaceans) or are contained in more general accounts (García Raso et al. 1992, 2010), in addition to a few of diverse nature (such as Fischer-Piette 1959; Kensler 1964, 1965; Castellanos et al. 2003; Shemesh et al. 2009; Guerra-García et al. 2011).

9.2.1 Supralittoral Rocky Shore

The supralittoral stage corresponds to the "splash zone", i.e. rock surfaces permanently emerged but receive moisture from wave action. Its vertical extension varies between a few centimetres in calm areas, to a few meters, depending on the topography of the coast, its inclination and exposure to surf. The extension of this habitat in the Alboran Sea coincides with that of rocky shores, including artificial substrates such as piers and groins.

The community of the supralittoral rock is mainly characterized by various lichens, especially those of the genus *Verrucaria* (*V. amphibia* and *V. maura*). The most characteristic animal species are the periwinkles *Melarhaphe neritoides* and *Echinolittorina punctata* (a thermophilous species found in West Africa and only in the warmer parts of the Mediterranean which feed on cyanophyceae) (Fig. 9.3) and the detritivorous isopod *Ligia italica*. Otherwise, the rock surface is usually barren.

9.2.2 Supralittoral Boulders

This is an intermediate habitat between sedimentary and hard substrates. Technically it would belong to the former if the diameter of the boulders is less than 64 cm. It usually occurs in certain coves exposed to wave action (Templado et al. 2012).

Fig. 9.3 Two species of littorinids, *Melarhaphe neritoides* and *Echinolittorina punctata* (with white dots on the shell), gathering over a fissure in supralittoral rocks of Marbella coast (Málaga province, Spain) [José Enrique García Raso]

Fig. 9.4 **(a)** Supralittoral boulders at Baños del Carmen (Málaga) are the home of little known and specialized animals such as **(b)** marine collembolans [Serge Gofas]

Although the boulders are heavily exposed to sunlight, the underpart of those that remain half-buried keeps permanent moisture and retains organic matter of plant debris. This habitat is rarely found in the Alboran Sea, being mostly developed in the Strait of Gibraltar and, within the city of Málaga, at the site of Baños del Carmen (Gofas et al. 2011).

This peculiar environment (Fig. 9.4) hosts gastropods, such as *Paludinella globularis*, *Leucophytia bidentata*, *Pseudomelampus exiguus* and *Pedipes dohrni* (the latter, a thermophilous species), collembolans such as *Anurida maritima* and other arthropods (pseudoscorpions, centipedes) which require further study.

9.2.3 Midlittoral Rocky Shore

The midlittoral fringe corresponds to the intertidal zone, which is constantly exposed to wave action. In most of the Mediterranean Sea, the slight oscillations of sea level (which do not exceed 40 cm) are not cyclical and are due mainly to changes in atmospheric pressure. In the Alboran Sea, the influence of the tides is still conspicuous, but it fades as we move away from the Strait of Gibraltar. The communities of the midlittoral fringe are definitely organized as belts or horizons (Fig. 9.5), usually

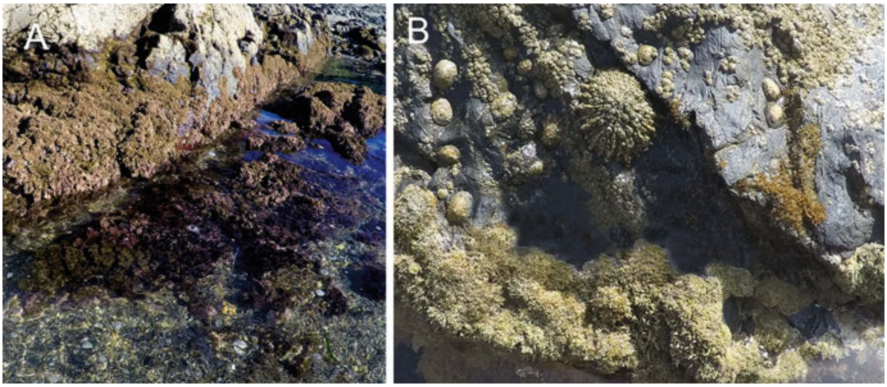

Fig. 9.5 Midlittoral rocks at low tide in the Calahonda SAC (Málaga). **(a)** The algal turf of the lower horizons is dominated by the coralline alga *Ellisolandia elongata*, and the levels below the water, with brown algae *Halopteris scoparia*, already belong to the infralittoral. **(b)** The upper horizon is virtually devoid of macrophytes and dominated by barnacles and is the home to limpets (here *Patella ferruginea*) and false limpets *Siphonaria pectinata* [Serge Gofas]

well delimited and structured by sessile organisms, mainly algae and barnacles, whose composition and extent depend largely on the degree of wave action.

The upper belt of the midlittoral is characterized by the abundance of chthamalid barnacles (*Microeuraphia depressa*, *Chthamalus montagui* and *C. stellatus*) which can cover a large part of the substrate and the presence of the highly mobile crab *Pachygrapsus marmoratus.* Among other algae, the rhodophyte *Rissoella verruculosa* may appear in the upper levels in some well-preserved areas such as the Chafarinas Islands. The limpets *Patella rustica* and *P. ferruginea*, the latter an endangered species restricted to the Alboran Sea, North Africa, Sardinia and Corsica, are noteworthy elements at this level and compete for space with the barnacles, which usually also settle on their shells. The trochids *Phorcus articulatus* (in sheltered sites) and *P. turbinatus* (in sited exposed to wave action) retreat to sheltered crevices at the time of low tide.

Below the horizon of barnacles, there is an algal turf in which the coralline alga *Ellisolandia elongata* is prominent. In the most sheltered areas and in those with high levels of eutrophication, the red algae are replaced by green algae such as *Ulva* spp. As it happens in the supralittoral and infralittoral levels, the extension of these communities is constrained by the extension of the rocky shoreline.

Species richness increases drastically in the middle and lower parts of the midlittoral, where an algal turf usually develops (Guerra-García et al. 2011). There is also a clear species turnover, where the abovementioned barnacles are replaced by larger species (such as *Perforatus perforatus* and *Amphibalanus amphitrite*) and the genus *Pachygrapsus* is represented instead by *P. transversus* and *P. maurus* (more rare) in fissures of rocks. The most characteristic molluscs are the limpets *Patella caerulea* (also *P. depressa* in the western part of Málaga coast and in the Strait of Gibraltar) and *Cymbula safiana* (a prevalently West African species), which replace

P. rustica and *P. ferruginea* in the lower horizon of the midlittoral, many species of trochids and the false limpet *Siphonaria pectinata*, a pulmonate mollusc convergent in shape with the true limpets; the polyplacophoran *Lepidochitona caprearum* is also frequent. The mussels (*Mytilus galloprovincialis* and *Perna perna*) form mixed aggregations where wave action is sufficient, and the sea anemone *Actinia equina* is also a conspicuous element in shaded areas of exposed sites. At the lower levels among the algal turf, the fauna is very diverse, and there are many other small species of different groups. Molluscs are quite thoroughly studied (Gofas et al. 2011), and the most characteristic species in the midlittoral algal turf are *Skeneopsis planorbis*, *Nodulus spiralis*, *Pisinna glabrata*, *Tricolia miniata*, and *Cassiella abylensis*, the latter an endemic species of the Strait of Gibraltar. Other groups (pycnogonids, amphipods, copepods, isopods, polychaetes, tanaids, insect larvae, ostracods, mites, nematodes, ophiuroids, echinoids, sponges, bryozoans and foraminifera) are also diverse but not studied in detail yet. A study about gammarid amphipods inhabiting intertidal seaweed of Tarifa found a distinct vertical segregation of the species (Krapp-Schickel et al. 2011). Some isopods also occur under stones in this level such as *Sphaeroma serratum* and species of the genera *Cymodoce* and *Dynamene*. The hermit crab *Clibanarius erythropus* characteristically forms dense aggregations among intertidal rocks and protects itself in shells of the local gastropods (e.g. *Cerithium lividulum*). In the intertidal zone, the gap under loose rock slabs and the fissures of the bedrock constitute a refuge from desiccation and predation and are the home of many species such as decapods (e.g. *Porcellana platycheles*; the crabs *Xantho poressa*, *Eriphia verrucosa* and *Pilumnus hirtellus*; the prawn *Athanas nitescens*), many molluscs (e.g. *Steromphala racketti*, *Ocinebrina edwardsii*, *Columbella rustica*, *Striarca lactea*, *Cardita calyculata*), polychaetes (mainly serpulids) and sessile invertebrates such as colonial tunicates or sponges. Occasionally conditions are met for some species of the infralittoral, like the urchin *Paracentrotus lividus* and the sea anemone *Anemonia viridis*, forming "enclaves" in rock pools on under large slabs (Templado et al. 2012).

In some areas, the so-called vermetid reefs (Fig. 9.6) are formed by the sessile gastropod *Dendropoma lebeche* (formerly known as *D. petraeum*) whose dense aggregates are being filled and cemented by the encrusting calcareous alga *Neogoniolithon brassica-florida*. These are found in the Strait of Gibraltar and reach their maximum development in the coasts of Alicante, Murcia and Almería and in the Chafarinas Islands (Guallart and Calvo 2006; Guallart and Afán 2013) but surprisingly show a large gap in the coast of Málaga, even in rocky areas. The crevices and hollows inside the vermetid reef provide shelter to numerous organisms, such as polychaetes, the gastropod *Fossarus ambiguus*, the bivalves *Lasaea adansoni* and *Leiosolenus aristatus*, the sipunculid *Phascolosoma stephensoni* or the intertidal fish *Coryphoblennius galerita*, the latter using the cavities to harbour its spawn (Moreno 2006).

All rocky shores can theoretically fit the loose concept of Habitat 1170 "Reefs" as defined in the EU Habitats Directive (92/43/EEC) (see Templado et al. 2009), but intertidal rocky shores are seldom claimed as such in Nature 2000 reports. Nevertheless, much of the intertidal rocky shore is comprised in several of the existing

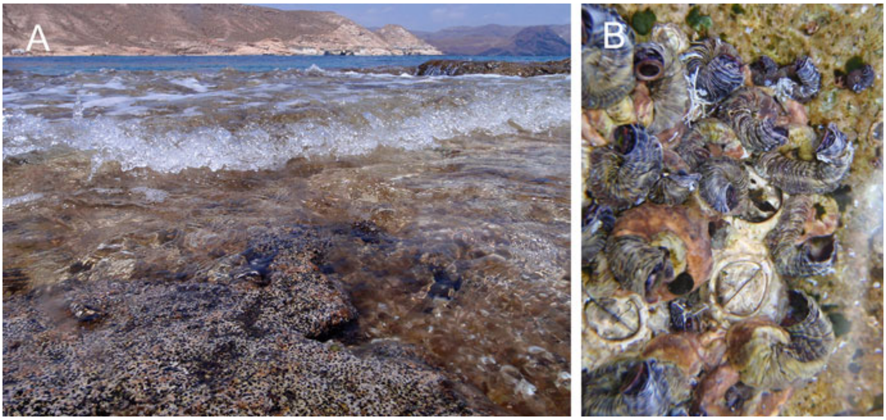

Fig. 9.6 **(a)** *Dendropoma* reefs, here in the Cabo de Gata-Nı́jar Natural Park, are a typical community of the lower midlittoral level of the southwestern part of the Mediterranean. **(b)** A close-up of the vermetids with two balanids [Diego Moreno]

marine protected areas. The main driver for protection of intertidal sites remains in the occurrence of species catalogued as endangered, such as *P. ferruginea* and *D. lebeche,* whose presence triggers restrictions to any intervention affecting their habitat. Threats and pressures are many because of the accessibility of this habitat and include illegal harvesting as well as trampling and oil spills.

9.2.4 Supra- and Midlittoral Sedimentary Substrates

On the supralittoral part of sandy beaches, amphipods of the family Talitridae (such as *Talitrus saltator*) are very characteristic intertidal crustaceans in the Alboran Sea and elsewhere; these are known as “sea fleas” and remain buried during the day, being more active at dusk and at night in search of organic detritus that constitute their food. In the intertidal strip of sandy beaches, isopods of the genus *Eurydice* and amphipods of the genera *Haustorius*, *Bathyporeia*, *Urothoe* and *Leucothoe* are found; these species show a zonation in their distribution, but due to the small tidal range and steep slope of the beaches, this zonation is not well defined in the Alboran Sea and species broadly overlap.

The bivalve *Donacilla cornea* is usually found in the lowermost part of the intertidal zone of coarse sand beaches. Intertidal areas with muddy sands are suitable for the construction of galleries, which favours the presence of burrowing decapods such as *Upogebia pusilla* and *Gilvossius tyrrhenus* as well as of amphipods belonging to the genera *Corophium* and *Monocorophium*.

In some areas, mainly in the Almería province and in the Chafarinas Islands, the characteristic leaf-litter accumulations of *Posidonia oceanica* harbour a good number of species, mostly detritivores, such as the amphipods of the genus *Orchestia*, various isopods, insects and the oligochaete *Pontodrilus litoralis* among others (García Raso et al. 1992).

9.3 Coastal Lagoons

The coastline of the Alboran Sea currently has extensive sandy beaches, cliff areas and some large bays (Algeciras, Almería), leaving only very few inlets that can be considered coastal lagoons (Ojeda Zújar 2004). The evolution of the coast in the Quaternary, with the Flandrian transgression (about 6000 years ago), allowed some valleys of Andalusia (Guadiaro, Guadalhorce and Andarax) to be flooded, forming inlets and making navigable the final sections where the Phoenicians and Romans constructed their ports. Those are now filled with sediment, and very limited areas with a favourable topography allowed the formation of sand bars that delimited coastal lagoons.

The most extensive coastal lagoon of the Alboran Sea is undoubtedly the Mar Chica or Sebkha Bou Areg, located in Morocco east of Melilla (Zine 2003; Ruiz et al. 2006). It is a large lagoon of 11,500 ha with a semi-circular shape and a maximum depth of 8 m. The Mar Chica is separated from the Alboran Sea by two sandy strips, Boukana (10 km long) to the north west and Aljazeera (12.5 km) to the south east, separated by a mouth 120 m wide, where it connects with the Mediterranean. Several cities are settled on its banks, being the most important Nador, located on the inner shore and representing a source of urban and agricultural spills.

The Mar Chica mostly comprises soft bottoms, sandy or mud, historically with dense meadows of seagrasses and of the alga *Caulerpa prolifera*. The seagrasses *Zostera marina*, *Cymodocea nodosa* and *Zostera noltei* were reported by González García and Conde Poyales (1994), but only the latter two are mentioned in recent reports (Ruiz et al. 2006).

A less extensive area of coastal lagoons is located in Rio Martil near the city of Tetuan, on the Moroccan coast, in which Pallary (1920) mentioned several species of hydrobiids found also on the Atlantic coasts.

On the north coast of the Alboran Sea, the most important coastal lagoons are those of Adra (Albufera Honda of 13 ha and Albufera Nueva of 29 ha). Some coastal lagoons have been transformed into saline ponds by man. There were several of these “salinas” on the north coast of the Alboran Sea in the provinces of Granada (Motril) and Almería (Guardias Viejas, Cerrillos, Roquetas and Cabo de Gata). Among them, only those of Cabo de Gata Natural Park (400 ha) are still yielding annual harvests of salt. The salt process involves the entry of marine water through a long channel in which there is marine fauna (Ojeda Zújar 2004).

Due to the scarcity of coastal lagoons, the Alboran Sea acts as a major biogeographic barrier between the numerous lagoons of the European and Moroccan Atlantic coasts and those of the Western Mediterranean starting from Cabo de Gata eastwards.

In Sebkha Bou Areg, frequent species are the gastropods *Bulla striata* and *Bittium reticulatum*; the bivalves *Polititapes aureus*, *Cerastoderma* sp., *Abra* sp. and *Gastrana fragilis*; the polychaete *Sabella pavonina*; the decapods *Palaemon serratus* and *Carcinus maenas*; the echinoderm *Holothuria tubulosa*; and the tunicates *Clavelina lepadiformis* and *Botrylloides leachii* (Bueno del Campo and González-García 1996). The seagrass meadows are also reported as the habitat of the bivalve *Pinna nobilis* and the cephalopod *Sepia officinalis* among others. In the last third of the twentieth century, in areas of freshwater outcrop within the lagoon, the native shrimp *Penaeus kerathurus* was still fished in great quantity, but at present it is very scarce due to contamination of the south shore and by the installation of aquaculture companies dedicated to Japanese shrimp *Penaeus japonicus* (Bueno del Campo and González-García 1996).

In Cabo de Gata, the channels leading to the salt pans harbour species such as the gastropods *Aplysia punctata*, *Philine quadripartita* and *Haminoea orteai* (Ballesteros et al. 1986; Talavera et al. 1987), the decapod crustacean *Palaemon serratus* and several fish (López Carrique et al. 2004). In areas of lower salinity in the interior of the saline lagoon (Fig. 9.7), the silt-dwelling bivalves *Abra segmentum*, *Scrobicularia plana* and *Cerastoderma glaucum* are abundant, as well as the gastropod *Hydrobia acuta*, among the filamentous algae (Gofas et al. 2011). In the ponds with higher salinity, the branchiopod crustaceans *Artemia* spp. (*Artemia salina*, *A. parthenogenetica* and the introduced *A. franciscana*) are dominant and represent the basis of the food of the pink flamingo *Phoenicopterus roseus* (García Rodríguez et al. 1982; López Carrique et al. 2004).

The Albufera de Adra lagoons are peculiar because they are currently secluded from the sea and their fauna is mainly freshwater, with some species of euryhaline fish such as *Aphanius iberus*, *Anguilla anguilla*, *Atherina boyeri* and *Chelon labrosus* (Vidal and Castro 1990; Paracuellos et al. 2019).

In Spain, the lagoons such as those of Adra and Cabo de Gata are included in the Special Areas of Conservation under the Nature 2000 network, but the occurrence of priority habitat 1150 “Coastal lagoons” of the Annex I of the EU Habitats Directive was never claimed in the official registrations as Site of Community Importance. In Morocco, Sebkha Bou Areg is declared as “Site d’Interêt Biologique et Ecologique”. All three sites are listed as Ramsar wetlands of international importance. Coastal lagoons that are permanently connected to the sea are also listed as “Essential Marine Habitats (EMH) of relevance for the management of priority species” by the Scientific Advisory Committee of the General Fisheries Commission for the Mediterranean (General Fisheries Commission for the Mediterranean 2009). Despite all these classifications, coastal lagoons in the Alboran Sea are under heavy pressure, mainly because of urban and agricultural discharges (Zine 2003; Ruiz et al. 2006).

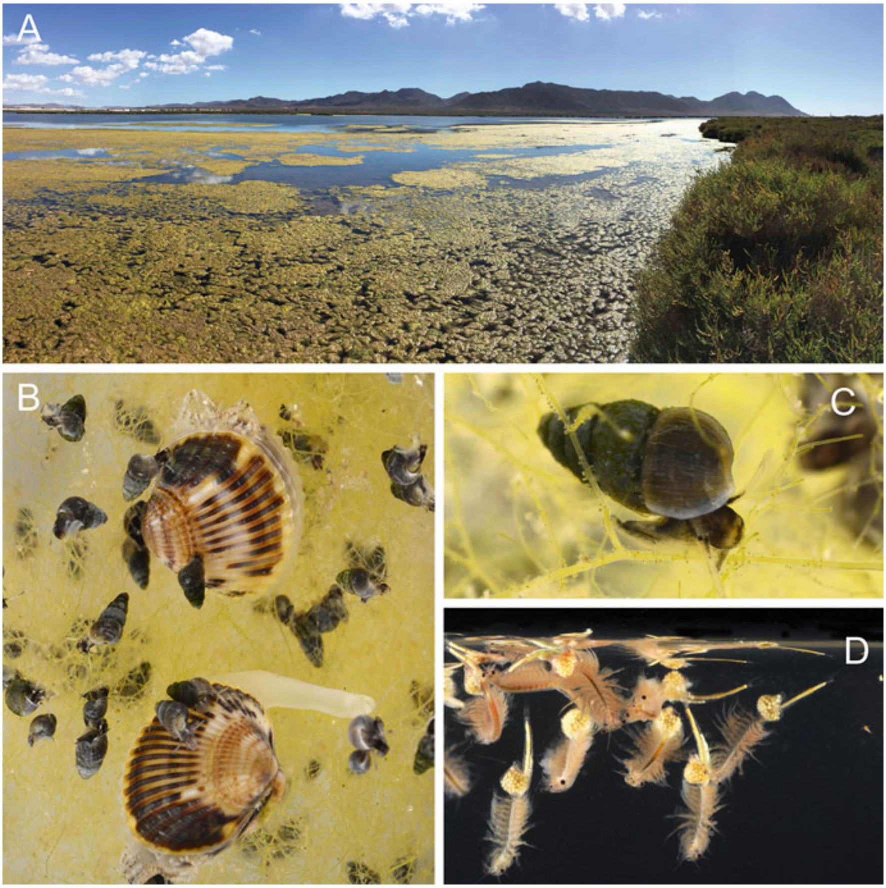

Fig. 9.7 The saline ponds of Cabo de Gata. **(a)** View of the "salinas". **(b)** Several species of molluscs live in the ponds with lower salinity, such as the bivalve *Cerastoderma glaucum* and **(b, c)** the mudsnail *Hydrobia acuta* (surrounding the bivalves in figure b and detail in figure c). **(d)** *Artemia* species support higher salinity [Diego Moreno]

9.4 Hard-Bottom Communities of the Continental Shelf

The infralittoral hard bottoms are very heterogeneous, depending on the exposure to wave action, the slope and orientation of the substrate and the intensity of light which decreases progressively as the depth increases (Templado et al. 2012). The photophilous communities are dominated, both physiognomically and in biomass, by macrophytes, whereas in sciaphilous communities, the animal component tends to predominate and the substratum is occupied by sessile species.

9.4.1 Communities of Photophilous Macroalgae

The community of photophilous algae is characteristic of shallow areas, although, with adequate conditions of transparency of the water, it can reach 30 m depth or more. In the Western Mediterranean, the infralittoral rocky bottoms with moderate to high exposure to wave action are dominated by species of Fucales mainly belonging to the genus *Cystoseira*. These are usually erect with a medium or large size (usually between 20 cm and more than 1 m, in the case of *C. usneoides*) and provide a habitat which can be compared to a miniature forest (Luque and Templado 2004; Templado et al. 2012). Below this, there is a turf stratum formed by small algae and a basal layer formed by encrusting calcareous algae and by sediment deposited in small depressions of the substrate. In the Alboran Sea, well-structured communities dominated by *Cystoseira* spp. only appear in the Eastern part (e.g. Cabo de Gata, Almería, Alboran Island, Chafarinas Islands). In shallow, calmed environments of the infralittoral of the western part, the brown alga *Halopteris scoparia* (Fig. 9.8) tends to replace *Cystoseira* in large areas (Sánchez Moyano et al. 2001a, 2002; Urra et al. 2013a). Several species of conspicuous invasive macroalgae (e.g. *Asparagopsis taxiformis*, *A. armata*, *Rugulopteryx okamurae*, *Caulerpa*

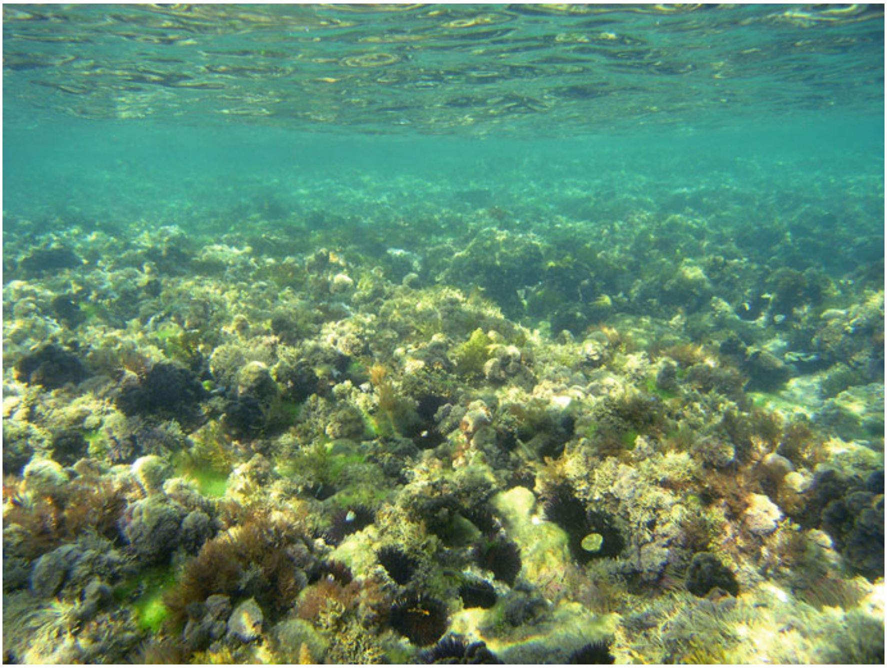

Fig. 9.8 The community of photophilous algae thrives on shallow, well-illuminated rocky bottoms, here near Punta Calaburras, Málaga. Many invertebrates, like the urchins *Paracentrotus lividus*, find shelter and food among algae [José Luis Rueda]

cylindracea) are nowadays common on these shallow environments, displacing numerous indigenous species.

Two different strata (sediment and frond) form the habitat of macroalgal communities, and the associated species use these microhabitats selectively. For example, the molluscs inhabiting the algal fronds are dominated by microalgae or periphyton grazers, whereas depositivores, plankton and seston feeders and carnivores dominate the sediment in the underlying stratum (Urra et al. 2013a). Among the most characteristic animal species in these algal communities of calm environments are the sea urchins *Paracentrotus lividus* and *Arbacia lixula*, which graze on the algae, allowing the installation of some sessile animals such as *A. sulcata* or *Aiptasia mutabilis*, or even generate barren rock surfaces known locally as "blanquizales", where crustose coralline algae of the genus *Lithophyllum* dominate the substrate.

In the Alboran Sea, invertebrate communities associated with infralittoral macroalgal beds are dominated by crustaceans and molluscs, followed by echinoderms and polychaetes. Most published works on macroalgal communities of the Alboran Sea were focused on communities associated with *H. scoparia* and *Ellisolandia elongata* beds of the northwestern part. The brown macroalgae *H. scoparia* provides shelter to an astoundingly diverse array of small animals, mostly molluscs (ca. 200 species), crustaceans (ca. 100 peracarid species, mainly amphipods; 35 decapod species) and polychaetes (over 80 species) (Sánchez-Moyano and García-Gómez 1998; Conradi and López-González 1999; López and Viéitez 1999; Sánchez-Moyano et al. 2002; Castellanos et al. 2003; López and Gallego 2006; Urra et al. 2013a; Mateo-Ramírez et al. 2018). Gastropods such as *Rissoa guerinii*, *Bittium reticulatum*, *Nodulus contortus* and *Eatonina fulgida* or bivalves such as *Musculus costulatus* were the most abundant species on these *H. scoparia* beds (Urra et al. 2013a). Regarding crustaceans, Conradi and López-González (1999) found 116 benthic gammarid amphipod species inhabiting different habitats of Algeciras Bay, of which 41 occurred in *H. scoparia*. In relation with other peracarid taxa, the tanaidaceans *Chondrochelia dubia* and *Tanais dulongii*, the cumaceans *Cumella limicola* and *Nannastacus unguiculatus* as well as the isopods *Paranthura nigropunctata* and *Stenosoma capito* were the most abundant species on *H. scoparia* beds of the Strait of Gibraltar (Guerra-García et al. 2009b). Regarding decapods, *Hippolyte leptocerus*, *Pilumnus hirtellus*, *Sirpus zariquieyi*, *Acanthonyx lunulatus*, *Athanas nitescens* and *Achaeus gracilis* were the dominant species in shallow algal communities from Málaga coast (Mateo-Ramírez et al. 2018). The study by Acero and San Martín (1986) on polychaetes of the first horizon of photophilous algae from localities of the Alboran Sea (Málaga) and nearby Atlantic (Cádiz) showed a similar species composition, but diversity was higher in Mediterranean samples, probably due to the stronger tides in the Atlantic area. López and Viéitez (1999) studied the polychaete assemblages associated with different algae beds from Chafarinas Islands. They reported ca. 37 species inhabiting the community of algae exposed to wave action (*Ellisolandia elongata*, *Asparagopsis armata*, *Cystoseira tamariscifolia* and *Laurencia obtusa* facies), with *Syllis prolifera*, *Salvatoria vieitezi*, *Exogone naidina*, *Sphaerosyllis hystrix* or *Amphiglena* *mediterranea* among the main species. The high abundance of *Sphaerosyllis hystrix* and *S. austriaca* in this habitat seems to be related to the relatively simple structure of the fronds that did not allow larger predatory species to settle (López and Gallego 2006). Sánchez-Moyano et al. (2002) cited the polychaetes *Platynereis dumerilii*, *S. hystrix*, *S. prolifera* and *A. mediterranea* as abundant species among *H. scoparia* in the Strait of Gibraltar.

Ellisolandia elongata is a calcifying macroalga that occurs in both the lower horizons of the intertidal zone and the upper infralittoral. Its fronds are smaller compared to those of *H. scoparia*, and consequently the invertebrate assemblage is less diverse (Guerra-García et al. 2009a). Crustaceans of this community were studied in detail and are characterized by the caprellids *Caprella hirsuta*, *C. penantis* and *C. grandimana*; the amphipods *Protohyale schmidti*, *Hyale stebbingi*, *Jassa marmorata*, *Stenothoe monoculoides* and *Ampithoe* spp.; as well as the isopod *Ischyromene lacazei* and the tanaid *Tanais dulongii* (Guerra-García and Izquierdo 2010; Izquierdo and Guerra-García 2011). The peracarid communities around the Strait of Gibraltar (including European and African locations) show similar values of abundance and species richness (Guerra-García et al. 2009a).

There are some studies about the invertebrate fauna associated with invasive algae such as *Asparagopsis armata*. The crustacean communities associated with this species are dominated in terms of species richness and abundance by amphipods, being the most abundant species *C. penantis* and *P. schmidti*, *Podocerus variegatus* and *A. mediterranea* (Pacios et al. 2011; Soler-Hurtado and Guerra-García 2011). Other groups such as isopods (*Paranthura costana* and *Stenosoma acuminatum*), tanaids (*Tanais dulongii*) and decapods (four species, with *Pilumnus hirtellus* and *Acanthonyx lunulatus* as dominant species) are poorly represented (Pacios et al. 2011; Soler-Hurtado and Guerra-García 2011) compared to brown algae. In the Strait of Gibraltar, Pacios et al. (2011) found 41 crustacean species (18 gammarids, 7 caprellids, 10 isopods, 3 tanaidaceans and 3 decapods). These studies suggest that species richness of crustaceans associated with *A. armata* is comparable with that of the native intertidal algae species, but changes on the abundance of some species occur. Nevertheless, another study conducted in the coast of Málaga and Granada highlighted that the invasive macroalgae *Asparagopsis taxiformis* hosted an impoverished peracarid assemblage (both in terms of abundance and species richness) in comparison to that associated with the sympatric native *H. scoparia* (Navarro-Barranco et al. 2018).

Most of the species found among photophilous algae in the Alboran Sea display an Atlanto-Mediterranean distribution, but in the western part, thermophilous West African elements such as *Modiolus lulat* and *Cochlis vittata* can occur (García Raso et al. 2010). The composition of the assemblages may vary according to hydrodynamic conditions, sedimentation rate and algal morphology (Sánchez-Moyano and García-Gómez 1998; Sánchez-Moyano et al. 2001a, 2002).

Some components of the community, such as molluscs, present a marked seasonal relationship with the vegetative cycle of the algae (Urra et al. 2013a). Others, such as decapods, move between adjacent habitats (e.g. *C. nodosa*) inducing seasonal variations (Mateo-Ramírez and García Raso 2012; Mateo-Ramírez et al. 2018).

Like the midlittoral rocky shore, infralittoral hard bottoms including the community of photophilous algae can theoretically enter the loose concept of Habitat 1170 "Reefs" from the EU Habitats Directive. Because it is so extensive, this habitat is well represented in most of the existing marine protected areas. Threats and pressures are many because of the accessibility of this habitat and include illegal harvesting as well as trampling and oil spills.

9.4.2 Posidonia oceanica

The Mediterranean angiosperm *Posidonia oceanica* is the largest of the marine phanerogams found in the Alboran Sea and the most outstanding as for habitat engineering. It is very demanding in terms of ecological requirements and does not tolerate large variations of salinity; therefore, it is not found in brackish or hyperhaline lagoons, neither near river mouths. It is also very sensitive to eutrophication and to most of the pollutants and also does not tolerate high sedimentation rates (Boudouresque et al. 2006; Templado et al. 2012 and references therein). It can be considered, therefore, an indicator of clear, well-oxygenated and pollution-free waters. *Posidonia* meadows occupy a wide bathymetric range (from 0 to more than 30 m deep), which implies that it occurs through a gradient in various biological factors and hydrological parameters, such as wave action, light and temperature.

Posidonia meadows are a complex ecosystem, in which the leaf stratum and the lattice of rhizomes have very different characteristics and associated fauna. The leaf stratum is a relatively unstable habitat in which the leaves are continually renewed and are subjected to wave action and to the grazing action of some species, such as the salema (*Sarpa salpa*). The stratum of rhizomes is more stable, albeit illumination may vary according to leaf growth and presents greater complexity.

Posidonia may grow both on sedimentary and rocky substrates, but when installed on soft bottoms, the rhizome stratum forms a rigid structure which provides the features of a hard bottom. When the meadow is installed on sandy bottoms, the rhizomes may be mostly buried and leave little space for animals; otherwise the rhizomes leave an intricate network of cavities, populated by the sciaphilous species characteristic of hard substrates. The rhizome stratum grows at very slow rates (10 cm–1 m per century) and may build up to several metres in thickness in some parts of the Mediterranean (Boudouresque et al. 2006).

Whereas extensive *Posidonia* beds are found in most of the Mediterranean Sea (see Giakoumi et al. 2013; Telesca et al. 2015), the occurrences in the Alboran Sea are patchy (Junta de Andalucía 2008–2019; Aranda and Otero 2014). On the northern shore, the most extensive meadows are found along the eastern coast of Almería, in the Cabo de Gata-Níjar Natural Park (Fig. 9.9) and in several Special Areas of Conservation (SACs) nearby, like those of Fondos Marinos de Punta Entinas-Sabinar and that of Fondos Marinos del Levante Almeriense. A small

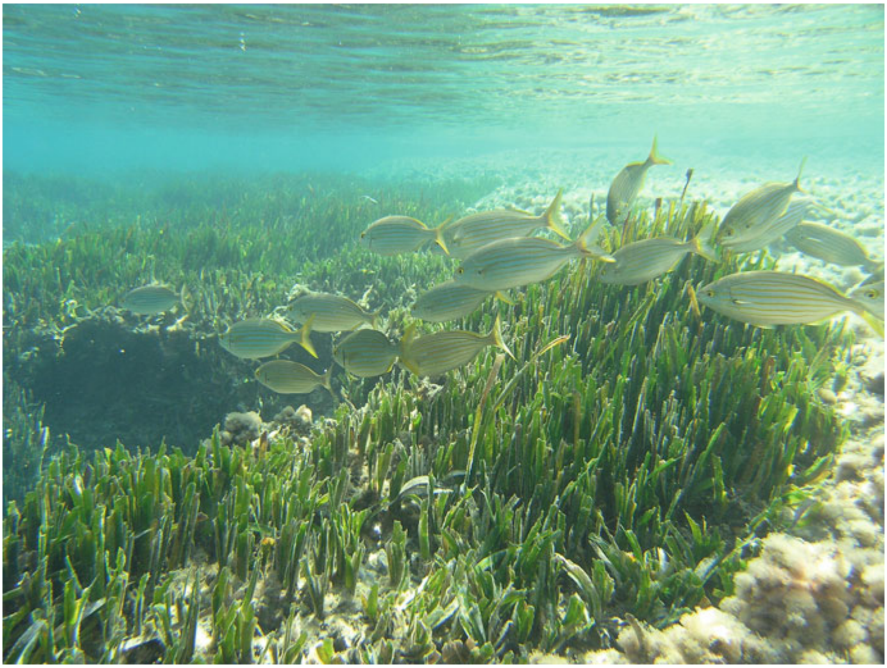

Fig. 9.9 The edge of a *Posidonia oceanica* meadow on a rocky bottom in Cabo de Gata-Níjar Natural Park, with a school of *Sarpa salpa* grazing on the leaves. There is much exchange between *P. oceanica* meadows and the neighbouring community of photophilous algae [José Luis Rueda]

meadow is reported in the Acantilados de Maro-Cerro Gordo SAC, at the limit between Granada and Málaga provinces, and the westernmost stands are found in the SACs of Calahonda (Málaga), El Saladillo-Punta de Baños and Bahía de Estepona. All those have been mapped in detail during the LIFE+ project for the conservation of *P. oceanica* meadows in the Andalusian Mediterranean (LIFE09 NAT/E/000534) starting in 2011 (Aranda and Otero 2014). The westernmost meadows around Calahonda are patchy and are unique in their architecture, differing from most Mediterranean meadows by their shallow occurrence (0–5 m), a phenology with short leaves (29–45 cm in spring) and a sediment-filled rhizome stratum (García Raso et al. 2010; Urra et al. 2013b). On the southern shore, *Posidonia* meadows are reported around Beni Saf and Cap Blanc, west of Oran, Algeria (Khodja 2013), then there is an isolated occurrence in the Chafarinas Islands (Guallart and Afán 2013), but the species is missing in the large area under the influence of the mouth of the Moulouya River and has not been reported further west along the Moroccan coast even in apparently appropriate areas such as Al Hoceima National Park (Guallart and Afán 2013).

Luque and Templado (2004) coordinated one of the most exhaustive bibliographic compilations on the composition and, in some cases, the structure of these communities based on the information obtained by researchers from different institutions (Universidad Autónoma de Madrid and universities of Málaga, Cádiz, Granada, Seville; Museo de Ciencias Naturales de Madrid-CSIC and the Environment Agency of the Junta de Andalucía). The community associated with the *P. oceanica* meadows has been intensively studied, both in the northwestern and northeastern Alboran Sea, although attention was biased to certain faunistic groups (e.g. polychaetes, molluscs, decapods, echinoderms or fish) (San Martín et al. 1990, García Raso 1990, García Raso et al. 1992, 2010; Luque and Templado 2004; Urra et al. 2013b; Mateo-Ramírez et al. 2015). The community associated with *Posidonia* is more complex and diverse than those associated with *Z. marina* or *C. nodosa* due to the simpler structure of the leaf and rhizome strata and usually shallower occurrence of those small seagrasses associated with soft bottoms (Luque and Templado 2004). As an example of this structural complexity, more than 800 species have been identified in the *Posidonia* meadows of the Almería coast (García Raso et al. 1992). The polychaetes stand out for their high species richness (240 species, San Martín et al. 1990; Luque and Templado 2004; Torres Gávila 2008) together with molluscs (over 200 species, García Raso et al. 1992; Luque and Templado 2004; Urra et al. 2013b), amphipods (over 70 species, Luque and Templado 2004), decapods (over 50 species, García Raso 1990; García Raso et al. 1992; Luque and Templado 2004; Mateo-Ramírez et al. 2015) and echinoderms (25 species, Luque and Templado 2004). Studies on other groups (e.g. foraminiferans, nemerteans, turbelarians) inhabiting the *Posidonia* meadows of the Alboran Sea are very scarce.

Posidonia leaves, which can reach more than 1 m in length in the eastern part of the Alboran Sea, including Chafarinas Islands, Cabo de Gata and other places in the Almería province, constitute a very particular habitat. It is a dense, permanently moving stratum, with illuminated and shaded areas (upper and lower surface of the leaves) which considerably increases the available surface of colonizable substrate. The most common epiphytic organisms in this substrate are calcareous algae, which dominate especially in the illuminated area of the leaves, followed by encrusting bryozoans (*Electra posidoniae*, *Patinella radiata*), hydroids (*Sertularia*, *Campanularia* and *Aglaophenia*), colonial tunicates, serpulid polychaetes (*Spirorbis*) and sea anemones (*Parastephanauge paxi*, better known under the incorrect name *Paractinia striata*) (Junta de Andalucía 2008–2019). Among the mobile fauna, the most abundant are gastropods (such as *Tricolia speciosa*, *Jujubinus* spp., *Gibbula ardens*, *Steromphala umbilicaris*, juveniles of *Crepidula unguiformis*, several rissoids such as *Rissoa auriscalpium* and *R. ventricosa* and the emerald neritid *Smaragdia viridis*. Among the crustaceans, there are characteristic isopods such as *Synischia hectica*, numerous amphipods and some characteristic decapods, such as *Hippolyte inermis*. The planarian *Planocera graffi* and the echinoderm *Asterina phylactica* (previously identified as *Asterina pancerii* in Andalusian coasts and reconsidered by López-Márquez et al. 2018) are also recorded, at least in the eastern part around Cabo de Gata. Some species of very small and cryptic fish, such as *Opeatogenys gracilis* and *Apletodon incognitus*, occur among the *Posidonia* leaves. In the westernmost part of the Alboran Sea, the "fundamental stock" of molluscan species described by Russo et al. (1984) as associated to the leaf stratum of *Posidonia* is either missing (e.g. *Tricolia speciosa*, *Rissoa ventricosa*, *Rissoa violacea*, *Gibbula ardens*, *Petalifera petalifera*, *Flexopecten hyalinus*) or present in very low numbers (e.g. *Steromphala umbilicaris*, *Rissoa auriscalpium*), a possible explanation being that the meadows are too patchy to sustain viable populations of these species (Gofas et al. 2011) or because they are strict Mediterranean species that become rarer towards the Strait of Gibraltar.

The *P. oceanica* rhizome stratum is very complex, with distinct micro-habitats (García Raso et al. 1992; Luque and Templado 2004). While the leaf stratum has characteristic species adapted with small and flattened forms, the stratum formed by the rhizomes has no exclusive fauna since it is composed of species that are also found in other adjacent hard substrates. Nevertheless, this stratum of rhizomes deserves special attention, since it is densely populated by organisms. For example, 50 different decapod species and more than 900 specimens have been recorded in a 30 × 30 cm frame (0.09 m^2) in *P. oceanica* meadows from Almería (García Raso 1990). Small specimens and juveniles dominate in this stratum, due to its role as protection and nursery for many species, as observed in a much lesser extent in the small seagrasses *Z. marina* and *C. nodosa*. Frequent macrofauna which inhabits the rhizomes are the sponges *Chondrosia reniformis*, *Phorbas fictitius* and *Crambe crambe*; the cnidarians *Pachycerianthus* sp. and *Aiptasia mutabilis*; the annelids *Salmacina* spp., *Protula intestinum*, *Bispira volutacornis* and *Sabella spallanzanii*; the bivalves *Striarca lactea* and *Barbatia barbata*; the chiton *Lepidopleurus cajetanus*; the gastropod *Chauvetia mamillata*; and the bryozoans *Schizobrachiella sanguinea*, *Schizoporella errata*, *Reteporella grimaldii* and *Schizomavella mamillata.* The echinoderms *Holothuria tubulosa*, *Paracentrotus lividus*, *Sphaerechinus granularis*, *Echinaster sepositus*, *Ophioderma longicauda* and *Antedon mediterranea*; the tunicates *Didemnum fulgens*, *Pseudodistoma obscurum*, *Phallusia mammillata* and *Pycnoclavella communis*; and fish such as *Gobius* spp. are also common in *Posidonia* meadows. In the rhizomes, two species of hermit crabs are dominant, *Cestopagurus timidus* (in shallow water, especially in 3–4.5 m) and *Calcinus tubularis* (in deeper water, ca. 9 m), and also show (especially the first one) day-night movements from the rhizomes to the leaves (García Raso 1990; Manjón-Cabeza and García Raso 1994, 1995). Other dominant decapods of this stratum are also common in sciaphilous enclaves of rocky bottoms and include *Athanas nitescens*, *Alpheus dentipes*, *Pisidia longimana* (also mentioned as *P. longicornis*) and *Pilumnus hirtellus* among others.

In the westernmost part, *Posidonia* meadows in Calahonda (Málaga) usually have a sediment-filled rhizome stratum, and the molluscan species found there as dominant, e.g. *Tritia incrassata*, *Bittium reticulatum*, *Steromphala racketti*, *Nodulus contortus*, *Tricolia pullus* and *Gibberula miliaria* (Urra et al. 2013b), are not specific to the *Posidonia* habitat but shared with neighbouring hard substrates with photophilous algae. In this area, some tropical Atlantic species such as the bivalve *Ungulina rubra* inhabit the rhizome stratum, having there the only known populations for the Mediterranean and the European coasts (Urra et al. 2013b).

Possibly one of the most characteristic species in *Posidonia* meadows is the mollusc *Pinna nobilis*, one of the largest bivalves in the world. Unfortunately, since 2016 this species suffered a massive mortality that has affected almost 100%

of the Spanish populations south of the Ebro Delta, including the Alboran Sea (see Chap. 10 of this book). *Pinna rudis*, a similar but smaller species that usually lives in hard substrates, is also frequently observed over *Posidonia* rhizomes, particularly in the western part, and has not been affected by this massive mortality event.

In addition to the communities associated with leaves and rhizomes, there are a number of mobile species that move through the meadow in search of shelter or forage for food. These are mostly fish (e.g. *Gobius* spp., *Symphodus* spp., *Serranus scriba*, *S. cabrilla*, *Coris julis*, *Sarpa salpa*) but also crustaceans and cephalopods, such as the cuttlefish *Sepia officinalis* (García Raso et al. 1992; Luque and Templado 2004).

There is definitely an interaction and connectivity between the *Posidonia* community and surrounding habitats, although the rhizome (due to its morphological characteristics, complexity and protection capacity) seems more stable. This exchange may minimize the negative effect that the fragmentation of *Posidonia* meadows (which is frequent in a large part of the Alboran Sea, near the western limit of its distribution) could cause on the animal community (Luque and Templado 2004; Urra et al. 2013b; Mateo-Ramírez et al. 2015). The seasonal dynamics of the associated fauna is driven by the annual variability of the dominant species, with greater abundance and specific richness observed in the spring and summer months in the case of molluscs (Urra et al. 2013b) and in autumn for the decapod crustaceans (Mateo-Ramírez et al. 2015), due to reproductive events.

Mesophyllum alternans is a coralline alga which takes the form of rather large (up to 20 cm) rosettes and is mostly associated with the rhizomes of *P. oceanica*. This alga encloses a complex network of cavities, which provides shelter to a rich and varied animal community and therefore enhances the biodiversity and the value of the *Posidonia* meadow in the Alboran Sea (Hergueta and Salas 1986; García Raso and Fernández Muñoz 1987; Fernández Muñoz and García Raso 1987; López de la Rosa and García Raso 1992; García Raso et al. 1996). The enclosed fauna is typically composed by gastropods, such as *Alvania nestaresi* and *Chauvetia mamillata*, bivalves such as *Hiatella arctica* and *Striarca lactea* and decapods such as *Alpheus dentipes*, *Pilumnus hirtellus*, *Pisidia longimana*, *Athanas nitescens* and *Cestopagurus timidus* (Luque and Templado 2004). Sponges such as *Sycon* spp. and *Leuconia* sp.; the polychaetes *Platynereis dumerilii*, *Ceratonereis costae* and *Syllis gracilis* (Luque and Templado 2004); the pycnogonids *Achelia langi* and *Tanystylum conirostre* (Munilla 1991); and the echinoderm *Amphipholis squamata*, among many others, are also common (Luque and Templado 2004). In addition, many juveniles of larger species find refuge in these structures, such as the sea urchins *Paracentrotus lividus* and *Arbacia lixula*. Some species, such as the excavating sponge *Cliona viridis*, perforate the concretions, while others such as the vermetid *Thylacodes arenarius* contribute to the growth of these structures. The mobile species, in any case, move between the rhizomes and the *Mesophyllum* concretions so that both communities are quite similar.

Posidonia beds are the only accurately defined marine habitat in the EU Habitats Directive and, fortunately, are treated therein as priority habitat “1120* Posidonia beds (*Posidonion oceanicae*)” (Díaz Almela and Marbà 2009) which requires that at least 60% of the surface occupied by this habitat must be included in Nature 2000 Special Areas of Conservation in order to consider their protection as sufficient (European Commission 2007: 43).

There are scanty nineteenth- and twentieth-century reports of *Posidonia* as far west as the bay of Algeciras, particularly from the Gibraltar harbour (Bull et al. 2010), and that could explain old records in that area of molluscs commonly linked to *Posidonia* meadows and nowadays absent from the area (e. g. *Tricolia speciosa*, *Cardites antiquatus*). Surveys in the Calahonda SAC (Málaga) show an alarming extension of dead *Posidonia* rhizomes now overgrown by macroalgal communities or covered by sand, pointing to ongoing decline of this emblematic species in the westernmost part of its distribution range (García Raso et al. 2010).

9.4.3 Kelp Forests

Large brown algae such as *Laminaria ochroleuca*, *Saccorhiza polyschides* and *Phyllariopsis* spp., widely distributed along the Atlantic coasts, reach some parts of the Alboran Sea. Surprisingly, despite the great animal diversity that lives in this complex habitat, the fauna that inhabits the kelp forest of the Strait of Gibraltar and Alboran Island has not been studied in detail. The only available data comes from the observations made during the Fauna IV campaign in the *Laminaria/Saccorhiza* forests surrounding the Alboran Island between 25 and 50 m in depth (Fig. 9.10). These data were included in a chapter within the book on the marine vegetal communities of Andalusia (Luque and Templado 2004) and later in the monograph of the fauna and flora of Alboran (Templado et al. 2006).

Few animal species can be found on the smooth blades of these large algae, possibly because they segregate antifouling substances and for being very beaten by the strong currents, which may make the larvae settlement difficult. Among these few species, the most outstanding is the bryozoan *Membranipora membranacea* (exclusive of the blades of Laminariales), the anemone *Alicia mirabilis* and the colonial ascidians of the genus *Botryllus*. Sometimes the sea urchin *Sphaerechinus granularis* can be found eating these blades, although their preferred food are encrusting red algae of the basal layer of the kelp forests. The limpet *Patella pellucida*, which is an obligate associate of the kelp, has not been seen on the kelps of the Alboran Sea, being reported only from Tangiers (Gofas et al. 2011).

The basal stratum of these forests (Fig. 9.10) is often composed of encrusting red algae and is inhabited by a rich community of sciaphilous species dominated by sponges and ascidians, often with a coverage close to 100%. Among the most conspicuous species are several gorgonians (*Eunicella verrucosa*, *Eunicella gazella*, *Eunicella labiata*, *Leptogorgia sarmentosa*) intermingled with the kelp. The white gorgonian *Eunicella verrucosa* may reach a high density (up to 20 colonies/m^2), although the size of their colonies is relatively small. Other frequent sessile species are the serpulid worms *Serpula vermicularis* and *Protula intestinum,* the octocorals *Alcyonium acaule* and *Parerythropodium coralloides* (the latter usually on the

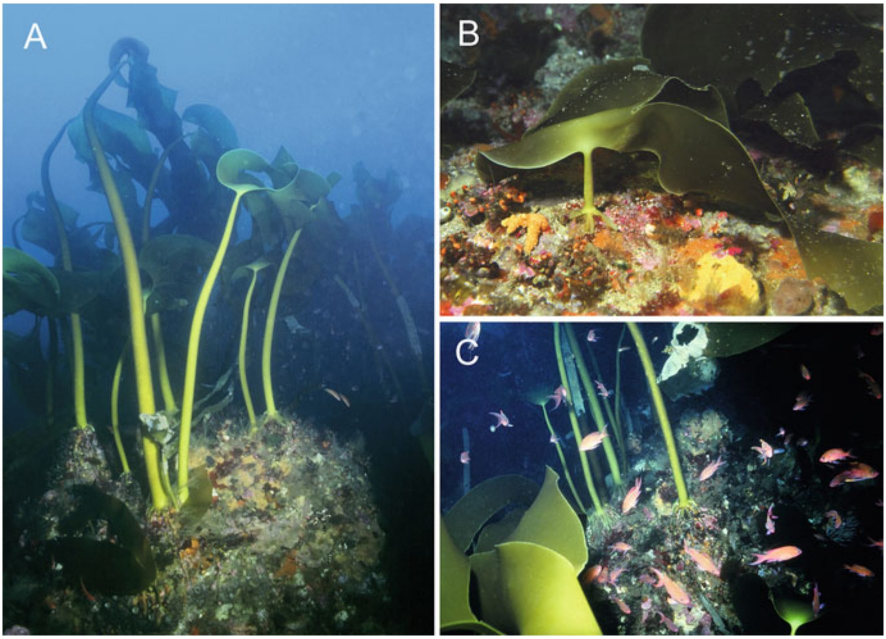

Fig. 9.10 **(a)** Kelp forest of *Laminaria ochroleuca* around Alboran Island at 30–40 m depth. **(b)** Juvenile holdfast and undergrowth with sponges and red algae; **(c)** inner view of forest with large holdfasts and numerous *Anthias anthias* [b: Diego Moreno, and a, c: Diego Moreno/Fauna Ibérica project-MNCN-CSIC]

gorgonians), the hydroids *Nemertesia antennina* (whose colonies can reach up to 30 cm in height) and some species of the genus *Aglaophenia*, several erect bryozoans of branched colonies (*Myriapora truncata*, *Frondipora verrucosa*, *Pentapora fascialis*, *Bugula spiralis*), ascidians (*Rhopalaea neapolitana*, *Phallusia mammillata*, *Aplidium elegans*, *Polycarpa mamillaris*, among others) (Ramos-Esplá 1991) and a large number of sponges, such as *Crambe crambe*, *Oscarella lobularis*, *Dysidea* spp., *Axinella damicornis* or *Aplysina aerophoba* (Maldonado 1993). Many of these species of the basal stratum are also found deeper in coralligenous communities.

Through this complex and shaded habitat, there are also a multitude of mobile animals, mainly polychaetes, gastropods such as *Calliostoma zizyphinum* and *Bolma rugosa*, crustaceans and echinoderms. Many species of fish also find refuge in these kelp forests, like many wrasses (e.g. *Coris julis* and *Labrus mixtus*) and serranids (mainly *Serranus scriba*), and the so-called three tails (*Anthias anthias*). Another common fish among the recesses of the undergrowth is the so-called torillo (*Blennius ocellaris*). Large schools of the sparid *Pagellus acarne* are frequent above the forest.

Despite representing a unique benthic community in the Mediterranean, kelp beds do not receive any other protection than their eligibility as "1170 Reefs" (Templado et al. 2009) of the EU Habitats Directive. Nevertheless, the kelp *Laminaria* *ochroleuca* is included in Annex I of the Berne Convention (strictly protected flora species) only for its Mediterranean populations. The status of kelp forests is not better in the Atlantic, where they are more widespread but where Norway, Iceland, Denmark, Ireland and the European Commission have strongly opposed at OSPAR's Biodiversity Committee, Berlin, March 6–10, 2017, the inclusion of kelp forests in the List of Threatened and/or Declining Species and Habitats.

9.4.4 Infralittoral Hard Bottoms Dominated by Sessile Invertebrates

Calcareous bio concretion structures are often developed under dim-light conditions by sciaphilous algae and other habitat-forming invertebrates, providing highly structured environments which, in turn, support a wide range of other sessile and mobile species (Ballesteros 2006). These biotic assemblages are more extensive at circalittoral depths of the Alboran Sea (Giakoumi et al. 2013), although they can be found as enclaves in the infralittoral zone under crevices and overhangs or at the entrance of marine caves.

This so-called pre-coralligenous community dominated by sessile invertebrates has been described both in the southern and northern areas of the Alboran Sea (e.g. Chafarinas Islands, Cap des Trois Fourches, Al Hoceima, Alboran Island, coast of Granada, the "Laja del Almirante" in the Calahonda Special Area of Conservation, Málaga). This habitat harbours sciaphilous coralline algae (e.g. species of the genera *Mesophyllum*, *Lithophyllum*), bryozoans (e.g. *Pentapora fascialis*, *Myriapora truncata*), polychaetes (e.g. *Salmacina dysteri*), sponges (*Oscarella lobularis*, *Reniera* spp., *Crambe crambe*, *Clathrina* spp., *Axinella* spp., *Ircinia* spp., *Aplysina cavernicola*, etc.), cnidarians (*Astroides calycularis*, *Eudendrium racemosum*, *Alcyonium* spp., *Eunicella* spp.) and echinoderms or ascidians (*Aplidium conicum*, *Didemnum* spp., *Halocynthia papillosa*) among others (Pérez-Ruzafa and López-Ibor 1988; Cebrián and Ballesteros 2004; Franzosini and Limam 2004; Sánchez-Tocino et al. 2009; García Raso et al. 2010; Bazairi et al. 2013). Exceptionally shallow occurrences of the gorgonian *Ellisella paraplexauroides* were recorded around the Chafarinas Islands by Maldonado et al. (2013) (see Chap. 10).

Along the coast of Granada, in the northern part of the Alboran Sea, these communities are characterized by a dominance of suspension feeders and higher biomass of calcium carbonate than in other temperate and Mediterranean sites (Cebrián et al. 2000; Cebrián & Ballesteros 2004). This pattern, together with its high diversity of species, seems influenced by the particular hydrodynamic conditions within this area (mixing of Atlantic and Mediterranean waters and the occurrence of upwelling events). Although they were not exclusive of coralligenous communities, many mobile species (some of them protected) are commonly associated with these sciaphilous environments. Among them are molluscs (*Luria lurida*, *Naria spurca*), decapods (*Scyllarides latus*, *Scyllarus arctus*, *Palinurus elephas*),

Fig. 9.11 Dense aggregations of the orange coral *Astroides calycularis* near the entrance of a cave at Punta de la Mona, Granada [Luis Sánchez Tocino]

echinoderms (*Echinaster sepositus*, *Ophidiaster ophidianus*, crinoids and brittle stars) and fish species (e.g. *Sciaena umbra*, *Scorpaena* spp., *Apogon imberbis*) (Templado et al. 2004).

The occurrence of coralligenous communities in the infralittoral zone is not only triggered by topographic features such as slope and orientation of the substrate. The ultimately important factor is reduction in the amount of light, and this can also be caused by turbidity. For example, a highly diverse coralligenous community dominated by gorgonians, bryozoans, molluscs and decapods has been reported at shallow depths of the Calahonda SAC due to the high turbidity levels in the water column (García Raso et al. 2010; Urra et al. 2012).

One of the most conspicuous and emblematic sciaphilous habitats in the shallow hard bottoms of the Alboran Sea is dominated and structured by the threatened orange coral *Astroides calycularis* (commonly known as Chalice coral or Star coral) (Fig. 9.11). The biological characteristics and relevance of this colonial scleractinian, as well as its geographical distribution, will be further detailed in Chap. 10.

Like the other benthic habitats of hard bottoms, the precoralligenous may fit the Habitat 1170 “Reefs” (Templado et al. 2009) as defined in the EU Habitats Directive. A particular consideration must be given to *A. calycularis*, which is included in the Spanish and Andalusian Catalogues of Threatened/Endangered Species (LESRPE and LAESRPE) with the category “vulnerable”, which entails effective protection of habitats where the species occurs. Besides its role as biodiversity reservoir, the precoralligenous habitat is also valuable from an aesthetic point of view, being focal points for recreational diving. Together with other main sources of human perturbation (e.g. coastal pollution, climate change), physical impacts due to scuba diving activities and fishing gear are noticeable due to the high fragility and low growth rate of calcareous organisms (Ballesteros 2006).

9.4.5 Circalittoral Hard Bottoms with Coralligenous Communities

Coralligenous communities represent complex bioconstructions developed over a basal layer of calcareous algal species and secondarily by different sessile and filter feeding macroinvertebrates with calcareous skeletons (e.g. anthozoans, sponges, serpulid annelids, bryozoans), which thrive under dim-light conditions on rocky crests, walls, overhangs and crevices, supporting high levels of biodiversity and a complex trophic net (Ballesteros 2006). This is an emblematic habitat in the Mediterranean Sea, locally starting in the infralittoral zone below 20 m (precoralligenous, see above) and widely developed in the circalittoral zone, where conditions of temperature, currents and salinity are relatively constant (Laborel 1987; Ballesteros 2006). Overall, the composition of the coralligenous community is highly determined by depth and the relief of rocky outcrops, becoming considerably different from one place to another separated horizontally or vertically by few meters, which promotes high species richness.

Coralligenous communities at circalittoral depths have been recently studied in detail in areas included within the Natura 2000 network (EU Habitat Directive) such as the Alboran Island (Gofas et al. 2014a; Sitjà and Maldonado 2014) and the Seco de los Olivos (de la Torriente et al. 2014), in the framework of the EU LIFE+ INDEMARES project. Coralligenous communities develop on rocky substrates that occupy large areas of the Alboran platform (30–100 m depth), mainly in the southern flank and in the southwestern outcrop and on the shallowest areas of the Seco de los Olivos (ca. 100 m depth), where light conditions still allow the growth of calcareous red algal species. The calcareous basal layer is mainly composed of *Lithophyllum stictiforme* and *Neogoniolithon mamillosum* in Alboran, plus *Mesophyllum alternans* in the Seco, and represents a hard substratum that is colonized by sessile large-size animals with bioconstruction potential.

Overall, gorgonians are the most characteristic taxa in this community, with *Eunicella verrucosa*, *Paramuricea clavata* and *Leptogorgia sarmentosa* (Fig. 9.12) dominating between 30 and 90 m depth. Secondary typifying species at this depth range include other anthozoans such as the zoantharian *Savalia savaglia*, the black coral *Antipathella subpinnata*, the soft octocoral *Alcyonium acaule* and the coral *Dendrophyllia ramea* (de la Torriente et al. 2014; Gofas et al. 2014a).

The sponge fauna also represents an important component of the coralligenous community, with a great amount of encrusting, branching and massive sponges sharing habitat with the octocorals. This faunal component has been deeply studied

Fig. 9.12 Diverse and spectacular cnidarian assemblage on a circalittoral bottom off Chafarinas Islands, with the gorgonians *Ellisella paraplexauroides*, *Paramuricea clavata* and *Leptogorgia sarmentosa*, the coral *Dendrophyllia ramea* and an orange encrusting sponge [Luis Sánchez Tocino]

in the case of the Alboran platform, where common sponges include *Dysidea fragilis*, *Sarcotragus pipetta*, *Hexadella racovitzai*, *Penares helleri*, *Crambe tailliezi*, *Caminus vulcani*, *Dercitus plicatus*, *Craniella cranium* as well as several species of the genera *Axinella*, *Suberites*, *Calthropella*, *Erylus*, *Haliclona*, *Spongosorites* and *Phorbas* (Maldonado 1992, 1993; Sitjà and Maldonado 2014). Other common organisms include the polychaete *Sabella pavonina*, which can develop dense aggregations in some areas of the Alboran platform, becoming a typifying species of the community; the bryozoans *Myriapora truncata*, *Pentapora fascialis* and *Reteporella grimaldii*; the ascidians *Diazona violacea*, *Ascidia mentula*, *Botryllus schlosseri*, *Polycarpa mamillaris*, *Polycarpa pomaria*, *Styela canopus* and *Microcosmus vulgaris* among others; and the brachiopods *Megathiris detruncata*, *Terebratulina retusa*, *Novocrania anomala* and *Megerlia truncata*. Furthermore, a great diversity of mobile organisms swarms around these complex bioconstructions, including a large number of small-size polychaetes, molluscs, crustaceans and echinoderms. Echinoderms are among the best represented large-size organisms and include the sea urchins *Sphaerechinus granularis*, *Gracilechinus acutus* and *Centrostephanus longispinus* and especially the basket sea star *Astrospartus mediterraneus*, which is observed on several gorgonians with their branched arms totally extended. Besides, threatened and/or protected species are frequently observed in the coralligenous community including several species with

Fig. 9.13 Abundant red coral (*Corallium rubrum*) growing under a rocky overhang at ca. 100 m depth on the Alboran platform. On the upper part, the substrate is mostly covered by gorgonians of the genus *Eunicella* [LIFE+ INDEMARES Alboran]

high commercial value such as the spiny lobster *Palinurus elephas*, the European lobster *Homarus gammarus*, the Mediterranean slipper lobster *Scyllarides latus*, the spider crab *Maja squinado*, the knobbed triton *Charonia lampas* or the date mussel *Lithophaga lithophaga*. Among fishes, *Anthias anthias* is among the commonest species and forms swarms next to some overhangs of the rocky bottom. Groupers such as *Epinephelus marginatus* and the cuckoo wrasse *Labrus mixtus* are also characteristic of this habitat.

At deeper areas and down to 200 m depth or more, coralligenous communities turn to a "Roche du Large" community (*sensu* Pérès and Picard 1964) with a different faunal composition. The community on the Alboran platform is dominated by the gorgonians *Viminella flagellum*, *Acanthogorgia hirsuta*, *Acanthogorgia armata* and especially *Callogorgia verticillata*, a typical species of the bathyal level that can develop dense "gorgonian gardens" (Gofas et al. 2014a). Other typical species include small-size gorgonians (e.g. *Bebryce mollis*) and scleractinians (*Dendrophyllia cornigera*). The red coral *Corallium rubrum*, although occasionally occurring in caves as shallow as 20 m, is a typical component of the deeper part of the circalittoral and reaches its maximum densities under rocky overhangs below 100 m depth (Fig. 9.13). The sponge fauna is also very characteristic (Fig. 9.14), being represented on the Alboran platform and the Seco de los Olivos by large specimens of the predominantly Atlantic *Asconema setubalense*, *Phakellia robusta*,

Fig. 9.14 Deep rocky bottom on the Alboran platform with a large *Phakellia robusta* and many small "lollipop" sponges; the substrate is here covered by a thin layer of muddy sediment [LIFE+ INDEMARES Alboran]

Phakellia ventilabrum and *Poecillastra compressa*, together with a great variety of small erect sponges with stalked "lollipop" morphologies (e.g. *Podospongia lovenii*, *Rhizaxinella elongata*, *Rhizaxinella gracilis*, *Crella pyrula*) and branching morphologies (e.g. *Axinella vellerea*, *Axinella pumila*, *Stelligera stuposa* and *Stelligera rigida*) (Maldonado 1992, 1993; Sitjà and Maldonado 2014) (see Chap. 10 for details).

At the Seco de los Olivos, gorgonians and sponges are also important faunal components, especially in the rocky pinnacles that surround the main edifice. Characteristic gorgonians include *Swiftia dubia*, *Bebryce mollis*, *Acanthogorgia hirsuta*, *A. armata*, *Placogorgia coronata*, *Dendrobrachia fallax*, *Callogorgia verticillata* and *Viminella flagellum*, sometimes intermixed with large hexactinellid sponges (e.g. *Asconema setubalense*) which form important aggregations in bathyal rocky bottoms. On the summit of these pinnacles, mainly in areas exposed to strong currents, black coral communities composed of *Leiopathes glaberrima*, *Antipathes dichotoma* and less frequently *Antipathes subpinnata* are usually observed. Regarding sponge communities, they can vary spatially, with small boring sponges (e.g. *Hymedesmia paupertas*, *Antho* sp.) dominating rocky bottoms with scarce sessile organisms, large sponges (e.g. *Pachastrella monilifera*, *Poecillastra compressa* and *Phakellia* spp.) dominating deep rocky bottoms or isolated large sponges (e.g. *Spongosorites flavens*, *Haliclona perlucida* and *Geodia* sp.) found in sites with large boulder deposits (de la Torriente et al. 2014).

Additionally, several submarine canyons have been studied within the Alboran basin in the last decade, providing some information of the coralligenous communities inhabiting these systems. Regarding this, La Línea de la Concepción and Guadiaro submarine canyon heads in the northwestern part of the Alboran shelf (60–100 m depth) display mixed bottoms composed of rocky boulders, gravels and biogenic remains that are colonized by the abundant *Eunicella verrucosa*, together with *Leptogorgia sarmentosa* in the case of La Línea canyon, with individuals of *Astrospartus mediterraneus* laying on branched gorgonian colonies (Vázquez et al. 2015). Secondary typifying species of these communities include dispersed small colonies of the cold-water coral *Dendrophyllia cornigera*, as well as echinoderms such as *Centrostephanus longispinus* and *Cidaris cidaris* or the echiurian *Bonellia viridis*. In deeper settings (140–200 m), colonies of *Callogorgia verticillata*, *Dendrophyllia cornigera* and *Caryophyllia* solitary corals were observed in high density in coralligenous communities of the Guadiaro canyon (Vázquez et al. 2015).

All coralligenous (and precoralligenous) bottoms can easily be encompassed in the broadly defined habitat of “1170 Reefs” (Templado et al. 2009) of the EU Habitats Directive. Furthermore, the use of towed dredges and trawl nets fisheries over coralligenous bottoms is forbidden under Art. 4 of the Council Regulation (EC) No 1967/2006 concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea (Council of the European Union 2006). “Coralligenous beds” are also listed as “Essential Marine Habitats (EMH) of relevance for the management of priority species” by the Scientific Advisory Committee of the General Fisheries Commission for the Mediterranean (General Fisheries Commission for the Mediterranean 2009). A few of the characteristic species, e.g. the sea urchin *Centrostephanus longispinus* and more recently several species of gorgonians and black corals, have been included in Annex 2 of the Barcelona convention, but this is of limited consequence unless national bylaws enforce protection in practice. The red coral *Corallium rubrum*, the most sought after species in this environment, is of particular concern, and information on its conservation status and exploitation is thoroughly discussed in Chap. 10.

9.5 Caves

Despite being considered as unique and sensitive habitats requiring protection under EU Habitats Directive, the number of studies dealing with marine caves and their biota in the Alboran Sea is scarce, and, as a consequence, this is the Mediterranean region with the lowest number of marine caves reported (Giakoumi et al. 2013). To date, all ecological studies have been conducted in the northern part of the Alboran Sea (mainly in the coast of Granada) (Navarro-Barranco 2015), while the biota of Moroccan caves remain almost unexplored. Nevertheless, long stretches of the coastline along the southern margin of the Alboran Sea are composed by limestone cliffs which likely contain marine caves, some of them already reported at the Cap de Trois Fourches, Al-Hoceima National Park or Chafarinas Islands (Maldonado et al.

2011; Espinosa et al. 2015). Most of the marine caves studied in the area are small and shallow, although deeper (below 30 m deep) and longer (approximately 100 m long) caves have been also described (Navarro-Barranco et al. 2015).

A common biological feature is the so-called biocenosis of semi-dark caves, where dim light favours the dominance of sessile invertebrates, such as the sponges *Dysidea avara*, *Sarcotragus* spp., *Petrosia ficiformis* and *Chondrosia reniformis*, the anthozoans *Astroides calycularis* and *Parazoanthus axinellae*, different species of gorgonians, the bryozoans *Adeonella calveti* and *Pentapora fascialis* and the fishes *Phycis phycis* and *Conger conger* among others. Those species are not exclusive of cave habitats, being also found in other sciaphilous environments (crevices, overhangs, coralligenous assemblages) or photic habitats but with less coverage by sessile organisms.

The Cerro Gordo marine cave, located in the coast of La Herradura (Granada), is the most interesting and studied cave in this area. Due to their extensive length, inner areas within this cave are characterized by constant conditions of darkness and by water confinement. Benthic taxa occurring in the innermost part of the cave are highly specialized species (Fig. 9.15), mainly encrusting sponges and bryozoans, brachiopods (*Novocrania anomala*, *Megathiris detruncata*) or serpulid polychaetes (Navarro-Barranco et al. 2015).

Unlike sessile communities, other elements of Alboran cave fauna (mainly crustaceans) are relatively well known in comparison with other Mediterranean areas. The singularity of mobile epifaunal assemblages inhabiting cave sediments and hard substrates has been highlighted (Navarro-Barranco et al. 2013, 2014). The spatial distribution, trophic ecology and colonization patterns of the Amphipoda, which constitute the best-known cave-dwelling macrofaunal group in this area (49 species reported until know), have also been explored (Navarro-Barranco 2015; Navarro-Barranco et al. 2015). Dense swarms of the Mediterranean endemic mysid *Hemimysis margalefi* can be found inside some of the caves (Rastorgueff et al. 2014), as well as the sponge-feeding molluscs *Naria spurca*, *Luria lurida*, *Peltodoris atromaculata* and *Berthella ocellata* or the decapods *Stenopus spinosus*, *Palaemon serratus*, *Lysmata seticaudata* and *Dromia personata*. Regarding fishes, the cardinal fish *Apogon imberbis* or the leopard-spotted goby (*Thorogobius ephippiatus*) are frequent in caves.

Ecological studies conducted in caves in the Alboran Sea have pointed out the slow rate of colonization, the uniqueness of their species composition and the high stability of the environmental conditions, supporting the current consideration of marine caves as highly valuable and sensitive habitats to human perturbation. Although recent studies conducted within the Cerro Gordo cave have highlighted its good environmental status, significant temporal variations of the sessile assemblage structure have occurred during the last decade (both at internal and external cave sectors) (Navarro-Barranco et al. 2015).

Submarine caves are adequately defined in the EU Habitats Directive as “8330 Submerged or partially submerged sea caves” (López-Bedoya and Pérez-Alberti 2009) and are therefore eligible for inclusion in a marine Special Area of Conservation. The major human source of impacts suggested for marine caves are due to

Fig. 9.15 Animals are the sole inhabitants of the cave wall and roof, here in the Cerro Gordo cave (province of Granada). **(a)** Brachiopods are represented here by *Novocrania anomala* and *Megathiris detruncata*; **(b)** shrimp *Stenopus spinosus* and **(c)** sponge *Chondrosia reniformis* are other characteristic elements [Luis Sánchez Tocino]

scuba diving, coastal infrastructures and global change, but specific studies have not been conducted in this area so far.

9.6 Soft-Bottom Communities of the Continental Shelf

Like in most marine environments, sedimentary bottoms are predominant in the Alboran Sea, where fine and medium sand generally extend down to 20–30 m depth, with more muddy patches in front of the river mouths, harbours and deeper zones (MAPAMA 2019). Exceptions are the Strait of Gibraltar and some sectors of the littoral of Granada, characterized by the presence of many cliffs in the coastal line. There, the shelf is very narrow, and most of the infralittoral soft bottom consists of patches of coarse bioclastic sand (Rueda and Salas 2003). Nevertheless, at both sides of the strait, there are long sandy beaches such as Caños de Meca on the Atlantic side or La Línea de la Concepción on the Mediterranean one.

Most of the studies on communities from sublittoral soft bottoms have been carried out in the northern margin of this basin, such as the Gibraltar area (Rueda et al. 2000; Rueda and Salas 2003), the littoral of Málaga province (García Raso 1982, 1983, 1987; Salas et al. 1984; Salas 1987; Urra et al. 2011, 2013c), the littoral of Granada province (Rueda et al. 2009a, b; Marina et al. 2015) or the bay of Almería (Rodríguez and Ibáñez 1976). The African part of the Alboran Sea has been less sampled and studied. In Morocco there are some data from few areas, such as the National Park of Al Hoceima (UICN 2012), Cap des Trois Fourches (Bazairi et al. 2013) and Jbel Moussa (Bazairi et al. 2016). The infralittoral soft bottom in these areas is represented by fine sand in the sheltered bays, from 3 to 20–30 m depth, some of them bordered by *Cymodocea nodosa* meadows, while in the capes the bottom is mainly coarse bioclastic sand. In Algeria the data from the Alboran margin are from the littoral of Oran (Hussein 2015) and Rachgoun Island (Ramos-Esplá et al. 2016). In the latter, most of the infralittoral zone is occupied by rock with photophilous algae, with *Posidonia* beds in the southern littoral of the island. The infralittoral soft bottom of the Oran area is mainly represented by coarse bioclastic sand with meadows of *Posidonia oceanica* and *Cymodocea nodosa* (Hussein 2015).

In general, the most extensively represented infralittoral biosedimentary units in the Alboran Sea are the shallower well-sorted fine sands, coastal bioclastic sand and gravel and coastal terrigenous muds, the latter in areas with less current and usually under influence of rivers or aquaculture facilities which supply the mud.

9.6.1 Well-Sorted Fine Sand

This assemblage is located in the shallower part of the infralittoral zone, usually between 1 and about 20 m, but there are substantial differences between the surf zone and the deeper parts (Pérès and Picard 1964; Dauvin et al. 2017). The surf zone (1–3 m) is characterized by high instability due to strong wave action, and the bottom is medium-grained sand. The faunistic assemblages show low species richness and high dominances. Below, where the waves no longer have a direct effect, there are very homogenous sands of terrigenous origin with low mud content, the so-called well-sorted fine sands. These bottoms are usually devoid of macrophytes (except for seagrasses, see below). Most of their fauna belongs to the infauna, and their surface is apparently barren (Fig. 9.16). Altogether, this is probably the most extensive infralittoral habitat.

In the surf zone, the bivalve *Donax trunculus* (locally known in Spain as coquina) is the most characteristic mollusc, together with the Mediterranean *Donax semistriatus* and the Atlantic *Donax vittatus* (Salas 1987), the Mediterranean nassarid *Tritia grana,* as well as the tropical West African naticid *Sinum bifasciatum* (only occasionally, and restricted to the coast of Málaga) (Gofas et al. 2011). Among the decapod crustaceans, the characteristic species are *Philocheras trispinosus*,

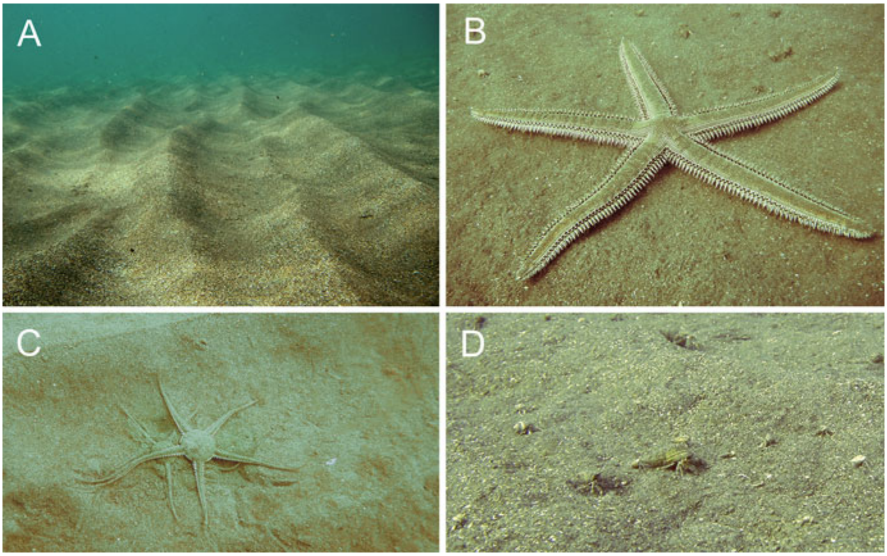

Fig. 9.16 **(a)** Soft bottoms at Caleta de Vélez (Málaga) with ripple marks generated by wave action. Most of the animals are infaunal but a few dwell on the sediment surface: **(b)** *Luidia atlantidea*, a tropical West African element, **(c)** *Ophiura ophiura* and **(d)** the dominant hermit crab *Diogenes pugilator* [Pablo Marina]

Philocheras monacanthus and the crabs *Liocarcinus vernalis* and *Portumnus latipes* (Salas et al. 1984; García Muñoz et al. 2008). These two latter species prey on the foot of *Donax* species (Salas et al. 2001). From 5 m downwards, the faunal assemblage shows higher species richness than the surf zone (Urra et al. 2011) but still with dominance of few species, such as the commercially exploited bivalve *Chamelea gallina* (locally known as chirla), the most characteristic species of this assemblage at 5–10 m depth, together with *Acanthocardia tuberculata*, *Spisula subtruncata*, *Donax venustus* and *Tellina tenuis*. The bivalves *Callista chione* and *Glycymeris nummaria* are abundant between 15 and 20 m depth. Most of the gastropods are scavengers (*Tritia reticulata*, *Tritia pygmaea*) or carnivorous (*Bela zonata*, *Euspira* spp.). The hermit crab *Diogenes pugilator* is the dominant decapod in this bottom (García Muñoz et al. 2008), with maximum abundance between 5 and 15 m depth. Other common decapods are the crabs *Atelecyclus undecimdentatus* and *Liocarcinus depurator*. The burrowing echinoderms *Echinocardium cordatum* and *Echinocardium mediterraneum* coexist in this geographic area and type of bottom, together with dense populations of the epibenthic *Ophiura ophiura* and different species of *Astropecten*. The polychaete *Ophelia neglecta* is also common in this bottom, together with different species of nereids. Many species of fish, such as the sparids *Lithognathus mormyrus* and *Diplodus* spp., make incursions on these bottom when foraging, but most characteristic and permanently living in this habitat are flatfish such as *Bothus podas* and the weeverfish *Trachinus draco* and *Echiichthys vipera* (García Raso et al. 1992, 2010). A number of tropical West African species, such as the gastropods *Mesalia varia*, *Tritia vaucheri* and *Gibberula epigrus* (Urra et al. 2011), also characterize this habitat in the westernmost part, mostly along the western coast of Málaga province. The African sea star, *Luidia atlantidea*, has been recently found in the littoral of Málaga (Gallardo-Roldán et al. 2015) (see Chap. 10).

Some seasonality has been observed for the assemblage of molluscs in the soft bottoms of the littoral of Málaga, with maximum of species richness, abundance and diversity in autumn (Urra et al. 2013c). The latter was related with the dynamics of some bivalves, such as *Donax trunculus*, *Acanthocardia tuberculata* or *Callista chione*, probably due to the high fishery activity during the summer, the tourist season and the settlement of larvae in September and October.

All shallow soft bottoms could fall under the loose definition of Habitat 1110 "Sandbanks permanently covered by sea water" of the EU Habitats Directive. Taking into account the extension of this kind of habitats, this has only been claimed in the case where seagrasses are settled on the sandy bottom. Nevertheless most, if not all, marine protected areas of the Alboran Sea harbour a more or less extensive representation of soft-bottom habitats. In practical terms, the main impacts and the protection status of infralittoral sandy bottoms are mostly related to fisheries of shellfish species, such as *D. trunculus*, *Chamelea gallina*, *C. chione* and *A. tuberculata* (Tirado and Salas 1999; Tirado et al. 2002, 2003, 2017; Urra et al. 2018) and to beach replenishments that results in the smothering of the infaunal communities.

9.6.2 Vegetated Infralittoral Soft Bottoms

The communities associated with the small seagrasses *Zostera marina* and *Cymodocea nodosa* have been studied into a lesser extent, compared to *Posidonia*, and only certain faunistic groups have been the subject of detailed studies (e.g. molluscs, decapods, caprellids or fishes) in relation to other phyla (e.g. polychaetes, echinoderms) (Luque and Templado 2004; González et al. 2007, 2008; Rueda et al. 2009a; Marina et al. 2012; Mateo-Ramírez and García Raso 2012). There are hardly any studies on the community associated with *Zostera noltei* present in both estuarine and marine locations (e.g. Bay of Algeciras, Mar Chica lagoon, Smir lagoon), and these studies would be necessary to understand the ecological role and importance of this seagrass for fauna. The faunistic diversity associated with these seagrass meadows of the Alboran Sea is greater than in other places of their area of distribution, due to the biogeographical confluence of species from northern Europe, the Mediterranean Sea, the western coasts of Africa or endemic species from southern Spain (Luque and Templado 2004; Rueda et al. 2009a, 2010; García Raso et al. 2010).

9.6.2.1 *Zostera marina* Meadows

The *Zostera marina* meadows were common in the Andalusian coasts of the Alboran Sea until a decade ago, mostly in Marine Protected Areas (e.g. Acantilados de Maro-Cerro Gordo Special Area of Conservation), but they suffered a strong decline, being currently reduced to small patches in very specific areas of the coast of Granada and Almería, and can be considered almost extinct (Urra et al. 2008; Rueda et al. 2009b; Junta de Andalucía 2008–2019; Arroyo et al. 2015). Since *Z. marina* is an Atlantic species, the progressive warming of the water in the Alboran Sea seems to be unfavourable. In the Moroccan coasts, these meadows have been very little studied, but they do seem to be still present (Hocein 2015).

The most studied eelgrass meadows are those that occurred between the coast of Málaga and Granada. They were located in soft bottoms but at greater depths (5–17 m) than those of other areas of the Iberian Peninsula (1–10 m); therefore their biological communities presented certain differences with respect to other shallower *Z. marina* meadows of the European Atlantic coasts (Luque and Templado 2004; Rueda et al. 2009a). More than 200 species have been recorded at the time when these meadows were thriving (Luque and Templado 2004; González et al. 2007, 2008; Rueda et al. 2009a).

In the leaf stratum (Fig. 9.17), the dominant organisms were benthic foraminifera; colonies of hydrozoans (*Coryne* spp.); the gastropods *Jujubinus striatus* (due to their high and constant reproductive activity), *Smaragdia viridis*, *Mitrella minor* (feeding on egg masses of different species) and *Rissoa membranacea* or *R. monodonta* (both obligate associates with smaller seagrasses); small microherbivorous shrimps *Hippolyte holthuisi*, *H. niezabitowskii*, *H. inermis* and *Periclimenes scriptus* (García Raso unpublished data); the bryozoan *Electra pilosa*; the ascidian *Diplosoma*

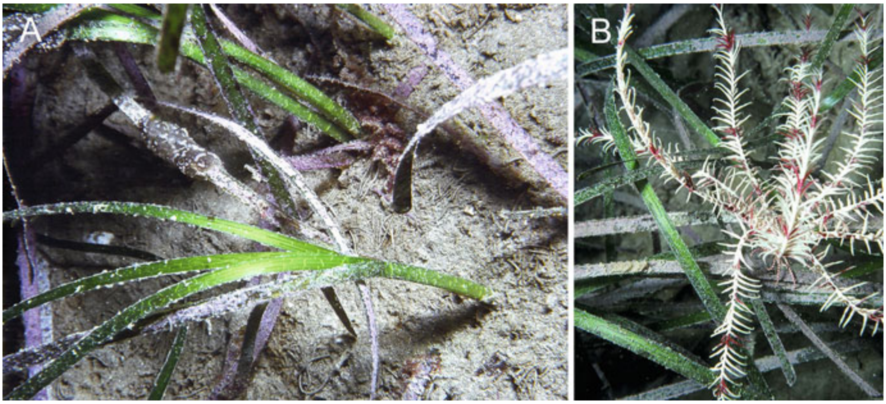

Fig. 9.17 Extensive meadows of *Zostera marina* used to be found in a depth range of 12–14 m depth on soft bottoms along the coasts of Málaga, Granada and Almería. They vanished around year 2006 for reasons not yet well understood but which may involve progressive warming, illegal trawling and disease. Detail of the plant and species of the leaf stratum: **(a)** *Diplosoma spongiforme* and **(b)** *Antedon mediterranea* [Diego Moreno]

spongiforme; and the crinoid *Antedon mediterranea* (Rodríguez and Cabrera 2002; Luque and Templado 2004; Rueda et al. 2009a). Some of these species, such as the hippolytids or the gastropods *S. viridis*, are perfectly adapted to live in and between the leaves, because their shape and colour (or transparency) give them an amazing ability to camouflage. In addition, some species, such as hippolytid shrimps, are able to modify their coloration according to the colour scheme of the leaves and that of the epiphytes that cover them. Generally, these species were not dominant, but they characterized these habitats and show interesting biological traits (Cobos et al. 2005, 2011; Manjón-Cabeza et al. 2009, 2011). For example, the neritid *S. viridis* shows a strong association with this plant, feeding on the younger epidermal tissues and preferring this species against other small seagrasses (e.g. *Cymodocea nodosa*) (Rueda and Salas 2007; Rueda et al. 2011). Among the fishes, *Opeatogenys gracilis*, endemic to the Mediterranean Sea and south of Portugal, is linked to the leaf stratum of this and other seagrasses and currently represents the smallest teleost of the Mediterranean Sea (Luque and Templado 2004: 152). The demersal community was mainly composed of cephalopods (e.g. *Sepia elegans*, *Sepietta oweniana*, *Sepiola affinis*) and about 70 fish species (dominating the syngnathids *Nerophis ophidion* and *Syngnathus* spp.) (Luque and Templado 2004). In general, the specific richness and abundance of the demersal and epibenthic fauna increased in both small seagrasses during the summer and autumn, and especially during the night, and showed a strong positive correlations with the leaf biomass (García Raso et al. 2006; Rueda and Salas 2008; Rueda et al. 2008).

The sediment colonized by *Z. marina* commonly harboured infaunal anthozoans, such as *Cereus pedunculatus*, *Condylactis aurantiaca* and *Cerianthus membranaceus*; the sedentary polychaetes *Sabella spallanzanii*, *Spiochaetopterus* sp., *Myxicola infundibulum* or *Lanice conchilega*; the scavenger gastropods *Tritia pygmaea* and *T. reticulata*; and the bivalves *Moerella distorta*, *Tellina fabula*, *Lucinella divaricata* or *Solemya togata*, the latter in partially anoxic sediments with a high content of organic matter from certain areas of the seagrass meadow (Luque and Templado 2004; González et al. 2007; Rueda and Salas 2008). The infaunal species presented peaks of abundance in autumn, with bivalve species (e.g. *Moerella distorta* and *Tellina fabula*) that reached high densities (~2000 ind/m^2) and displayed a strong correlation with the organic matter content of the sediment (Rueda and Salas 2008). Among the decapods, the dominant species were *Philocheras echinulatus* and pagurids such as *Diogenes pugilator*. Echinoderms (e.g. *Astropecten aranciacus*, *Coscinasterias tenuispina*, *Sphaerechinus granularis*, *Holothuria tubulosa*) are similar to those present in *C. nodosa* meadows, including species that are also common in the adjacent soft bottoms (Luque and Templado 2004).

In fact, the specific composition and structure of these communities associated with *Z. marina* or *Cymodocea nodosa* are quite influenced by that of the surrounding habitats, with much connectivity between vegetated and unvegetated soft bottoms. Therefore the structure of the communities varies significantly depending on the seagrass phenology and diel or seasonal movements of the mobile species (Rueda et al. 2008; Mateo-Ramírez et al. 2015, 2018).

After the regression and loss of *Z. marina* meadows in the northern Alboran Sea, a concurrent regression of the epifauna was detected, as well as changes in the structure of the infauna, with an increase in the densities of some species of bivalves (e.g. *Moerella distorta*, *Chamelea gallina*) (Rueda et al. 2009b).

9.6.2.2 *Cymodocea nodosa* Meadows

Apart from lagoon environments, *Cymodocea* meadows are most developed in the eastern part of the Alboran Sea, particularly in the Cabo de Gata-Níjar Natural Park (García Raso et al. 1992; Luque and Templado 2004). In the western part, *Cymodocea* is patchier and may even settle on hard bottoms, as it does in the Calahonda (Málaga) Special Area of Conservation (García Raso et al. 2010; Mateo-Ramírez and García Raso 2012).

About 200 species have been documented in *Cymodocea nodosa* of the northern Alboran Sea (Luque and Templado 2004). Some studies of deep meadows of *C. nodosa* from the coasts of Almería (10–15 m) have documented 59 fish species, dominated by *Symphodus cinereus*, *Bothus podas* and *Syngnathus abaster*; 54 species of molluscs, dominated by *Rissoa monodonta*, *R. membranacea*, *Gibbula leucophaea*, *Smaragdia viridis* and *Tricolia tenuis* (Marina et al. 2012); and 48 species of decapods, dominated by *Hippolyte niezabitowskii*, *H holthuisi* and *H. inermis* (García Raso et al. 2006). In shallow *Cymodocea* meadows, the specific richness is lower, with dominant species such as the decapods *Hippolyte leptocerus* or *Hippolyte garciarasoi* (Mateo-Ramírez and García Raso 2012) or the molluscs *Tritia donovani*, *T. cuvierii* and *Smaragdia viridis*. Echinoderms can be abundant in these meadows, but the species present are often those typical of soft bottoms (*Ophiura ophiura*, *Astropecten* spp., *Echinocardium mediterraneum*) (Luque and Templado 2004) or of neighbouring hard bottoms (*Holothuria* spp.). During the night, there is a flux of species from the adjacent unvegetated sedimentary bottom (García Raso et al. 2006), such as *Processa modica*, *P. macrophthalma* and *P. edulis*, crabs of the genus *Liocarcinus* (*L. navigator* and especially juveniles of *L. vernalis*), *Portunus hastatus*, the armoured shrimp *Sicyonia carinata* and species of the genus *Philocheras*, such as *P. bispinosus*, or from the nearby macroalgal bottoms, such as the prawn *Eualus cranchii* and juveniles of the spider crabs *Macropodia rostrata* and *Maja* spp.

Therefore, the number of species associated with the leaf stratum of *C. nodosa* increases during the night, drawing from adjacent bottoms, with the presence of different species of fish (e.g. sparids) or decapods (e.g. *Processa modica* and *Palaemon xiphias*, García Raso et al. 2006; Marina et al. 2012). On the other hand, a positive relationship between the abundance and the specific richness of different groups of crustaceans has been documented with the biomass or complexity of the seagrass (number of leaves and density of shots) (González et al. 2008; Mateo-Ramírez and García Raso 2012).

Information on other groups such as peracarid crustaceans, polychaetes or echinoderms is very scarce for *C. nodosa* meadows of the Alboran Sea (Luque and

Templado 2004). Nevertheless, some recent studies have shown the presence of the caprellids *Phtisica marina*, *Pseudoprotella phasma* and *Pariambus typicus* (González et al. 2008), the irregular sea urchin *Brissus unicolor* (García Raso et al. 2010), the isopod *Cymodoce robusta* (Castelló and Carballo 2001) as well as epiphytic brown algae of the order Ectocarpales (*Acinetospora crinita* and *Ectocarpus siliculosus*), whose proliferations in summer can change the structure of the mollusc and decapod assemblages (García Raso et al. 2006; Marina et al. 2012).

9.6.2.3 *Caulerpa prolifera* Meadows

Caulerpa prolifera meadows settle preferably on more muddy and sheltered bottoms than *Cymodocea* or *Zostera* and sometimes form compound meadows with the latter. The best known occurrence in the Alboran Sea is in Algeciras Bay (Sánchez Moyano et al. 2001b, 2007; Sánchez-Moyano and García-Asencio 2009) where it may have replaced former seagrass meadows when environmental conditions were downgraded. There are also reports in sheltered inlets or harbours around Cabo de Gata (Luque and Templado 2004).

In the *C. prolifera* beds from Algeciras Bay, Sánchez-Moyano et al. (2001b) reported a total of 140 taxa, among which 50 molluscs, 41 polychaetes, 35 crustaceans and 5 echinoderms. The dominant molluscs on the fronds were the bivalve *Anomia ephippium* and the gastropods *Pusillina radiata* and *Jujubinus striatus*, whereas the infauna included bivalves such as *Loripes orbiculatus* and *Abra alba*. At least three species of molluscs, the sacoglossans *Oxynoe olivacea*, *Lobiger serradifalci* and *Ascobulla fragilis*, are obligate associates of *C. prolifera*, the former two on the fronds and the latter on the rhizoids (Gofas et al. 2011). The crustacean community was further analysed by Sanchez-Moyano et al. (2007), who reported 45 species (17 amphipods, 8 cumaceans, 9 decapods, 6 isopods, 4 tanaidaceans and 1 leptostracan) belonging to epifauna and infauna. Amphipods and tanaidaceans were the most abundant groups. A total of 51 species of polychaetes and 1 oligochaete were reported by Sánchez-Moyano and García-Asencio (2009), of which a few species (the oligochaete *Aktedrilus* cf. *monospermathecus*, the capitellids *Notomastus latericeus* and *Capitella capitata*, the syllid *Exogone verugera*, the nereid *Neanthes acuminata* and the cirratulid *Aphelochaeta filiformis*) represented more than 80% of the total. The annelid and molluscan assemblages in *C. prolifera* meadows are similar to those of smaller seagrass meadows and may have been inherited from the latter, thanks to the morphological similarity between *Caulerpa* fronds and seagrass leaves.

Seagrass meadows and *C. prolifera* meadows on sedimentary bottoms are comprised in the currently accepted definition of Habitat 1110 “Sandbanks permanently covered by sea water” of the EU Habitats Directive and described as such when included in proposals for the Natura 2000 network. All the seagrass species, including *Zostera marina* and *Cymodocea nodosa*, are listed in Annex 2 of the Barcelona Convention and in the Spanish List of Wildlife Species in Special Protection

Regime, although with no particular mention of threat. The causes of the demise of *Z. marina* beds in the Alboran Sea are not precisely known, but illegal trawling or dredging, global warming and disease may have contributed.

9.6.3 Bioclastic Sands and Gravels

This kind of habitat is found generally below 20 m depth, and the sediment is formed by medium to coarse sand with abundant bioclasts and a higher content of mud and organic matter than the well-sorted fine sand. Most of the sediment originates from the degradation of shells or other skeletal remains (Pérès and Picard 1964; Pérès 1982). In the shallower settings, this is the so-called "détritique côtier" which normally grades offshore to more muddy sediments. At greater depths, typically below 95–100 m and down to the shelf edge, is found the "détritique du large" where the bioclasts are commonly remnants of Quaternary thanatocenoses. When the mud input is low, both may form a continuum. In fact, the term "détritique" is a misnomer because, in geological vocabulary, it should refer to products of erosion of pre-existing rocks, whereas here the elements result from bioconstruction and should properly be referred to as bioclasts.

Coastal bioclastic sands and gravels are quite extensive in the Strait of Gibraltar area, e.g. near Barbate (Manjón-Cabeza and García Raso 1998; Rueda et al. 2000; García Raso and Manjón Cabeza 2002) and Punta Cires (Bazairi et al. 2016) in a setting where strong currents winnow the finer sediment particles. They are also well represented in some parts of the coast of Málaga (Urra et al. 2013a, b, c) and Granada (Marina et al. 2015). The extension of this habitat along the Moroccan coast is not precisely known, but taking into account the scarcity of sediment input from rivers, it should be considerable.

Coastal bioclastic sands and gravels generally show high species richness and low dominance values, thanks to the heterogeneity generated by the larger bioclasts. Among the molluscs, the gastropods are dominant in number of species, but the bivalves show, in general, higher abundances (Rueda et al. 2000; Rueda and Salas 2003; Urra et al. 2011). Characteristic species are the bivalves *Digitaria digitaria*, *Gouldia minima*, *Nucula hanleyi*, *Lembulus pella*, *Laevicardium crassum*, *Parvicardium scabrum*, *Pitar rudis* and *Timoclea ovata*. Among the gastropods, *Calyptraea chinensis*, which lives inside large empty valves lying on the sediment, is one of dominant species. Other characteristic gastropods are the carnivorous *Euspira nitida*, *Crassopleura maravignae*, *Fusinus pulchellus* and *Bolinus brandaris*. Among the crustaceans, the pagurids are dominant in the littoral of Málaga, mainly *Paguristes eremita* and *Anapagurus hyndmanni*, but *Diogenes pugilator*, *Anapagurus alboranensis*, *Dardanus arrosor*, *Pagurus forbesii* and *P. pseudosculptimanus* are also abundant (García-Muñoz et al. 2008, 2014). Other characteristic crustaceans of this bottom are *Ebalia tumefacta*, *E. deshayesi*, *Pisidia longicornis* and *Galathea intermedia.* In the littoral of Granada, *Anapagurus alboranensis* is also a dominant species in the assemblage (Marina et al. 2015).

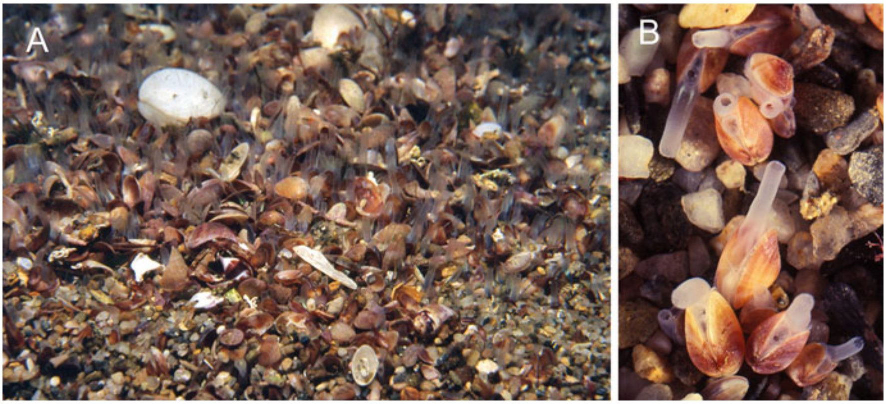

Fig. 9.18 **(a)** High density of the bivalve *Ervilia castanea* in coarse sand 23 m depth and **(b)** detail (1995, Natural Park Cabo de Gata-Níjar, Almería, Andalusia) [Diego Moreno]

Different species of sea stars can be present, most of them from the genus *Astropecten*, such as *A. irregularis*, *A. aranciacus*, *A. johnstoni* or *A. platyacanthus.* The nemertean *Cerebratulus marginatus* is also common. In the littoral of Granada, the echinoderms *Ophiocten affinis*, *Amphiura* spp. and *Astropecten bispinosus* were frequent (Marina et al. 2015). This assemblage did not show a significant seasonal dynamic, probably due to the existence of low dominances, high species richness and high complexity (Urra et al. 2013c).

In the last decade of the twentieth century, large banks of the bivalve *Ervilia castanea* (Fig. 9.18) were located in coarse sand bottoms of Granada (Punta Negra) and Almería (Cabo de Gata Natural Park and other zones) between 10 and 23 m depth (Moreno 1998). The extension of these banks (tens of meters wide) and their density with up to 90,000 individuals/m^2 were really impressive. In the community were abundant, in addition to *Ervilia castanea*, the polychaete *Nereiphylla rubiginosa*; the gastropods *Bittium submammillatum*, *Calyptraea chinensis*, *Aglaja tricolorata* and *Embletonia pulchra*; the bivalves *Digitaria digitaria*, *Goodallia triangularis* and *Corbula gibba*; and the echinoderm *Echinocyamus pusillus* among others. It is interesting to note that these banks detected in 1995 and 1996 have no longer been observed (Diego Moreno, personal observation). The progressive warming of the waters may be adverse for the settlement in the Alboran Sea of *Ervilia castanea*, an Atlantic species that finds its best populations in the Azores Islands.

Deeper bioclastic bottoms have been less studied than coastal ones, and most of the available information deals with specific shelf areas of the northern Alboran Sea (Templado et al. 1993; de la Torriente et al. 2014; Gofas et al. 2014a; Marina et al. 2015; Moya-Urbano et al. 2016). Most of these studies have given some information on the spatial distribution of some faunistic groups, mainly of molluscs, decapods and echinoderms, and in some cases in relation to environmental variables (Marina et al. 2015; Moya-Urbano et al. 2016).

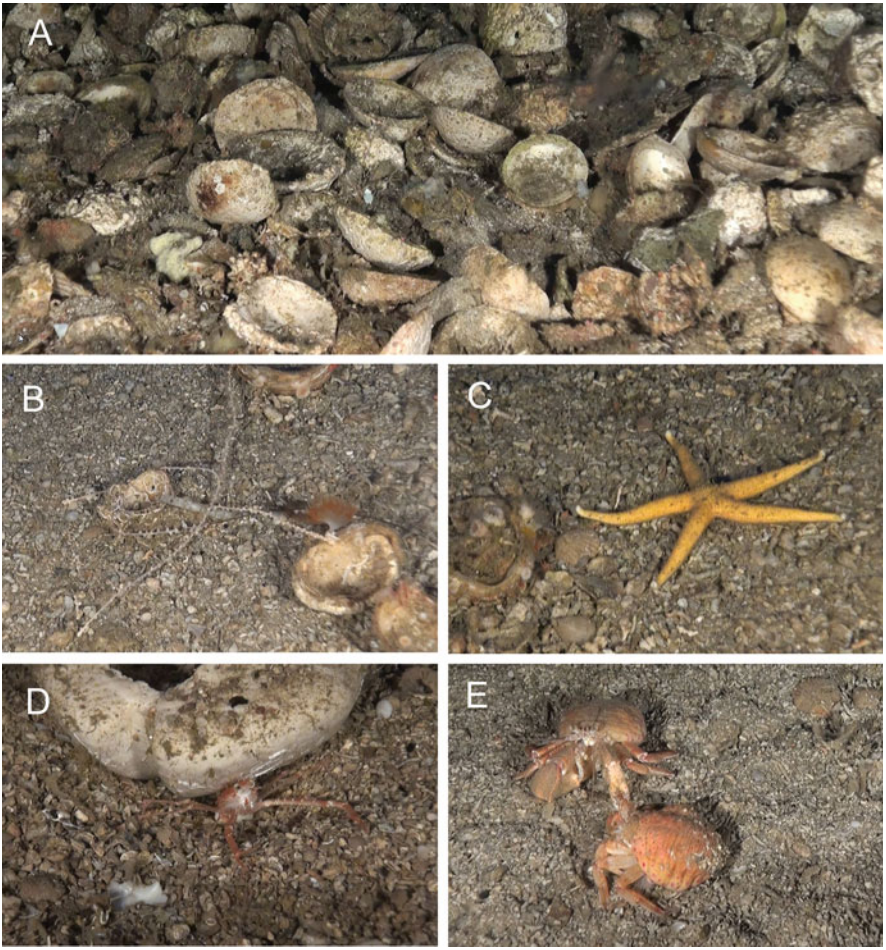

Fig. 9.19 **(a)** Bioclastic sands and gravels, here photographed on the platform surrounding Alboran Island, are mainly formed by skeletal remains of benthic organisms (in this case valves of *Glycymeris* sp.). This kind of coarse sedimentary bottoms harbour a very diverse fauna. **(b)** Here illustrated the unattached gorgonian *Eunicella filiformis*, **(c)** the starfish *Chaetaster longipes*, **(d)** the decapod *Munida speciosa* and **(e)** hermit crabs *Pagurus prideaux* with their commensal sea anemone *Adamsia palliata* [LIFE+ INDEMARES Alboran]

Shelf-edge bioclastic bottoms were studied in detail on the Alboran platform (Fig. 9.19) and on Seco de los Olivos (also known as Chella Bank) through the recent LIFE + project INDEMARES, and they probably represent the best known of their kind in the Alboran Sea, in terms of benthic composition and structure (de la Torriente et al. 2014; Gofas et al. 2014a). In general, the associated fauna is very diverse and includes the large benthic foraminifera *Miniacina miniacea* on bioclasts (especially in the outer shelf at depths of more than 100 m); the rare sponges *Axinella spatula*, *A. salicina*, *A. alborana* and *Rhizaxinella elongata* (Sitjà and Maldonado

2014); and many cnidarians. Among the latter, the gorgonian *Eunicella filiformis* lies loose on the bottom; the hydroids *Modeeria rotunda* and *Aglaophenia tubulifera*, the solitary coral *Caryophyllia* spp. and the gorgonian *Leptogorgia sarmentosa* settle on large bioclasts; and some sea pens (*Veretillum cynomorium*, *Pennatula rubra*) may also occur. The annelid *Hyalinoecia tubicola* crawls over the sediment, *Lanice conchilega* builds a semi-buried tube, and serpulids settle on the bioclasts. Among molluscs, the most frequent species are the gastropods *Anatoma aspera*, *Clelandella miliaris*, *Calyptraea chinensis*, *Fusinus pulchellus*, *Orania fusulus* and *Xenophora crispa* as well as the rare and protected cowry *Schilderia achatidea* and the bivalves *Bathyarca pectunculoides*, *Parvamussium fenestratum*, *Neopycnodonte cochlear*, *Arca tetragona* and *Parvicardium minimum*. The most common decapods are *Inachus dorsettensis*, *Munida speciosa*, *Galathea intermedia*, *Anapagurus breviaculeatus*, *Pagurus prideaux*, *Eurynome aspera* and *Ebalia granulosa*. The crinoid *Antedon mediterranea*, the starfishes *Anseropoda placenta* and *Chaetaster longipes*, the holothurian *Parastichopus regalis* and different ophiuroids (*Ophiothrix quinquemaculata*) are representative of the echinoderms. The bryozoans *Cellaria salicornioides* and *Reteporella* spp. and the ascidian *Molgula appendiculata* grow commonly on medium-sized bioclasts. Interestingly, a part of Alboran platform shelf bioclasts is composed of subfossil shells of *Modiolus modiolus* and other boreal species that inhabited these bottoms and then close to the coast due to lower sea level, during the last Ice Age.

Despite their unquestionable species richness, bioclastic gravels do not benefit from any kind of formal protection other than being encompassed in marine protected areas designated for other components. Perspectives for specific protection are scant because these bottoms are a major target for trawling and because they can be very extensive. A fair representation of coastal bioclastic gravels is found in Parque Natural del Estrecho, in the Calahonda Special Area of Conservation and in the "Site d'Intérêt Biologique et Ecologique" of Jbel Moussa among others. The deeper "shelf edge" gravels are included in the offshore Special Areas of Conservation planned on the Alboran Platform and Seco de los Olivos (Gofas et al. 2014a; de la Torriente et al. 2014).

9.6.4 "Maërl"/Rhodolith Beds

"Maërl" or rhodolith beds are defined by the presence of free-living calcareous red algae over the underlying sediment. The Breton word "maërl" was used since 1867 for Atlantic bottoms of this kind off the NW coast of France, mainly formed by the branched calcareous algae *Phymatolithon calcareum* and *Lithothamnion corallioides* (Cabioch 1969). The term "rhodolith" (Ginsburg and Bosellini 1973), meaning red stone, was subsequently coined to designate unattached nodules formed by coralline algae, spanning a large array of forms (branched or not) and sizes (from a few millimetres to over 10 cm), and this term became used worldwide (Bosence 1983a, b; Foster 2001). Both "maërl" and "rhodolith" are often used indifferently (e.g. in EUNIS (2019)), but Basso et al. (2016) pointed out that “maërl” in a strict sense refers only to branched rhodoliths. In the Alboran Sea, the common morphology is that of rounded rhodoliths.

Mediterranean “maërl” beds were considered to be a facies of the “coastal detritic bottoms” by Pérès and Picard (1964), a criterion followed in the classification of benthic marine habitat types for the Mediterranean region (UNEP/MAP/RAC-SPA 2006). That is because the calcareous algae grow and accumulate on a variety of soft bottoms mainly composed by bioclastic gravels or coarse sands (calcareous detritus of coralline algae, molluscs, echinoderms, anthozoans, etc.) originated locally or from the neighbouring biocenoses. “Maërl” or rhodolith beds are usually composed of varying proportions of living and dead rhodoliths, with or without additional sediment (Bosence 1983a, b). Fine sand or mud may fill interstices, with mud content below 20% (Picard 1965), since these bottoms are under moderate to high hydrodynamism. The nature of the underlying sediment is crucial because suitably sized grains for spore settlement must be present. Once established, the rhodoliths themselves provide this suitable substrate.

The best and most extensive representation of this habitat in the Alboran Sea is found on the Alboran insular platform between 25 and at least 100 m (Fig. 9.20). The INDEMARES Alboran project (Gofas et al. 2014a) mapped 76 km^2, covering more than one-third of the Alboran platform. The summit platform of Seco de los Olivos, situated off Almería in the northeastern part of the Alboran Sea, is covered by rhodoliths between 76 and about 100 m depth (de la Torriente et al. 2014). Occurrences along the mainland coast are extremely limited and patchy along the Andalusian coast. This is consistent with expectations since the buildup of “maërl” beds requires flat, current swept bottoms in the 20–100 m depth range, a substrate of sand or gravel without too much mud and clear, transparent waters away from the input of rivers. The Strait of Gibraltar meets some of these conditions but lacks flat sedimentary bottoms, and the bay of Málaga is too muddy in the appropriate depth interval. The sole significant occurrence documented so far is off Punta de la Polacra in the Cabo de Gata-Níjar Natural Park (Luque and Templado 2004). The continental platform of the Moroccan and Algerian parts of the Alboran Sea could meet the requirements in more extensive areas, but much exploration is still needed to assess the actual extension of “maërl”/rhodolith beds, documented so far off Cap des Trois Fourches (Bazairi et al. 2013).

Rhodolith beds are remarkable as bioconstructions and contribute to elaborate a complex and heterogeneous habitat which supports high species richness and diversity favoured by their three-dimensional structure (Foster 2001; Gofas et al. 2014a; de la Torriente et al. 2014). The main species that make up the rhodoliths in the Alboran platform are *Lithophyllum racemus*, *Lithothamnion corallioides*, *Lithothamnion philippi* and *Phymatolithon calcareum*, although up to 21 different species of coralline algae have been identified using molecular tools, of which 11 are still under study (Gofas et al. 2014a). Samples yielded a total of 415 benthic species (algae other than those forming maërl and fish excluded). These bottoms harbour an interesting fauna of sponges and anthozoans, including some rare or new species. Most common sponges are *Bubaris vermiculata* of a striking red colour, *Diplastrella*

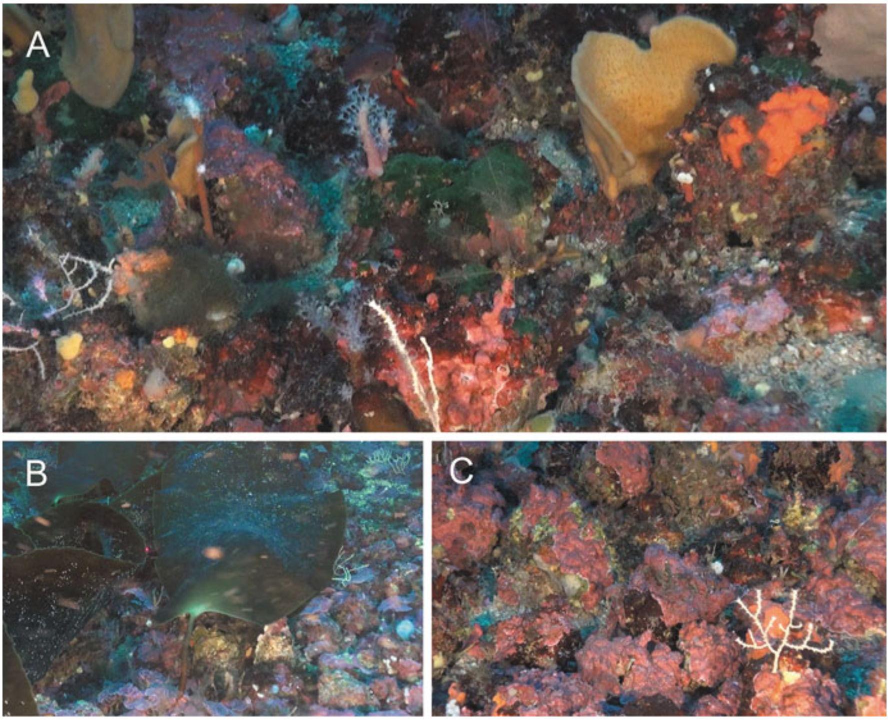

Fig. 9.20 "Maërl" or rhodolith beds are among the most spectacular bottoms on the platform surrounding Alboran Island, between 20 and 100 m depth. **(a)** At 74 m depth, rhodoliths are overgrown by a variety of sponges (to the right, a fan-shaped *Phakellia* and the orange encrusting *Bubaris vermiculata*), cnidarians (the small gorgonian *Eunicella* sp. and the soft coral *Paralcyonium* sp.) and other organisms. **(b)** This substrate often supports kelp (*Phyllariopsis* sp. at 62 m depth), **(c)** when the rhodoliths are large and conform a stable substrate [LIFE+ INDEMARES Alboran]

bistellata of orange colour and several species of the genera *Eurypon* and *Axinella*. Small encrusting sponges are pervasive on the rhodoliths, especially on the large ones. The species *Crambe tailliezi*, considered rare in the Mediterranean, appears usually in the rhodolith bottoms surrounding the island of Alboran. Anthozoans are mainly represented by different octocorals (*Alcyonium coralloides*, *Alcyonium* sp., *Paralcyonium spinulosum*, *Eunicella filiformis* and *Eunicella* spp.) attached to rhodoliths. Among the most frequent mobile animals are some echinoderms, among which the brittle star *Ophiactis balli*, which occupies the crevices of the rhodoliths, is one of the most abundant. Other common echinoderms in this habitat, and usually rare, are the starfish *Chaetaster longipes* and *Hacelia attenuata* and the sea urchin *Genocidaris maculata*. The most characteristic molluscs are epifaunal bivalves such as *Hiatella arctica*, *Gregariella semigranata* and *Modiolula phaseolina*; some polyplacophorans (chitons), among which *Callochiton septemvalvis* takes the colour of the red algae; and the gastropod *Bolma rugosa*.

Among decapod crustaceans are abundant the small slipper lobster *Scyllarus pygmaeus*; several hermit crabs, such as *Paguristes eremita* and *Dardanus arrosor*; and numerous species of crabs, among them *Ebalia* spp. and *Parthenopoides massena*. To summarize, rhodoliths are a real microcosm which houses a great diversity of small invertebrates which thrive through the labyrinth of crevices and are still poorly studied (Gofas et al. 2014a). In the Seco de los Olivos, rhodoliths are covered in some areas by small sessile invertebrates (sponges, hydrozoans, bryozoans), whereas in other areas, they show a dense covering of alcyonaceans (*Alcyonium palmatum* and *Paralcyonium spinulosum*), large sponges (*Chondrosia reniformis*, *Aplysina aerophoba*, *Axinella polypoides*, *Tedania* sp.) and gorgonians (*Paramuricea clavata*, *Eunicella verrucosa*) and even black corals (*Antipathella subpinnata*) or bryozoans (*Reteporella grimaldii*, *Omalosecosa ramulosa*). Echinoderms like *Echinus melo*, *Holothuria forskali* and *Chaetaster longipes* are common (de la Torriente et al. 2014). Demersal fish associated with "maërl" beds around Cabo de Gata-Níjar and on the Alboran insular platform are *Scorpaena notata*, *S. scrofa* and *Chelidonichthys lastoviza* (Luque and Templado 2004; Ramos Esplá and Luque 2008; Gofas et al. 2014a).

The importance of "maërl" beds has been acknowledged by several national or international agreements, binding or not. The OSPAR commission has included "Maërl beds" habitat on the OSPAR List of Threatened and/or Declining Species and Habitats (OSPAR agreement 2008-6; see OSPAR Commission 2010). Regarding the Mediterranean Sea, the Council Regulation (EC) 1967/2006, concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea (Council of the European Union 2006), prohibited fishing with trawl nets, dredges, shore seines or similar nets above coralligenous habitats and "mäerl"/rhodolith beds. In addition to this legally binding regulation, the European Commission's "Scientific, Technical and Economic Committee for Fisheries Opinion on Sensitive and Essential Fish Habitats in the Mediterranean Sea" has recognized "maërl" beds as a priority item among "sensitive fish habitats in the Mediterranean Sea" defined as "fragile habitats that are recognized internationally as ecologically important and which support important assemblages of commercial and non-commercial fish species and which may require special protection" (European Commission 2006). Following this, "Association with rhodoliths (including all of its facies)" is listed as "Essential Marine Habitat (EMH) of relevance for the management of priority species" by the Scientific Advisory Committee of the General Fisheries Commission for the Mediterranean (General Fisheries Commission for the Mediterranean 2009). Despite this and the clamour of the scientific community (Barberá et al. 2003; Otero and Basso 2016), "maërl"/rhodolith beds have no recognition at all in Annex I of the EU Habitats Directive.

The Spanish Law 5/2007 of 3 April 2007 of the National Parks network includes "maërl" beds as a marine natural system required to be represented in the network. Finally, the Order APA/767/2018, of June 19, 2018, modifies the Order of 8 September 1998 and expands the prohibition of trawling in the Marine Reserve of Alboran Island in depths lower than 100 m (70 m in the former 1998 Order), specifically targeted to protect the rhodolith beds, which extend down to 100–110 m in this area. A major anthropogenic impact on Mediterranean rhodolith beds is due to otter trawling (Barberá et al. 2003; Bordehore et al. 2003, and references therein). "Maërl"/rhodolith beds constitute a very vulnerable habitat, due to the slow growth rate of their components, low reproductive potential and the long time of regeneration.

9.6.5 Coastal Terrigenous Mud

This kind of bottom can be found already in the infralittoral zone, particularly in bays or inlets under the influence of rivers, which supply terrigenous fine sediments and cover extensive areas of the continental shelf (Pérès and Picard 1964). The percentage of mud is high, and most of it is of inorganic origin; therefore the percentage of organic matter is moderate.

Characteristic species of shallow muddy bottoms of the littoral of Málaga are molluscs such as the tropical West African gastropod *Tritia elata* and the bivalve *Spisula subtruncata*. *Chamelea striatula* can reach high densities and replaces *Chamelea gallina* where the mud content increases. Some species are associated with cnidarians, such as the rare architectonicid *Basisulcata lepida*. Regarding crustaceans, the pagurids are also dominant, such as *Anapagurus breviaculeatus*, *A. petiti*, *Pagurus excavatus*, *P. cuanensis* and *P. prideaux* (García Raso et al. 2010). Sea pens such as *Veretillum cynomorium*, *Pteroides griseum* and *Cavernularia pusilla* may occur, although more commonly found in deeper parts of the continental shelf. Among the echinoderms, the brittle star *Acrocnida brachiata* is common in this type of bottom. Besides, the aquaculture of the mussel *Mytilus galloprovincialis* in the infralittoral of southern Spain has been a great expansion in the last decades (Tirado et al. 2011), and suspended mussel cultures generate large amounts of mud under the rafts, promoting the onset of this type of assemblage.

Benthic communities of circalittoral muddy sand bottoms are generally dominated by different cnidarians (*Epizoanthus arenaceus*), molluscs (the gastropods *Alvania testae*, *Sorgenfreispira brachystoma*, *Turritella communis*, *T. mediterranea* and *Bivetiella similis* and the bivalves *Saccella commutata*, *Chamelea striatula*, *Timoclea ovata*), annelids (*Hyalinoecia tubicola*, *Ditrupa arietina*), decapods (*Plesionika heterocarpus*, *Philocheras bispinosus*, *Anapagurus alboranensis*, *Processa canaliculata*, *P. nouveli* and *Galathea* spp.) and echinoderms (*Astropecten irregularis*, *Paraleptopentacta tergestina*, *Ophiocten affinis*) (Marina et al. 2015; Moya-Urbano et al. 2016).

Some of these species can also occur on more fully muddy bottoms, in which the community is composed by the cnidarians *Veretillum cynomorium*, *Cavernularia pusilla*, *Pennatula rubra*, *Alcyonium palmatum* and *Cerianthus membranaceus*; the annelids *Spiochaetopterus* cf. *costarum* and *Sternaspis scutata*; the gastropods *Tritia ovoidea* and *Turritella communis*; the bivalves *Tellina compressa*, *Nucula sulcata*, *Abra alba*, *A. nitida*, *Chamelea striatula* and *Venus nux*; the decapods *Philocheras bispinosus*, *Goneplax rhomboides*, *Alpheus glaber* and *Inachus dorsettensis*; and the echinoderms *Astropecten irregularis*, *Amphiura* spp., *Oestergrenia digitata* and *Ocnus planci* (Cano and García 1982; Moya-Urbano et al. 2016). Muddy sediments generally occur at greater depths, and their high organic content promotes higher abundances of deposit feeders, representing an important variable explaining the distribution of the benthic communities (Marina et al. 2015; Díaz et al. 2017).

In these types of circalittoral soft bottoms, some habitat-forming species such as sea pens (*Veretillum*, *Pennatula*) and gorgonians (*Spinimuricea* cf. *atlantica*) provide hard substrate and food for other invertebrates (e.g. *Armina maculata* feeding on *Veretillum cynomorium*) (Gofas et al. 2011). Nevertheless, the sessile habitat-forming species are suffering impacts from trawlers and have declined during decades. They sometimes display higher abundances close to rocky bottoms where they are protected from trawling (Gofas et al. 2014a).

Although temporal changes have been poorly studied in circalittoral bottoms and thought to be less acute than in infralittoral bottoms, Díaz et al. (2017) detected a higher abundance of benthic and demersal cephalopods (e.g. *Octopus vulgaris, Sepia* spp.) in autumn and winter in the circalittoral bottoms of the bay of Málaga.

The circalittoral muddy bottoms of the Alboran Sea are not encompassed by any specific regulation for their protection. They are in general exposed to a higher trawling activity than the bathyal ones due to their proximity to the fishing ports, and this may have produced continued impacts on the habitat-forming species such as the sea pens. The OSPAR Convention recognizes “Sea-pen and burrowing megafauna communities” among the list of threatened and declining habitats, and although outside the scope of this Convention, this should be taken into account to promote some kind of status within the Mediterranean Sea.

9.7 Deep-Sea Communities

In the Alboran Sea, the bathyal level, ranging from the edge of the continental shelf to the deepest part of the basin, features a broad diversity of benthic communities. The deep-sea benthic communities of the region are strongly influenced by the peculiar oceanographic setting in which the superficial Atlantic Water (AW), with a high level of primary productivity, flows within the first 200 m above the outgoing Levantine Intermediate Water (LIW). These communities are also influenced by their geographical location, resulting in the overlap of Mediterranean fauna and typical “Atlantic” species (Gofas et al. 2014b).

9.7.1 Bathyal Hard Bottoms

Bathyal hard-bottom communities are patchily distributed over the heterogeneous and complex topography of the Alboran Sea basin and are restricted to prominent geomorphological features, such as seamounts, coral mounds, canyons and ridges

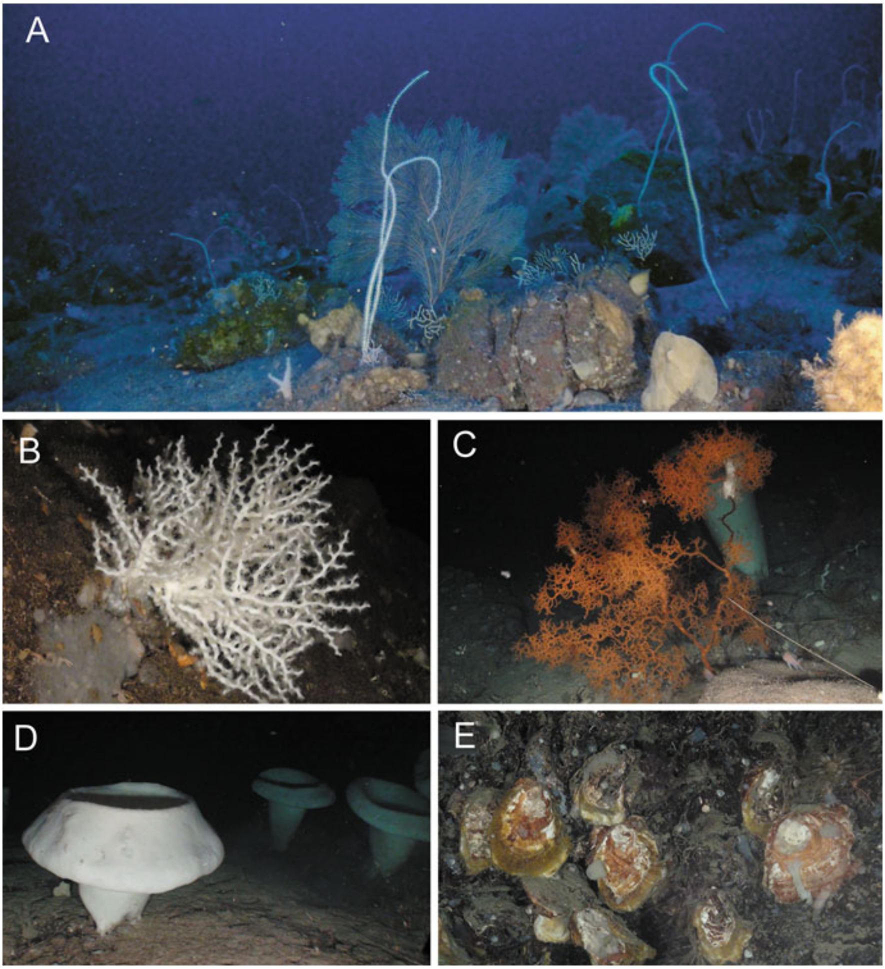

Fig. 9.21 Sessile organisms on deep-sea hard substrates of Seco de los Olivos. **(a)** Whip gorgonians *Viminella flagellum*, fan-like *Callogorgia verticillata* and sponges. Other characteristic habitat-forming species are **(b)** the white coral *Madrepora oculata*, **(c)** the antipatharian *Leiopathes glaberrima*, **(d)** the large hexactinellid sponge *Asconema setubalense* and **(e)** the giant deep-sea oyster *Neopycnodonte zibrowii* on a vertical rock wall [OCEANA]

(Muñoz et al. 2008; Würtz 2012; Fink et al. 2013; Rovere and Würtz 2015). Information is still scanty and regards mostly Seco de los Olivos (Fig. 9.21), the Cabliers and Djibouti seamounts and the edge of the Alboran platform (Hebbeln et al. 2009; Pardo et al. 2011; Lo Iacono et al. 2012; de la Torriente et al. 2014, 2018; Gofas et al. 2014a, b; Corbera et al. 2019; Lo Iacono et al. 2019). From the few acquired information, it emerges that the seamounts of the Alboran Sea harbour vulnerable marine ecosystems, including cold-water coral communities and gorgonian, black coral and sponge aggregations (see Chap. 10). This diverse group of habitat-forming taxa provides a three-dimensional structure for refuge and food for many more benthic species and offers attachment substrates for different sessile invertebrates (Sebens 1991; Buhl-Mortensen et al. 2010).

Cold-water coral communities (see also Chap. 10) are one of the most emblematic and diverse habitats in the northeast Atlantic and the Mediterranean, including the Alboran Sea (Rueda et al. 2019). They are mainly structured by the scleractinian corals *Madrepora oculata* and *Desmophyllum pertusum* (formerly known as *Lophelia pertusa*), which are suspension-feeders and require hard substrates to settle and develop. Their occurrence on areas exposed to constant current regimes responds to a delicate interplay between the delivery of nutrient particles and avoidance of excess sedimentary input, which could hinder their development. However, cold-water corals are also sensitive to the physical characteristics of the water masses, such as temperature, salinity, pH and oxygen concentration (Gori et al. 2013).

Other scleractinians such as *Dendrophyllia cornigera* typically occur on the outer part of the continental shelf and were recorded on rocky bottoms between 40 and 160 m depth around the Alboran Island (Gofas et al. 2014a) and are still found on coral mounds and the slope (Corbera et al. 2019). The scleractinian *Anomocora fecunda* also settles on bathyal hard substrates, as well as other species such as *Caryophyllia calveri*, *C. smithii* and *Desmophyllum dianthus* which because of their small size and low density are not considered as habitat-forming taxa but appear as part of the corals, gorgonian and sponge communities (de la Torriente et al. 2014).

Although corals are the most conspicuous elements, the deep-water rocky-bottom harbours more concealed associated species which are poorly documented due to the difficulty of sampling this kind of bottoms. Among other species, the small bivalve *Limopsis angusta* has been reported as abundant on Xauen Bank (Salas 1996).

Gorgonians and antipatharians ("black corals", e.g. *Leiopathes glaberrima*, *Antipathes dichotoma*, *Antipathella subpinnata* and *Parantipathes larix*) often form dense and extensive assemblages in the deep sea, with a great variety of morphologies (fan-like structure, whips, branched forms, etc.) (see Chap. 10). Each species develops in those areas where particular environmental conditions are met: *Viminella flagellum* alternates dense meadows with sparse colonies and is usually associated to other soft corals forming mixed gardens. These species are gradually replaced by others such as *Callogorgia verticillata* and *Acanthogorgia hirsuta* as depth increase. Dense and conspicuous forests of *C. verticillata* have been found between 70 and 240 m depth in rocky outcrops around the Alboran Island, being rather unusual the occurrence of this bathyal species at such shallower bottoms (Gofas et al. 2014a), and also on dead cold-water coral frameworks, at a depth of 400 m (Corbera et al. 2019). Other smaller species such as *Bebryce mollis*, *Dendrobrachia bonsai*, *Muriceides lepida*, *Paramuricea macrospina*, *Placogorgia coronata*, *P. massiliensis*, *Swiftia dubia* and *Villogorgia bebrycoides* are also typical of these communities (de la Torriente et al. 2014, 2018).

The bathyal bottoms of the Alboran Sea shelters a remarkable diversity of sponges and is the only part of the Mediterranean where aggregations of large hexactinellids, such as those of *Asconema setubalense*, have been reported usually close to steep escarpments. On the Seco de los Olivos (Fig. 9.21), areas dominated by this large sponge have been recorded throughout the two main ridges surrounding the main central guyot (Pardo et al. 2011; de la Torriente et al. 2018) and represents a dominant accompanying species in the Cabliers cold-water coral reefs (Corbera et al. 2019). Another hexactinellid sponge, the small and stalked *Sympagella delauzei*, was recently described from several seamounts of the Alboran Sea, growing on rocks but also on coral rubble (Boury-Esnault et al. 2015).

Other species forming part of the bathyal sponge communities are *Geodia* sp., *Phakellia robusta*, *P. ventilabrum* and the "lollipop" sponges of the genera *Podospongia*, *Crella* and *Stylocordyla* (de la Torriente et al. 2014, 2018; Gofas et al. 2014a). The latter small sponges may be abundant on the substrate forming a dense undergrowth beneath larger sponges and gorgonians. *Poecillastra compressa* and *Pachastrella monilifera* are also key structuring sponges from the circalittoral to the bathyal in the Alboran Sea (Sitjà and Maldonado 2014).

Dense aggregations of the giant deep-sea oyster *Neopycnodonte zibrowii* colonizing vertical walls and overhangs have been found on the Djibouti Banks (Hebbeln et al. 2009) and Seco de los Olivos (de la Torriente et al. 2014), whereas aggregations of the smaller *Neopycnodonte cochlear* can be found almost everywhere in the Alboran Sea at shallower depths (80–200 m).

Additionally, other species which may be found on bathyal hard bottoms of the Alboran Sea are mobile species such as sea urchins (*Cidaris cidaris*, *Gracilechinus acutus*), sea cucumbers (*Holothuria* spp.), brittle stars (*Ophiothrix* spp.) and crinoids (*Leptometra phalangium*), but they are not restricted to hard bottoms and can also be found on deep bioclastic gravels. Particularly, dense aggregations of *Cidaris cidaris* and *Leptometra phalangium* were recorded on the Seco de los Olivos (de la Torriente et al. 2014) and Djibouti Banks (Gofas et al. 2014a), respectively. There is also a wide representation of crustaceans such as crayfish (*Palinurus mauritanicus*), squat lobsters (*Munida* sp.) and shrimps of the genera *Plesionika* (*P. edwardsii*, *P. gigliolii*, *P. narval*) (Aguilar et al. 2008).

The hard bottoms of the bathyal zone are included in the broad concept of "1170 Reefs" (Templado et al. 2009) of the EU Habitats Directive. In addition, the use of towed dredges and trawl nets in fisheries at depths beyond 1000 m is forbidden under Art. 4 of the Council Regulation (EC) No 1967/2006 concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea (Council of the European Union 2006). "Submarine canyons", "Seamounts", and "Deep sea corals (*Lophelia pertusa* and *Madrepora oculata* beds)" are listed as "Essential Marine Habitats (EMH) of relevance for the management of priority species" by the Scientific Advisory Committee of the General Fisheries Commission for the Mediterranean (General Fisheries Commission for the Mediterranean 2009). Although the Alboran Sea is not within the scope of OSPAR convention, it is worth taking note that "carbonate mounds", "coral gardens", "deep-sea sponge aggregations" and "*Lophelia pertusa* reefs" are placed on the OSPAR list of threatened and/or declining species and habitats. Recently in 2013, some progress has been made in including several species of cold-water corals (*M. oculata* and *D. pertusum*) and antipatharians (e.g. *Leiopathes glaberrima*) in Annex 2 of the Barcelona Convention, and they have been incorporated into the Spanish List of Wildlife Species in Special Protection Regime.

9.7.2 Bathyal Soft Bottoms

Soft bottoms are the most widespread habitats in the bathyal stage of the Alboran Sea and elsewhere, the sediments originating either from deposition of planktonic organisms or from sediment mobilization from the shelf to the slope or along the slope due to the contouritic transport (Emig 1997; Muñoz et al. 2008; Cartes et al. 2004; Templado et al. 2012). These sediments can be of different textures (from bioclastic gravel to clay), and they generally display a higher mud content in deep areas with low hydrodynamism (Muñoz et al. 2008; Ciércoles et al. 2018). Although these bathyal soft-bottom communities occur from the shelf break to the base of the slope, most available information comes from the upper and middle slope (between 200 and 600 m depth) compared to the lower slope (Sibuet 1974; Salas 1996; García Raso 1996; Abad et al. 2007; Hebbeln et al. 2009; Gofas et al. 2011, 2014b; Pardo et al. 2011; de la Torriente et al. 2014, 2018; Ciércoles et al. 2018).

A prominent feature of the upper bathyal slope, often continued from the shelf edge, is the local occurrence of coarse bioclastic sands and gravels in areas with moderate to strong bottom currents that winnow the fine sediments (e.g. cold-water coral rubble) (de la Torriente et al. 2014). The benthic fauna of these bottoms includes some small solitary corals (*Caryophyllia* spp.) and actiniarians (*Actinauge richardi*); small gorgonians (*Bebryce mollis, Swiftia dubia*); both sedentary (*Serpula vermicularis* on bioclasts) and mobile (*Hyalinoecia tubicola*) polychaetes; the molluscs *Limopsis aurita*, *Xenophora crispa*, *Fusiturris similis*, *Antalis panorma*, *Bathyarca philippiana*, *B. pectunculoides*, *Astarte sulcata* and *Neomenia carinata*; the decapods *Ebalia nux, Cymonomus granulatus*; the crinoid *Leptometra phalangium*; and the echinoid *Cidaris cidaris*, both of them also dominating sometimes hard bottoms (Salas 1996; García Raso 1996; Abad et al. 2007; Hebbeln et al. 2009; Gofas et al. 2011, 2014b; de la Torriente et al. 2014, 2018; Ciércoles et al. 2018; Moya-Urbano and Rueda pers. comm.). In some areas with dense aggregations of *Leptometra phalangium* (e.g. Djibouti Bank, Fig. 9.22), a high diversity of molluscs has been registered with more than 150 species, including new records for the Mediterranean Sea (e.g. *Turbonilla vaillanti*) and new species for science (e.g. *Melanella scarifata*, *Graphis pruinosa*, *Alexandromenia avempacensis*) (Gofas et al. 2014b; Pedrouzo et al. 2014). Suspension feeders seem to be dominant in this type of community as a result of the moderate bottom currents that occur in graves and coarse sand bottoms (Gofas et al. 2014b). Because of its exceptional richness, both in numbers and in the quality of the species, this type of bathyal community with *Leptometra* and *Limopsis* must be considered a high priority for habitat conservation in the Mediterranean deep sea (Grinyó et al. 2020).

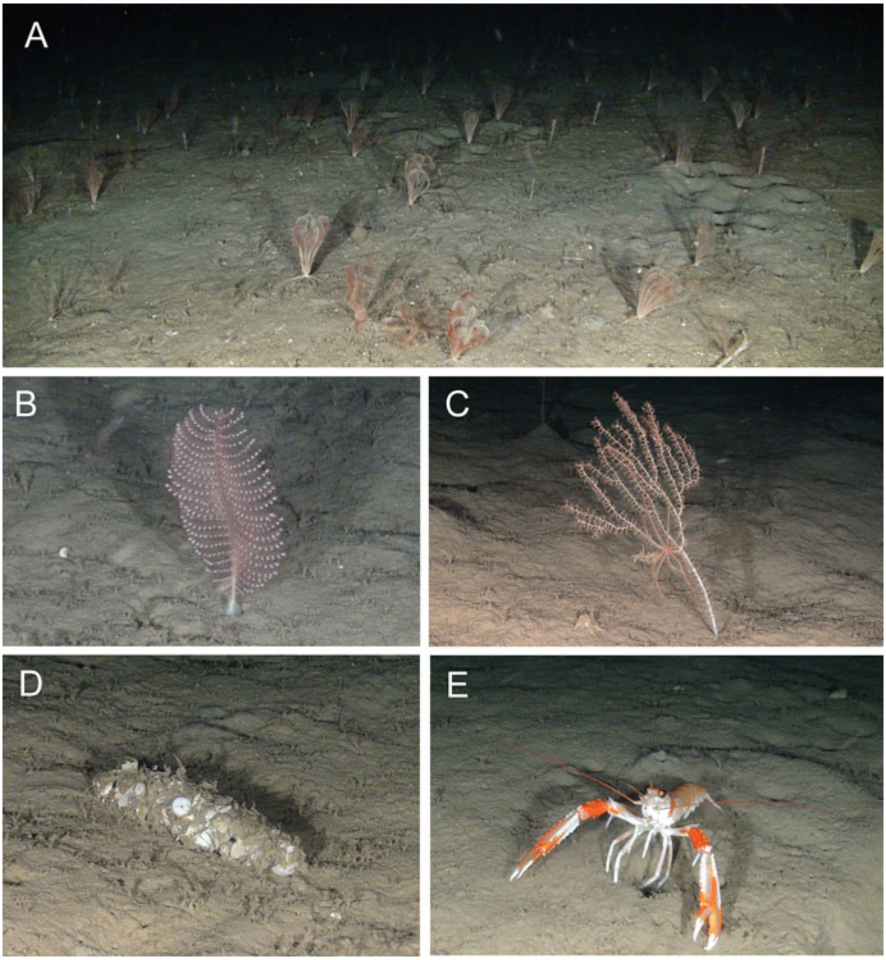

Fig. 9.22 **(a)** A dense aggregation of the crinoid *Leptometra phalangium* and the sea pen *Kophobelemnon stelliferum* on Djibouti Banks. Characteristic animals of bathyal soft bottoms of Seco de los Olivos are **(b)** the sea pen *Pennatula aculeata*, **(c)** the bamboo coral *Isidella elongata*, with the snail *Aporrhais serresiana* on the mud, **(d)** the sea cucumber *Mesothuria intestinalis* and **(e)** the Norway lobster *Nephrops norvegicus*, the latter a target species of the bottom trawling fleet [OCEANA]

In bathyal sand bottoms, the associated fauna shares many components with the abovementioned offshore gravels and with the more fully muddy bottoms and often constitute a transition between both. The sponge *Thenea muricata*; the molluscs *Callumbonella suturalis*, *Euspira fusca* and *Parvicardium minimum*; the crustaceans *Parapenaeus longirostris*, *Solenocera membranacea*, *Plesionika edwardsii*, *Philocheras echinulatus*, *Processa nouveli* and *Ergasticus clouei*; as well as the echinoderms *Ophiura ophiura*, *Ophiocten abyssicolum*, *Luidia sarsii*, *Parastichopus regalis* and *P. tremulus* are commonly found in this kind of bottoms (Salas 1996; García Raso 1996; Abad et al. 2007; Gofas et al. 2011; Hebbeln et al. 2009; de la Torriente et al. 2014, 2018; Ciércoles et al. 2018; Moya-Urbano and Rueda pers. comm.).

Bathyal muddy bottoms (Fig. 9.22) are probably the most widespread bottom type in the Alboran Sea and are generally colonized by different cerianthids (*Cerianthus* spp., *Arachnanthus oligopodus*), bamboo coral (*Isidella elongata*) and sea pens (*Virgularia mirabilis*, *Kophobelemnon stelliferum*, *K.* cf. *leuckarti*, *Funiculina quadrangularis*), polychaetes (*Sabella* sp., *Spiochaetopterus* sp.), molluscs (*Abra longicallus*, *Kelliella miliaris*, *Nucula sulcata*, *Cuspidaria* spp., *Aporrhais serresiana*, *Buccinum humphreysianum*, *Galeodea rugosa*), decapods (*Nephrops norvegicus*, *Monodaeus couchii*, *Goneplax rhomboides*, *Pagurus alatus*, *Plesionika* spp., *Calocaris macandrae*), the holothurian *Mesothuria intestinalis*, the fragile starfish *Hymenodiscus coronatus*, the echinoid *Brissopsis lyrifera* and the small ophiuroid *Ophiocten abyssicolum* that sometimes can be the dominant macrobenthic component (Salas 1996; García Raso 1996; Abad et al. 2007; Hebbeln et al. 2009; Gofas et al. 2011; Pardo et al. 2011; Ciércoles et al. 2018; Moya-Urbano and Rueda pers. comm.).

Sea pen communities have also been detected in coarser sandy bottoms of the Djibouti Banks, the Alboran Ridge and Seco de los Olivos, mainly on areas characterized by low-medium slopes (Hebbeln et al. 2009; Pardo et al. 2011; de la Torriente et al. 2018) and in deep slope sedimentary bottoms (Grinyó et al. 2020).

The bamboo coral *Isidella elongata* is known to occur in the Alboran Sea and has been documented in several places, such as Seco de los Olivos seamount and Cabliers and Djibouti Banks (Pardo et al. 2011; de la Torriente et al. 2018) as well as in deep slope bottoms (Grinyó et al. 2020), with scattered colonies on muddy bottoms, probably due to trawling activity (see Chap. 10).

Another group that can be abundant in some deep soft bottoms of Alboran Sea are bryozoans, although with only a few species. Among them, the most common are the stalked bryozoans *Kinetoskias* sp., which were thought to have entered from the Atlantic via the Gibraltar Strait (Harmelin and d'Hondt 1993) but have later been found further inside the Mediterranean Sea, at the Balearic Islands (Aguilar et al. 2013).

The soft bottoms of the bathyal zone do not fit, even approximately any of the habitats listed in the EU Habitats Directive. Their sole legal protection derives from the Art. 4 of the Council Regulation (EC) No 1967/2006 concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea (Council of the European Union 2006), which prohibits the use of towed dredges and trawl nets in fisheries at depths beyond 1000 m.

The bamboo coral *Isidella elongata* is a critically endangered species, following IUCN Red List category (Mastrototaro et al. 2017; Otero et al. 2017). Habitats harbouring *Leptometra phalangium*, *Funiculina quadrangularis* and *Isidella elongata* and more generally the deep-sea habitats below 1000 m depth are listed as "Essential Marine Habitats (EMH) of relevance for the management of priority species" by the Scientific Advisory Committee of the General Fisheries Commission for the Mediterranean (General Fisheries Commission for the Mediterranean. 2009).

9.7.3 Cold Seeps

Cold seeps are outstanding components of some slope areas of the Alboran Sea and even more so in the adjacent Gulf of Cádiz, where they are more widespread and diverse due to the geological past and wide availability of fluid-enriched sediments (Vanreusel et al. 2009). In the Alboran Sea, cold seeps are mainly represented by mud volcanoes (seafloor edifices formed by mud and fluid extrusion) and pockmarks (seafloor depressions formed by fluid extrusion and further seafloor collapse) (Comas et al. 2003; Sautkin et al. 2003). These cold seeps are mostly located in the West Alboran Basin between 350 and 1600 m depth. Most studies have been performed on specific mud volcanoes (e.g. Perejil, Kalinin) and pockmarks (e.g. Crow's foot pockmark field) of the southern field on the Moroccan margin (Comas et al. 2003; Hilário et al. 2011; Rodrigues et al. 2011; López-Rodríguez et al. 2014). Cold seep communities of the Alboran Sea have been poorly studied in comparison to those of the Gulf of Cádiz or the western Mediterranean Sea, and the available information is only based on the presence of some chemosymbiotic species. Initially, Comas et al. (2003) detected chemosynthetic communities with "pogonophorans" (now considered siboglinid polychaetes) in Kalinin mud volcano, beneath few centimetres of pelagic drape. Later on, Hilário et al. (2011) collected four fragments of stiff-walled tubeworms in a cluster of NE–SW pockmarks, named "Crow's foot" pockmarks. One of them contained the anterior part of a vestimentiferan or siboglinid tubeworm that was assigned to the genus *Lamellibrachia*. This represented the first record of a vestimentiferan polychaete in the western Mediterranean and indicated some fluid venting activity in these pockmarks because *Lamellibrachia* is typically associated with the presence of carbonates and sulphide at the sediment surface. Furthermore, Rodrigues et al. (2011) indicated the occurrence of two chemosymbiotic bivalves (*Myrtea* sp., *Lucinoma* sp.) and two siboglinids (*Lamellibrachia* sp., *Siboglinum* sp.) in cold seeps of the Alboran Sea. López-Rodríguez et al. (2014) also found bivalves of the genus *Acharax* at ca. 10 cm depth in the mud breccia of the flank of Perejil mud volcano, where methane bubbles were also detected as well as abundant vestimentiferan tubeworms at the top. Together with the preliminary characterization of the chemosymbiotic communities, different studies on the micro-paleontological communities (mainly foraminifera) of these mud volcanoes have been done for characterizing and dating the mud breccia sediments (Sautkin et al. 2003; Gennari et al. 2013). The presence of chemosymbiotic fauna on some mud volcanoes (e.g. Perejil, Kalinin) indicates that current methane/hydrocarbon seeping in some of them still occurs (Hilário et al. 2011). Nevertheless, the majority of the Alboran Sea mud volcanoes seem to be inactive or maybe just dormant, so it is very unlikely that chemosynthesis-based communities will develop on them (Comas et al. 2010).

Cold seeps are encompassed in the EU Habitats Directive as "1180 Submarine structures made by leaking gases", but the most noteworthy occurrences in the Alboran Sea are not within EU jurisdictional waters. Cold hydrocarbon seeps are listed as "Essential Marine Habitats (EMH) of relevance for the management of priority species" by the Scientific Advisory Committee of the General Fisheries Commission for the Mediterranean (General Fisheries Commission for the Mediterranean 2009).

9.8 Gaps of Knowledge and Further Steps

Benthic habitats as well as their associated biota have been studied in the Alboran Sea since the nineteenth century, with a significant increase of knowledge in the last decades. Nevertheless, there are still important gaps of information on different aspects such as the presence and mapping of some of these habitats, the characterization of the associated biota of specific habitats or the absence of information on some faunistic groups that compose the benthic communities.

In relation to the presence of habitats and their spatial distribution, this information is mainly available for the ones located in the intertidal and infralittoral zones, because these have been traditionally more accessible and the focal point of different projects from both universities and research institutions (e.g. Instituto Español de Oceanografía) as commented in the introduction. Most of the information is available for the northern sector of the Alboran Sea, and there is a need of carrying out similar exploration on the southern part of the basin. In the circalittoral and bathyal zones, the habitat mapping has been mostly done developed in some marine protected areas (MPAs) under the framework of the INDEMARES project, but it is still missing in extensive areas. Habitat mapping has mainly been performed within MPAs, and therefore information outside MPAs is nearly absent, and often not accurate at small scale (meters, 10s meters). This information is sometimes restricted to reports of the Andalusian regional authority or the Instituto Español de Oceanografía as well as papers for specific habitats (seagrass beds) or available online at the EMODNET Seabed Habitats. The information on the presence and mapping for some deep-sea habitats is very scarce and mostly limited to recently created MPAs. Regarding this, even some large seafloor geomorphological features surely containing different habitat types have not been explored so far such as some seamounts (e.g. El Segoviano, Maimonides 1 and 2, Al Mansour, Yussu) and submarine canyons (e.g. Almería canyon, Ceuta canyon, Motril and Carchuna canyons, etc.). Although habitat maps of some areas are available and some of these areas have been designed as priorities for conservation (current MPAs), similar works should be done in other ecologically important areas, especially in the deep sea, in order to develop a proper spatial management for the whole Alboran Sea in relation to habitats, habitat-forming species and the remaining species.

The information on the associated biota is not equal for the different habitat types, and, of course, the shallower habitats have been studied in more detail than the deep-sea ones as commented previously. There is still not enough information on the composition and structure of the communities associated with intertidal rocky shores, some infralittoral and circalittoral macroalgal beds (e.g. *Cystoseira*, kelp forests), coralligenous and maërl/rhodolith bottoms and circalittoral and bathyal sedimentary and hard-bottom habitats. In some habitats, the information is adequate for some parts (e.g. *Posidonia oceanica* beds of northeastern Alboran Sea) but scarce for other parts (e.g. *P. oceanica* beds of southern Alboran Sea). The information on the associated biota is still scarce for some key deep-sea habitats of the Alboran Sea such as the cold-water coral banks, the sponge aggregations and those sedimentary habitats colonized by octocorals (e.g. bamboo coral beds, sea pen communities, etc.).

Information on the temporal variation of the associated community of different habitats is extremely scarce and only available for specific groups (e.g. molluscs, crustaceans, fishes) and for infralittoral soft bottoms or some vegetated habitats (e.g. seagrass beds, infralittoral macroalgal beds). This information is even absent for habitats that are known to display significant seasonal and interannual changes in other parts of the Mediterranean Sea (e.g. intertidal habitats on rocky shores). Annual monitoring of habitats and benthic communities in the Alboran Sea is mostly available for the littoral areas of the northern Alboran Sea in relation to the Water Framework Directive and also to the Andalusian regional authority through the Sustainable Management of the Andalusian Marine Environment Program. Some MPAs also develop some annual monitoring in threatened habitats, but there is a lack of a standardized methodology that could be useful for contrasting results between MPAs, especially between the northern and southern sectors of the Alboran Sea. The MEDITS expeditions have also developed a monitoring sampling scheme, but, in this case, the information is only available for large macrobenthic species of trawlable grounds which can generally be collected with an otter trawl. Studies on the interannual changes are generally just available for some faunistic components of circalittoral and sedimentary habitats (results of MEDITS expeditions) or for threatened species (e.g. *Patella ferruginea*). Day and night variation of the associated community has only been studied in some seagrass beds, and this represents an important factor to take into account for further studies in other vegetated habitats (e.g. macroalgal beds). Moreover, studies on growth and development of habitat-forming species are null, even for those species that are endemic of the Mediterranean Sea and have their distribution limits in this basin (e.g. *Posidonia oceanica*) and may display significant differences due to the stressing conditions of being at the distribution limit (e.g. lower growth rate, lower reproductive output). The role of environmental variables in the distribution or temporal patterns of the fauna has been mostly analysed in macroalgal beds, seagrass beds and some sedimentary habitats. There are very few data on the interrelation between communities of different bottoms, during the annual cycle and movements related to reproduction and development. Finally, there is almost null information on the effects of the human activities in the communities associated with the majority of habitats of the Alboran Sea.

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Chapter 10
Invertebrates: The Realm of Diversity

José Templado, Ángel A. Luque, Diego Moreno, José Manuel Tierno de Figueroa, Luis Sánchez Tocino, Ricardo Aguilar, and Ana de la Torriente

10.1 Emblematic Species

There is a body of literature about the terminology related to “focal species” (flagship, keystone, umbrella or charismatic species) from an ecological or conservation point of view (e.g. Caro et al. 2004; Ducarme et al. 2013). Without going into this debate, we prefer to use simply here the term “emblematic species” for those representatives of the Alboran Sea which have successful populations and serve as a symbol to draw attention and stimulate conservation awareness and action. The term emblematic species overlaps in part with flagship or charismatic species (see

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Ducarme et al. 2013). Although normally large vertebrates monopolized these species, we selected here as examples three invertebrates: the limpet *Patella ferruginea*, the gorgonian *Ellisella paraplexauroides* and the stony coral *Astroides calycularis*.

10.1.1 Patella ferruginea

One of the most emblematic species of the Alboran Sea is the large limpet *Patella ferruginea* (Fig. 10.1), which can exceed 100 mm of maximum shell diameter. It lives in the upper midlittoral part of rocky coasts, mainly at the *Chthamalus* spp. level. Like other limpets, it is a broadcast spawner and a sequential protandrous hermaphrodite showing alternating sex reversal. All specimens reach adulthood as males, and later most of them change into females, having the capacity to reverse back to males (Guallart et al. 2013). The youngest specimens are found within the *Dendropoma lebeche* belt (which coincides with the mean sea level), and they move to higher levels when reaching a larger size (Guallart et al. 2017).

Patella ferruginea is a western Mediterranean endemic species, and it is considered one of the most endangered marine invertebrates of this sea. It was widely

Fig. 10.1 The large limpet *Patella ferruginea* is one of the most endangered marine invertebrates in the Mediterranean. Here it is close to *Patella depressa*, in the *Chthamalus stellatus* level (Ceuta, Strait of Gibraltar). [José Templado]

distributed all along the western Mediterranean coasts during the Pleistocene and was still quite common until the end of the nineteenth century. Since then, its populations have drastically decreased (Templado et al. 2004). Currently, it is considered extinct on the European continental coasts except for some localities of southern Spain (see Luque et al. 2018 for an updated review). Nowadays the main populations are restricted to the North African coasts, from the Strait of Gibraltar to Tunisia. Otherwise, some relict populations persist in certain island enclaves around Corsica, Sardinia and Sicily.

According to data compiled by Luque et al. (2018), more than 90% of specimens of *P. ferruginea* are concentrated along the coasts of the Alboran Sea, mainly on the African side, where its populations are quite scattered and fragmented. The main populations (with several thousands of adult limpets) are located in Ceuta (Strait of Gibraltar), Melilla, Chafarinas Islands, Habibas, Rachgoun and Plana islands (western coast of Algeria) and Zembra Island (Tunisia). Conversely, along the more than 700 kilometres of Andalusian coastline between the Strait of Gibraltar and Cabo de Gata, estimated numbers do not reach 8000 specimens (CMA 2014).

The decline of this limpet is attributed to human impact, such as overharvesting, development of coastal infrastructures (and the consequent degradation and fragmentation of the habitat) and marine pollution (Templado et al. 2004; Moreno and Arroyo 2008; Luque et al. 2018). *Patella ferruginea* is currently considered in danger of extinction and was included in 1992 as a “species in need of strict protection” in Annex IV of the Habitats Directive (92/43/CEE), in 1996 as an “endangered or threatened species” within Annex II of the Barcelona Convention, as “strictly protected” in 1996 in Annex II of the Bern Convention and as “in danger of extinction” in the Spanish Catalogue of Endangered Species (see Sect. 10.5).

10.1.2 *Ellisella paraplexauroides*

The gorgonian *Ellisella paraplexauroides* (Fig. 10.2) is one of the largest colonial invertebrates in the Mediterranean Sea and the only member of the genus *Ellisella* (Anthozoa, Alcyonacea, Ellisellidae) recorded in European waters (Grasshoff 1992). It forms brick-red candlestick like colonies, to just over 2 m high with ramifications arising from a common short stem and heading parallel upwards.

Ellisella paraplexauroides is an Atlantic-Mediterranean species rarely found in the Mediterranean (Templado et al. 2006; Arroyo et al. 2008; Angiolillo et al. 2012). In the Atlantic, the species occurs along the west coast of Africa (from Angola to Morocco) and off the Canary islands (Brito and Ocaña 2004), while in the Mediterranean, most of the records (reviewed by Angiolillo et al. 2012) are restricted to the Gibraltar Strait (Arroyo et al. 2008; Ocaña et al. 2009) and Alboran Sea (Templado et al. 2006; Arroyo et al. 2008). Inward into the Mediterranean, only isolated colonies have been reported off Algeria and Tunisia, Naples (doubtful record) and Pantelleria Island (data compiled by Angiolillo et al. 2012).

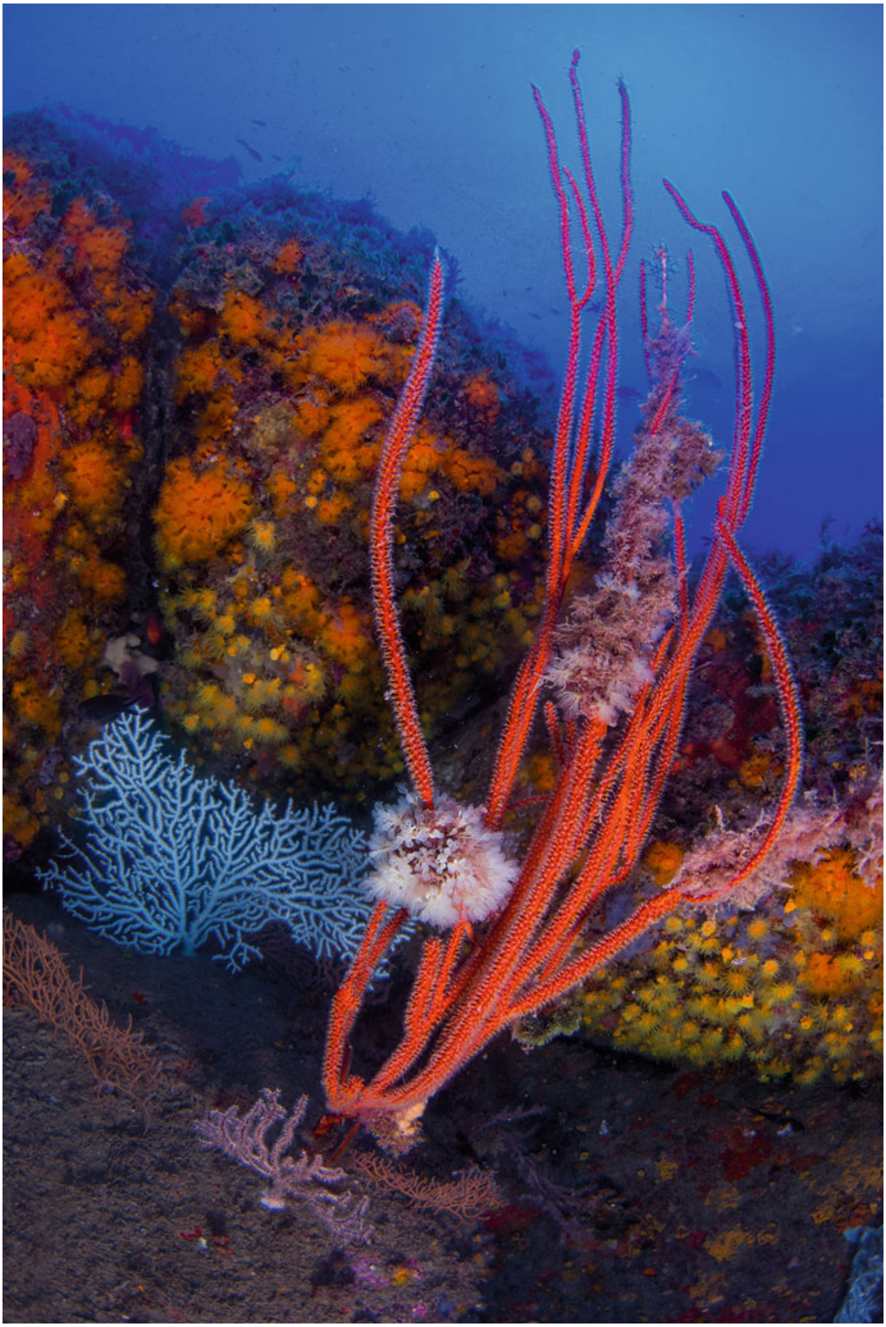

Fig. 10.2 The gorgonian *Ellisella paraplexauroides* is one of the largest colonial invertebrates in the Mediterranean Sea and dominates the rocky bottoms mainly between 20 and 25 m in the Special Area of Conservation of the Chafarinas Islands. Here it is close to other smaller gorgonians (from top to bottom, *Eunicella verrucosa*, *Leptogorgia sarmentosa* and *Eunicella labiata*), the orange

Despite being a large charismatic species, very little is known about its basic biology and ecology. In most of its distribution area, this gorgonian seems to be located on shelf bottoms mainly in the depth range of 50–200 m. Nevertheless, in the Canary Islands has been recorded at the extreme depths of 690 m (Brito and Ocaña 2004), while in the Strait of Gibraltar area and around the Chafarinas Islands can be found as shallow as 15–20 m depth (Ocaña et al. 2009; Maldonado et al. 2013). Scattered colonies have been found in the deep shelf around the Alboran Island (Templado et al. 2006; Gofas et al. 2014) between 70 and 200 m depth and in the Seco de los Olivos (also known as Chella Bank) below 80 m depth (Aguilar et al. 2008; de la Torriente et al. 2014). Likewise, some colonies were photographed and sampled from 80 to 94 m depth on the northeast coasts of Pantelleria Island (Angiolillo et al. 2012).

The occurrence of *Ellisella paraplexauroides* around the Chafarinas Islands is noteworthy. This species dominates the underwater rocky landscape from about 17–20 m deep with an average density of 0.5 colonies m^{-2} (maximum, 5 colonies m^{-2}) (Maldonado et al. 2013). These authors pointed out that this unique population requires serious conservation attention owing to considerable damage caused by small-scale fishing operations. Likewise, Otero et al. (2017) highlight that this gorgonian should be considered "vulnerable" in the Mediterranean basin, since its populations are concentrated around the few sites mentioned and have suffered a drastic decline over recent decades. This decline is mainly related to the impact of unregulated and illegal fisheries, particularly the use of benthic gillnets, trawling gear and longlines. These authors also draw attention to the exceptional value of the population of *E. paraplexauroides* of Chafarinas Islands. In fact, this species was included in 2013 in Annex II of the Barcelona Convention, among other gorgonians and corals (see Sect. 10.5), and listed as "vulnerable" in the IUCN Red List.

10.1.3 *Astroides calycularis*

Another conspicuous and emblematic species of the Alboran Sea is the scleractinian coral *Astroides calycularis* (Figs. 10.2 and 10.3), known as "Mediterranean orange coral" because of the deep orange colour of its coenosarc and polyps (Zibrowius 1995). This species is also well represented in few sectors of the Tyrrhenian Sea, Sicily and Malta and on the Zembra Island in Tunisia, but the greatest concentration and distribution of colonies occurs in the Strait of Gibraltar and Alboran Sea. It barely extends into Atlantic waters beyond the Strait of Gibraltar, and its known western limit of distribution is located at La Caleta, Cadiz City (Moreno et al. 2008a).

Fig. 10.2 (continued) coral *Astroides calycularis* and the yellow coral *Leptopsammia pruvoti* (22 m depth) [Luis Sánchez Tocino]

Fig. 10.3 A colony of the orange coral *Astroides calycularis* in the Special Area of Conservation Acantilados de Maro-Cerro Gordo (Granada), 3 m depth. This species adorns the shady rocky surfaces of the Alboran Sea from surface levels down to about 30 m [Luis Sánchez Tocino]

The orange coral lives in shaded habitats, such as vertical walls, overhangs and cave entrances, prefers areas with high wave action and can be found from the water surface down to a depth of just over 50 m, although it is mainly found in shallower waters. In some places, this coral is the dominant species covering up to 80–90% of wall surface (Ocaña et al. 2009). In exposed places, it typically forms massive colonies with polygonal corallites. In sheltered or deeper places, colonies tend to have a bush-shaped morphology with nearly circular corallites.

Based on fossil evidence, we know that this coral was widely distributed throughout the Western Mediterranean Sea during certain periods of the Pleistocene (Zibrowius 1995) but disappeared from the Northern Mediterranean areas during colder periods. Currently, the range distribution of *A. calycularis* is mainly restricted to rocky coastal areas of the southwestern basin of the Mediterranean, and it is considered a key species in the Alboran Sea (Cebrián and Ballesteros 2004).

Moreno et al. (2008a) and Terrón-Sigler et al. (2015) detailed its distribution in the north side of the Alboran Sea and pointed out that the species is especially abundant on the coasts of Cadiz and Granada. North of Cabo de Gata, *A. calycularis* is only found up to Cabo de Palos (Murcia) as very isolated and dispersed colonies. Conversely, there are scanty data of this coral in the southern side of the Alboran Sea. It is very abundant in Ceuta (Strait of Gibraltar), where it can reach high coverage (Ocaña et al. 2009) and has been also recorded in the Alboran Island, Melilla and Chafarinas Islands (Templado et al. 2004, 2006), where it is common but with relatively low densities. *Astroides calycularis* is also widely distributed along the coasts of Morocco with spectacular occurrences around Cape Tres Forcas (Bazairi et al. 2013) and in the Al Hoceima National Park (Franzosini and Limam 2004) and Algeria. Its southeastern limit seems to be located in Cap Bon and Zembra Island (Tunisia), where Boudouresque et al. (1986) pointed out that this coral covers extensive surfaces of shallow rocky bottoms down to 15 m depth.

Further north, Musco et al. (2016) recorded well-developed populations in the Sorrento Peninsula and the islands of Ischia and Capri along the coast of Campania; the Cilento Coast; the area between Calabria and Sicily, including the Straits of Messina and the Aeolian Islands; the northwestern coast of Sicily, including Ustica and the Egadi Islands; and the islands in the Strait of Sicily. Some colonies were found along the coast of Croatia (Grubelić et al. 2004) which suggests that the geographical range of *A. calycularis* is expanding northwards.

The strictly coastal habitat of *A. calycularis* and its preference for shaded enclaves in the upper infralittoral belt expose this coral to the impact of human activities. This, coupled with its narrow range of tolerance for temperature, seems to be causing its decline. On the other hand, its planula larvae show negative buoyancy and demersal behaviour, crawling along the rocky wall to find a suitable place on which to settle (Goffredo et al. 2010). Hence, the species' larvae have low dispersal capabilities, which leads to a restricted gene flow and connectivity, increasing differentiation among populations because of isolation by distance (Casado-Amezúa et al. 2012). All the above has determined that the orange coral is nowadays protected under Appendix II of the Bern Convention, Annex II of Barcelona Convention and Appendix II of CITES (with all scleractinian corals). It is also catalogued as "vulnerable" in the Spanish and Andalusian Catalogues of Endangered Species (see Sect. 10.5) but considered as of "least concern" in the IUCN Red List.

10.2 Rare Species

The vast majority of species are rare, having a low number of individuals or a restricted spatial occurrence. A particular species may be rare for several reasons, namely: small absolute population size, small geographic range, highly specialized mode of life in conditions that are themselves uncommon, low population density, incidental occurrence in environments not normally occupied by the species, successful breeding at only a few sites (Vermeij and Grosberg 2018) or simply be an artefact due to scarce knowledge linked to the availability of the relevant taxonomic specialists (Bianchi et al. 2014). Species which are represented anywhere by few, scattered individuals implies good dispersal abilities, while species which are restricted to a very peculiar habitat and are abundant there, but that habitat in itself is rare and/or inaccessible, are rather characterized by direct development and low dispersal potential, and their rarity may be an artefact due to our access limitation (Gaston 1994). It has long been recognized that populations below a critical density or number of individuals face a high risk of extinction, because of demographic fluctuations or reproductive failure due to different impacts (Vermeij and Grosberg 2018). Nevertheless, rarity may also hold the key to survival during crises (e.g., Bianchi et al. 2014), and many species persist chronically rare.

Most communities are composed of a few dominant species and a high number of rare species. Indeed, the bulk of biodiversity at species level consists of a host of small, inconspicuous and little-known species. Nevertheless, rare species are the neglected component of biodiversity, and they are often considered as "noise" and ignored in ecological studies (Piraino et al. 2002). Likewise, biodiversity conservation focuses mainly on a few charismatic species (generally either vertebrates or large and conspicuous invertebrates) and disregards what represents the most of the biodiversity. Conversely, the importance of rare species could be crucial as a reservoir of potential diversity and provide information for the possible future composition of a community after changes in environmental conditions. Highly distinct combinations of traits are supported predominantly by rare species. It is thus not only the quantity but also the quality of biodiversity that matters (Mouillot et al. 2013).

A broad array of species may allow ecosystems to maintain their functioning, and a high number of species serves as a buffer against the effects of environmental impacts and enhances the recovery potential of communities. Therefore, rare species are particularly important from the point of view of conservation, ecology and evolutionary biology (Lim et al. 2012). Furthermore, since rare species are represented by only a few individuals or small populations often restricted to particular habitats, they are vulnerable to being lost. To summarize, although still incomplete, there is growing scientific evidence that many rare or little-known species may play key ecological roles in the function, structure and composition of some ecological communities and could be important as a genetic reservoir and for long-term evolutionary potential. Nevertheless, rare or little-known species are, by their nature of being scarce, often not explicitly included in conservation and natural resource planning (Raphael and Molina 2007).

We consider here as rare species those that are very restricted in number of individuals or spatial occurrence but also those of unusual morphological or biological characteristics. Sometimes the supposed rare species are not so much but belong to groups of tiny animals very poorly studied. Indeed, the number of rare species in the Alboran Sea is very high, and here we will mention only a few of them as examples.

10.2.1 Porifera

The bottoms of the Alboran Sea are characterized by a high richness and diversity of sponges. Among this fauna, there are a significant number of Mediterranean endemisms and rare species, along with numerous "Atlantic" species found in this westernmost Mediterranean area where may reach notable abundances (Sitjà and

Maldonado 2014). As examples can be mentioned *Jaspis eudermis* and *Axinella vellerea*, previously only known from Azores and a Norwegian fiord, or *Hemiasterella elongata*, previously known only from its holotype collected in the Cape Verde Islands.

On the other hand, one of the most peculiar groups within the phylum Porifera is that formed by carnivorous sponges, all belonging to the family Cladorhizidae (Hestetun et al. 2016). Contrary to the aquiferous system used to filter water for particulate matter characteristic of this primitive phylum, the carnivorous sponges have developed the ability to trap prey items coupled with the complete or partial reduction of the aquiferous system. In the Mediterranean, these peculiar sponges are represented by two species: *Cladorhiza abyssicola* and *Lycopodina hypogea.* The former is a bathyal sponge widely distributed in the NE Atlantic that has been found in deeper waters of a few locations of the NW Mediterranean (Vacelet 1969) and one specimen in the Alboran Sea (Boury-Esnault et al. 1994). Meanwhile, *L. hypogea* was originally described (as *Asbestopluma hypogea*) from shallow submarine caves (15–25 m depth) in the Western Mediterranean Sea and the Adriatic (Vacelet and Boury-Esnault 1996; Bakran-Petricioli et al. 2007). Nonetheless this species has subsequently been observed in some deep Mediterranean and Atlantic locations (in the depth range 100–500 m), among them in the Seco de los Olivos (Aguilar et al. 2011b, at 167 m) and Cabliers Seamount (Chevaldonné et al. 2015, between 370 and 400 m) on the north and south margins, respectively, of the Alboran Sea.

10.2.2 Cnidaria

The small and semitransparent anemone *Sideractis glacialis* is mainly known in northern latitudes of the East Atlantic, usually in deep white coral banks. It was recorded in the NW Mediterranean by den Hartog et al. (1993) and more recently by Aguilar and Marín (2013) in some seamounts near the Balearic Islands and in the Seco de los Olivos. Due to its small size and inconspicuous colour, this species may often have been overlooked. The Mediterranean records reveals that it is more widely distributed than has previously been assumed, and its distributional range possibly coincides to a large extent with that of white coral banks formed by *Desmophyllum pertusum* and *Madrepora oculata*.

The large scyphozoan jellyfish *Drymonema dalmatinum* was described from the Dalmatian coast in the Adriatic Sea. Despite its conspicuous size, this medusa has been very rarely observed. Malej et al. (2014) reported an increased frequency of sightings in the last 15 years from the Adriatic and eastern Mediterranean Sea, and recently Kienberger and Prieto (2016) reported a single specimen observed and photographed by scuba divers near La Herradura (S Spain) at a depth of 12 m, with a bell diameter of approximately 70 cm.

Dendrobrachia bonsai (Fig. 10.4) is a delicate and small gorgonian whose whitish and inconspicuous colonies usually do not exceed 10 cm in height. This species was recorded by Zibrowius and Taviani (Zibrowius and Taviani 2005) as

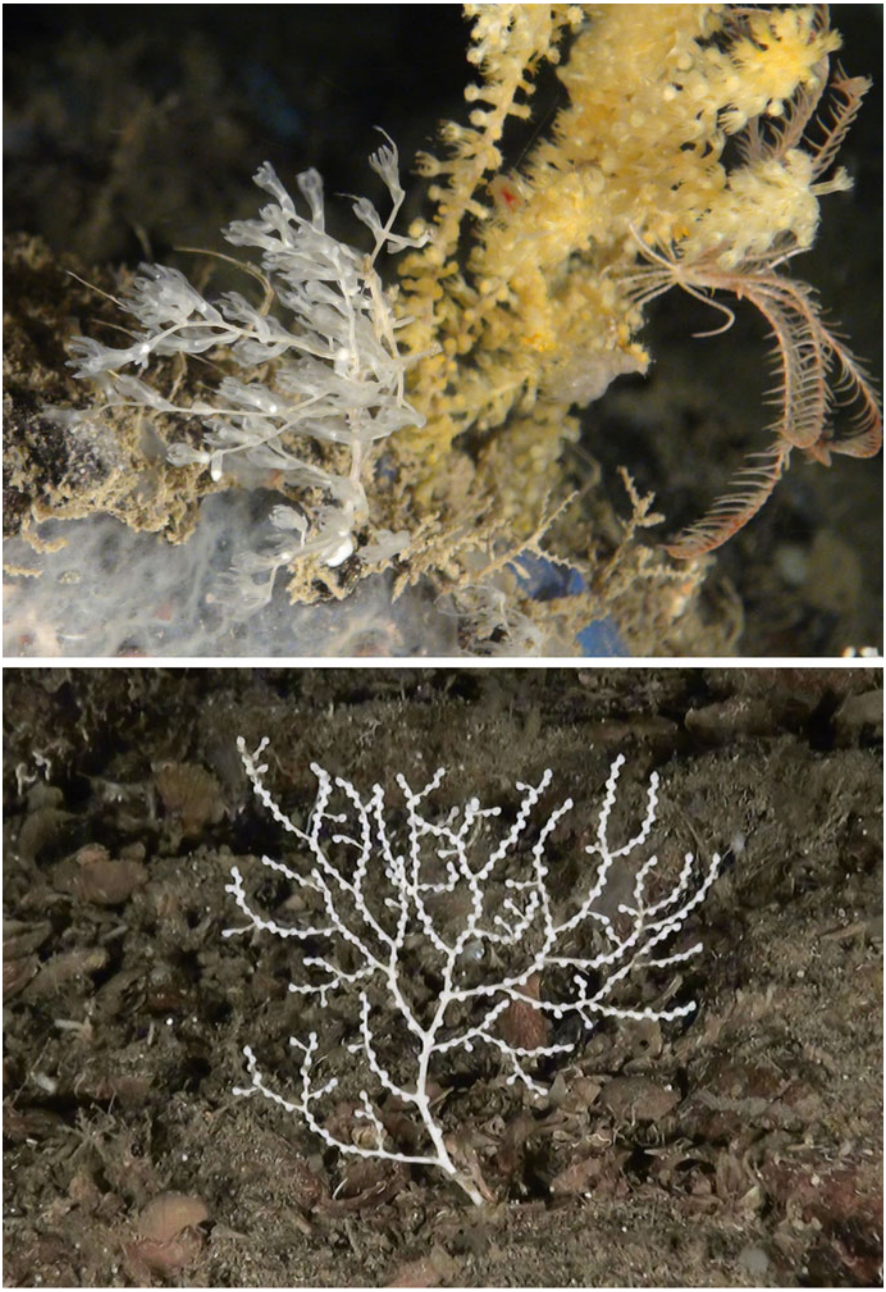

Fig. 10.4 Two delicate gorgonians, *Dendrobrachia bonsai* (above) that does not exceed 10 cm in height (Seco de los Olivos, 440 m depth) and the Atlantic *Nicella granifera* (below), recently found in the Seco de los Olivos (430 m depth) [Ricardo Aguilar, Oceana]

Fig. 10.5 Aggregations of dead colonies of the deep-water scleractinian coral *Anomocora fecunda*, previously only known from the Caribbean and Macaronesian Seas, have been found in Cabliers and Seco de los Olivos Banks (here in a detritic bottom dominated by *Cidaris cidaris* in the Seco de los Olivos around 400 m depth) [Ricardo Aguilar, Oceana]

D. fallax in bathyal bottoms south of Malta (Strait of Sicily) and in the Seco de los Olivos. Later, López-González and Cunha (2010) described these specimens together with others obtained in the Gulf of Cadiz and in Al Idrisi Seamount (Djibouti Plateau) as a new species (*D. bonsai*). More recently, Sartoretto (2012) noted the presence of this species in five submarine canyons between 200 and 500 m depth on the western coast of Corsica, mainly along the rocky walls and overhangs of high cliffs. Likewise de la Torriente et al. (2014, 2018) and Ocaña et al. (2017) found some colonies of *D. bonsai* in Catifas Bank and Seco de los Olivos between 380 and 450 m. Another small Atlantic gorgonian, *Nicella granifera* (Fig. 10.4), has been recently found for the first time in the Mediterranean in the Seco de los Olivos at 430 m depth (Ocaña et al. 2017) and then in the Emile Baudot Seamount in the Balearic Promontory (Ricardo Aguilar, pers. obs.).

Species belonging to the genus *Anthomastus* were recently recorded in the Cabliers and the Seco de los Olivos Banks (Pardo et al. 2011; de la Torriente et al. 2014, respectively). These deep-sea mushroom corals were previously known from the Indo-Pacific, Atlantic and Antarctic waters (Molodtsova 2013), mainly associated to seamounts and knolls, and are very easily distinguished by their external appearance with reddish tones and huge expanded autozooids, which are specialized in feeding. The records of species of this genus in the Alboran Sea expand its distribution to the Mediterranean Sea. In both Cabliers and Seco de los Olivos Banks, aggregations of dead colonies of the scleractinian *Anomocora fecunda*

(Fig. 10.5) were also found between 200 and 400 m depth (Pardo et al. 2011; de la Torriente et al. 2014; Ocaña et al. 2017). This species was previously known only from tropical waters of the western and eastern Atlantic (Caribbean and Macaronesian Seas).

10.2.3 Nemertea

The heteronemerteans *Micrura dellechiajei* (Fig. 10.6) and *Cerebratulus aerugatus*, previously known only from their type locality in the Gulf of Naples, had not been recorded again in 120 years until recently. Several specimens of the former were collected during two oceanographic surveys conducted in Spanish Mediterranean waters, in the Menorca Channel (Balearic Islands) and near the Alboran Island (Herrera-Bachiller et al. 2015), between 48 and 101 m depth. The second species was recently recorded in Ceuta (Strait of Gibraltar) by Junoy et al. (2018), along with other rare nemerteans, such as *Tetrastemma coronatum*, only known previously from the Azores and Madeira Islands, or *Prosorhochmus chafarinensis*, originally described from the Chafarinas Islands by Frutos et al. (1998).

Fig. 10.6 The nemertean *Micrura dellechiajei*, previously only known from the Gulf of Naples, has been recently found near the Alboran Island between 48 and 101 m depth [Juan Junoy]

10.2.4 *Meiofauna (Gastrotricha, Kinorhyncha, Tardigrada)*

The term “meiofauna” (or “meiobenthos”) include microscopic benthic invertebrates (size mainly between 0.5 and 1 mm) that live in both marine and freshwater environments. Most of the recognized animal phyla have representatives in meiofauna, but only five of them are exclusively meiofaunal. These tiny animals are a common component of the interstitial environment (between sand grains) where they reach a high abundance and are ubiquitous and ecologically important in sedimentary bottoms recycling detritus and dead organic matter. Nematodes are the dominant group of the marine interstitial environment, but this group has not been documented in the Alboran Sea. Other common components of marine meiofauna are Gastrotricha, Kinorhyncha or Tardigrada. These are very little studied groups (also in the Alboran Sea), and their rarity is due to limited knowledge rather than to real scarcity.

Gastrotricha is a clade of aquatic microscopic animals that are among the smallest metazoans, mainly living in the marine and freshwater interstitial environment and on the surface of aquatic plants. Only one species of this group, *Pleurodasys helgolandicus*, widespread along the North Sea and the Atlantic European coasts, is known to form stable populations along the Spanish coast of the Alboran Sea (Todaro et al. 2006).

Kinorhyncha is a phylum of meiobenthic organisms less than 1 mm in length and found exclusively in marine or estuarine sediments, from coarse sand or shell gravel to very fine mud. Sánchez et al. (2012) recorded about 12 kinorhynch species in south Spain (Algeciras Bay and Granada coast). Among them, *Echinoderes dujardinii* (Fig. 10.7) was collected by Sánchez-Tocino et al. (2011) in shallow waters near Almuñécar (Granada, Spain). Subsequently, two new species, *Dracoderes gallaicus* and *Pycnophyes almansae*, were described from specimens collected in Algeciras and Almuñécar (Sørensen et al. 2012; Sánchez et al. 2014).

Tardigrada are micrometazoans that occupy a diversity of niches in freshwater, marine and terrestrial habitats. In the Alboran Sea, this group has only been studied in the Chafarinas Islands by Villora Moreno and de Zio Grimaldi (1996) who recorded 14 species, 5 of which were new records for the Mediterranean Sea. Three of them were the first record after its original description: *Florarctus acer*, *F. asper* and *F. stellatus*. Further, *Halechiniscus chafarinensis* was described as a new species by de Zio Grimaldi and Villora-Moreno (1995).

10.2.5 *Cycliophora*

Cycliophora is one of the most recently described animal phyla whose members live commensally on the mouthparts of lobsters of the family Nephropidae (Obst et al. 2005). Up to date, two species have been described, *Symbion pandora*, from the Norway lobster (*Nephrops norvegicus*), and *S. americanus*, from the American

Fig. 10.7 The meiobenthic kinorhynch *Echinoderes dujardinii* has been recorded in shallow water near Almuñécar (Granada coast, S Spain) [Luis Sánchez Tocino]

lobster (*Homarus americanus*). Nevertheless, molecular studies show that more cryptic species can exist (Obst et al. 2005; Baker and Giribet 2007). *Symbion pandora* is widely distributed in the eastern Atlantic and has been also recorded in NE Spain (Catalonian coast), in the Tyrrhenian Sea and in the Alboran Sea (Granada coast, Sánchez-Tocino and Tierno de Figueroa 2008) living on the mouthpieces of the lobster *Nephrops norvegicus*.

10.2.6 Entoprocta

Only very few, small and poorly known species of the phylum Entoprocta are known in the Mediterranean Sea, all of them belonging to the family Loxosomatidae. Recently two new species of this small animal group have been described from the shores of Granada: *Loxosomella ameliae* and *Loxosomella almugnecarensis* (by Sánchez-Tocino and Tierno de Figueroa 2009a and Tierno de Figueroa and Sánchez-Tocino 2009a, respectively). Furthermore, three other species of *Loxosomella* have been recorded by these authors in the same area: *L. crassicauda* (Tierno de Figueroa and Sánchez-Tocino 2008), *L. pes* (Sánchez-Tocino and Tierno de Figueroa 2009a) and *L. tethyae* (Tierno de Figueroa and Sánchez-Tocino 2009b). All of them are tiny (<5 mm), sessile stalked animals, commensal mainly on sponges. Three of these species have been also found in the Chafarinas Islands, and this makes the Alboran Sea one of the better known areas for this group, together with the Gulf of Naples (Sánchez-Tocino and Tierno de Figueroa 2009b, c).

10.2.7 Polychaeta

Vestimentiferan tubeworms (Annelida, Siboglinidae) represent one of the most intriguing clades within polychaetes from both a phylogenetic and an ecological point of view and are typically associated with reducing habitats such as hydrothermal vents and cold seeps. They depend on organic compounds supplied by endosymbiotic chemoautotrophic bacteria and lack a mouth and gut in the adult phase. *Lamellibrachia anaximandri* is the only known representative of siboglinids in the Mediterranean Sea (Southward et al. 2011). This vestimentiferan tubeworm has recently been described at various deep locations of the Eastern Basin and Southern Tyrrhenian Sea (at the Palinuro volcanic complex) (Rubin-Blum et al. 2014) and has also been observed in a mud volcano field in the West Alboran Basin at 570 m depth (Hilário et al. 2011). Vestimentiferan tubes appeared grouped in dense bush-like aggregates, and they can exceed 1 m in length.

10.2.8 Crustacea

The isopod *Astacilla carlosoteroi* was previously only known from a single, incomplete female from the Ferrol estuary (Galicia, NW Spain, Atlantic), but recently some specimens (including males) have been found near the Alboran Islands (Rincón et al. 2018). This is the first report of the species from the Mediterranean Sea and the second worldwide record of the species.

10.2.9 Bryozoa

The pedunculate bryozoans of the genus *Kinetoskias* are typically abyssal and are characterized by an erect colony and an elongate peduncle supporting a cup-shaped crown of slender, unilaminar branches. The north Atlantic species *Kinetoskias smitti* Danielssen, 1868, was recorded in the Alboran Sea at a much shallower depth (428 m) than in the Atlantic (Harmelin and d'Hondt 1992), and this is the only record of this genus in the Mediterranean.

10.2.10 Echinodermata

The sea star *Coronaster briareus* is mainly known from the western Atlantic, where it extends from New Jersey to Venezuela and possibly South Brazil (Clark and Downey 1992). In the eastern Atlantic, it was recorded from the Cape Verde Islands and some seamounts (Clark and Downey 1992). Recently, several individuals of this starfish were reported for the first time from the Mediterranean Sea near the Maltese Islands between 240 and 562 m (Evans et al. 2018). Notwithstanding, one orange-red specimen was photographed in the southern flank of El Idrissi Bank, at 365 m depth (Hebbeln et al. 2009, Fig. 5.8c as *Coronaster* sp.).

The large starfish *Luidia atlantidea*, known hitherto in the Atlantic coasts of northwestern Africa, has been recently reported for the first time in the European margin of the Alboran Sea (Gallardo-Roldán et al. 2015). Most individuals were collected close to La Caleta de Vélez and Fuengirola. It was mainly found in shallow bottoms of fine sand with pebbles and/or bioclasts, where this starfish generally occurs together with the dominant molluscs *Chamelea gallina* and *Donax trunculus*.

10.3 Habitat-Forming Species

The term "animal forests" has been introduced to describe megabenthic communities dominated by sessile suspension feeder invertebrates (such as sponges, cnidarians or bivalves among others). These communities are complex three-dimensional environments that support a high biodiversity, by providing structure and shelter to many other organisms (Rossi et al. 2017). Animal forests are distributed worldwide, ranging from tropical to polar latitudes and from shallow to deep-sea bottoms. Some of the most characteristic underwater animal forest seascapes of the Alboran Sea are composed of anthozoans, such as the gorgonians and red and black coral forests, the fields of sea pens or the scleractinians forming the cold-water coral reefs. Some bivalves and sponges can also form highly complex and diverse three-dimensional structures.

10.3.1 Sponges

Sponges are an important component of the deep-shelf benthos, particularly on rocky bottoms, where they make peculiar assemblages characterized by a wide diversity of small, erect species forming a dense "undergrowth" among a scatter of large sponges and gorgonians (Sitjà and Maldonado 2014). Some of them are key bioengineer species forming three-dimensional structures during their long lifespans that provide suitable habitats for a wide variety of other marine species. A high diversity and abundance of small erect species growing among the large astrophorids and axinellids typically build in the Mediterranean the so-called "sponge gardens" or "sponge grounds" in depth ranges which are similar to those reported on North-Atlantic margins (Maldonado et al. 2016).

Sponges are one of the best studied and more diverse groups in the Alboran Sea and offer many novelties, as previously noted in Sect. 10.2.1. Specifically, about 200 species have been recorded around the Alboran Island (Sitjà and Maldonado 2014). Here we will focus only on highlighting the most dominant species that make up sponge gardens.

Among demosponges, the astrophorids *Poecillastra compressa* and *Pachastrella monilifera* appear to have the most extensive geographical distribution within the Mediterranean and give rise to dense aggregations (reaching densities of up to 10 individuals m^{-2}), sometimes as dominant species and others mixed with corals and gorgonians (Aguilar et al. 2017). Both species show an Atlantic-Mediterranean overlapped distribution and share a great morphological and dimensional plasticity, which allow them to grow into a variety of different environments, on several types of substrate and within a wide bathymetric range (Bo et al. 2012). They can be massive, plate-like or cup-like in shape, being *P. monilifera* generally white, while *P. compressa* exhibits orange colour when observed alive. Both species are common in the deep circalittoral hard bottoms of the Alboran Ridge (Sitjà and Maldonado 2014).

The demosponges of the genus *Phakellia*, with mostly Atlantic distribution, are also common in the Western Mediterranean (de la Torriente et al. 2014; Aguilar et al. 2017), becoming abundant in the deep circalittoral and upper bathyal zones, especially on slopy rocky plains and seamounts. Both chalice-shaped or fan-shaped sponges *Phakellia ventilabrum* and *P. robusta* are widespread in the Strait of Gibraltar and Alboran Sea (Maldonado 1992; Boury-Esnault et al. 1994; Carballo and García-Gómez 1994; Lo Iacono et al. 2012; Gofas et al. 2014; de la Torriente et al. 2018). In the Alboran Ridge, *Phakellia* species have been observed in mixed assemblages dominated by cnidarians and sponges on the deep circalittoral hard bottoms (Gofas et al. 2014) and rhodolith beds (Sitjà and Maldonado 2014).

On soft bottoms, the presence of sponge aggregations is limited to a few species, such as the northwestern Atlantic *Thenea muricata*, which is also common in muddy bottoms of the bathyal zone throughout the Mediterranean, including the Alboran Sea (Boury-Esnault et al. 1994). The *T. muricata* assemblage is usually monospecific, reaching a high biomass. It is affected by bottom trawling (Pansini and Musso 1991), since it is a common by-catch species.

The northeastern Atlantic large (up to 1 m tall) and vase-shaped hexactinellid sponge *Asconema setubalense* is the most important species forming aggregations in the Western Mediterranean (Boury-Esnault et al. 2015), mainly on seamount rocky bottoms at depths below 200 m, but has not been found beyond the Alboran Sea. Another widespread Atlantic glass sponge is *Pheronema carpenteri*, which can also give rise to important communities but in this case on muddy bottoms. In the Mediterranean, it has been found from the Alboran to the Tyrrhenian Sea at depths between 350 m and more than 2000 m (Boury-Esnault et al. 2015).

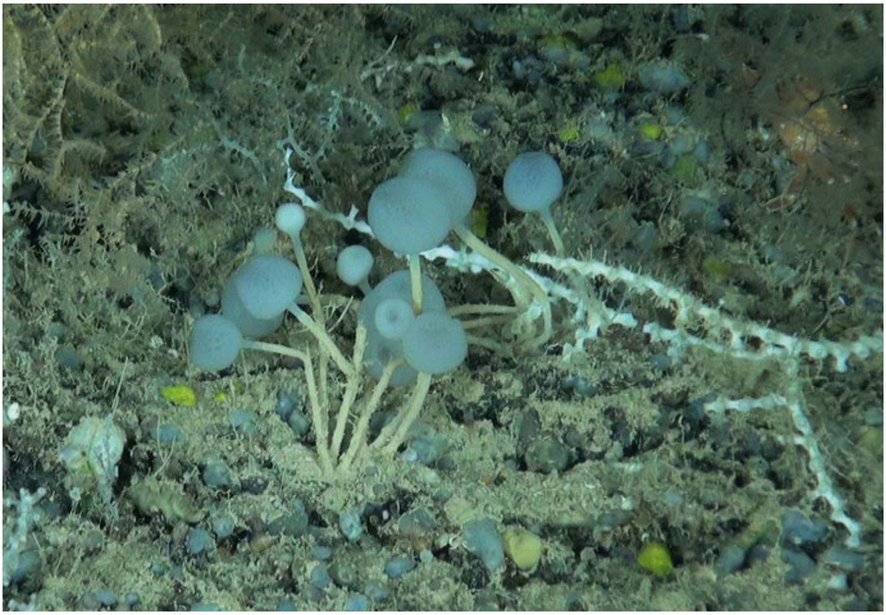

Fig. 10.8 The rare stalked sponge *Sympagella delauzei* has been recorded in several seamounts of the Alboran Sea (Avempace Bank at 388 m depth) [Ricardo Aguilar, Oceana]

The new recently described white urn-shaped and stalked hexactinellid *Sympagella delauzei* (Fig. 10.8) has been recorded on several seamounts of the Alboran Sea (Avempace, Seco de los Olivos, Catifas, Cabliers and Tofiño) between 320 and 480 m depth (Boury-Esnault et al. 2015). Out of the Alboran Sea, this species has been only found off West Corsica and the Gorringe Bank (NE Atlantic). Another recently described hexactinellid is *Tetrodictyum reiswigi*, but it is more widely distributed in the Mediterranean, reaching the eastern basin. This small species is formed by several tubes more or less coalescent, expanding from a narrower base of attachment to the substrate (Boury-Esnault et al. 2017), and can form aggregations on hard bottoms of seamounts, escarpments and canyons within the depth range of 200–2500 m. It was collected in two stations of the Alboran Sea during the BALGIM Cruise (1984) between 390 and 560 m depth and was previously identified as *T. tubulosum* by Boury-Esnault et al. (1994).

As mentioned before, numerous smaller sponges may form dense "undergrowths" among larger sponges and gorgonians, mainly in three major habitats of the deep shelf: "maërl" or rhodolith beds, rocky plains moderately sloping and isolated rocky outcrops surrounded by soft sediments (Sitjà and Maldonado 2014). Among them are frequent some submassive species of the genera *Suberites* (*S. compressa)*, *Sarcotragus* (*S. pipetta*) or *Spongia* (*S. agaricina*), others with branching morphology such as those of the genera *Axinella* (e.g. *A. vellerea*, *A. pumila*) and *Stelligera* (e.g. *S. rigida*, *S. stuposa*) and a variety of small digitate and stalked sponges such as *Crella pyrula*, *Podospongia lovenii*, *Rhizaxinella elongata*, *R. gracilis* or *Stylocordyla* sp.

10.3.2 Gorgonians

The so-called gorgonian forests are one of the most emblematic Mediterranean marine communities, showing a high diversity and great structural complexity. The nearly 30 species forming these forests have different morphologies, with sizes varying between a few centimetres and more than 2–3 m high and inhabit a wide range of environments (Gori et al. 2017). They are typical on hard bottoms, but some of them are also able to tolerate high levels of sedimentation or to anchor themselves on soft bottoms and form dense monospecific or multispecific assemblages that can extend over large areas.

Most of the Mediterranean species of gorgonians are present in the Alboran Sea, as well as some Atlantic species such as *Eunicella gazella*, *E. labiata*, *E. filiformis*, *Filigorgia guineensis*, *Spinimuricea atlantica* or *Ellisella paraplexauroides*, some of them coming from northwestern Africa. This fact determines that the bottoms of the Strait of Gibraltar and the Alboran Sea harbour more species than other Mediterranean or nearby Atlantic areas. Specifically, up to 19 species have been recorded in the bottoms surrounding the Alboran Island down to 500 m depth (Templado et al. 2006). In contrast, for example, only eight species were found in Tunisian waters within the depth range of 7–120 m (Ghanem et al. 2018), nine were observed between 40 and 360 m depth in the Menorca Channel (Grinyó et al. 2016), and five species were observed in the Algarve coast down to 30 m depth (Cúrdia et al. 2013).

Four gorgonian species are commonly present in shallow areas of the Mediterranean (Gori et al. 2012), namely, *Eunicella singularis*, *E. cavolinii*, *Paramuricea clavata* and *Leptogorgia sarmentosa*. In the Alboran Sea, *E. cavolinii* becomes very rare, being replaced by another species such as *Eunicella labiata* (Fig. 10.2). Furthermore, in the Strait of Gibraltar and Chafarinas Islands, the abovementioned *Ellisella paraplexauroides* (Fig. 10.2) can be found as shallow as about 20 m.

Eunicella singularis can be considered the most common and abundant gorgonian species and the only one known to host symbiotic algae. It is abundant throughout the western Mediterranean and Adriatic Sea, is occasionally present in the eastern Mediterranean and reaches the coasts of the Algarve in the near Atlantic. This species is common on rocky bottoms in shallow waters, as well as on deeper coralligenous formations. The extensive distribution of *E. singularis* on a regional scale may be related to its tolerance to a wide range of irradiance and abiotic factors, and it is found commonly on horizontal or sloping bottoms (Linares et al. 2008a; Gori et al. 2011). In contrast, the emblematic Mediterranean red gorgonian *Paramuricea clavata* show a more patchy distribution mainly in the western basin of the Mediterranean and the Adriatic Sea. It is associated with vertical rocky walls and occupied a narrow range of light and environmental conditions from about 20 m to at least 110 m. Both species are widely distributed in the Alboran Sea and Strait of Gibraltar (Templado et al. 2006; Ocaña et al. 2009).

Leptogorgia sarmentosa (Figs. 10.2 and 10.20) shows a patchy distribution (Templado et al. 2006; Ocaña et al. 2009). It is a quite resistant species, able to thrive in very shallow waters and harsh environmental conditions, such as those typical of harbour habitats (Betti et al. 2018) and possess the ability to tolerate high silting levels and turbid waters.

Eunicella gazella and *E. labiata* are West African gorgonians distributed from Portugal to Angola, entering the Alboran Sea where they show a patchy and dispersed distribution (Abou Oualid et al. 2016). These species are usually found as isolated colonies in shady rocky enclaves between 5 and 20 m. *Eunicella labiata* is the most frequent gorgonian on the coastal bottoms of the Algarve (Cúrdia et al. 2013), but in the Alboran Sea, it has been only recorded from the Granada coast and the Chafarinas Islands (Sánchez-Tocino et al. 2009), while *E. gazella* reaches the Columbretes Islands in the Balearic Sea (Templado et al. 2002).

With a tree-like morphology often moulded on that of gorgonians, the so-called gold coral *Savalia savaglia* (Fig. 10.9) (an epizoic zoanthid species) may form a facies together with gorgonians, with a significant role in benthic assemblages due to their relatively long life span. It is the sole zoanthid able to produce a rigid and thick-layered proteinaceous skeleton, which grows on the stem of gorgonians for several hundreds of years and can reach up to 2 m high, with a main trunk diameter up to 15 cm (Cerrano et al. 2010). This species has been recorded sporadically in the Mediterranean Sea, mainly in circalittoral coralligenous bottoms, but recent discoveries have extended its bathymetric range down to 900 m in the deep coral communities (Giusti et al. 2015).

Monospecific facies with high density of colonies of *S. savaglia* have been found in some circalittoral bottoms of the Canary Islands, where it can be confused with *Antipathozoanthus macaronesicus* (Ocaña et al. 2007). Further, some colonies have recently been found in northeastern Spain at a depth of 26–29 m (Altuna et al. 2010). In the area of the Strait of Gibraltar and Alboran Sea, sparse colonies of *S. savaglia* have been recorded within gorgonian forests, between 20 and 40 m in depth in Ceuta (Ocaña et al. 2009), Cape Tres Forcas and Chafarinas Islands (González García et al. 2005), between 40 and 90 m in rocky outcrops around the Alboran Island (Templado et al. 2006) and in bathyal rocky bottoms down to 900 m in Avempace and Seco de los Olivos Banks (Pardo et al. 2011; de la Torriente et al. 2018).

Several species of gorgonians can be found on the deeper part of the continental shelf (at about 110–200 m depth), often occurring in multispecific assemblages, which are more frequent in the rocky outcrops that occur toward the shelf edge. Among other species, *Paramuricea macrospina*, *Swiftia pallida*, *S. dubia*, *Acanthogorgia hirsuta*, *Viminella flagellum*, *Bebrice mollis*, *Eunicella filiformis*, *E. verrucosa* and *Callogorgia verticillata* are typical gorgonians of these bottoms (Gori et al. 2017) and sometimes extend their distribution deeper onto the upper slope. Coexistence is observed at low and intermediate densities among large- (e.g. *C. verticillata*), medium- (e.g. *E. verrucosa*) and small-sized species (*Swiftia*

Fig. 10.9 The zoanthid *Savalia savaglia* (called “gold coral”) starts growing on the stem of a gorgonian or antipatharian and then produce its own proteinaceous skeleton (Chafarinas Islands, 27 m depth) [Luis Sánchez Tocino]

spp.). This could indicate that differences in size may reduce interspecific competition for space and food (Grinyó et al. 2016).

Eunicella verrucosa (Fig. 10.2) has been described as an Atlantic species with a wide bathymetric range and seems to replace the Mediterranean *E. cavolinii* in the Alboran Sea. In the Strait of Gibraltar and Atlantic locations, this species may be found from shallow waters (6–8 m) down to about 80 m, but in the Alboran Sea, it is mainly found at deeper waters (35–200 m). Around the Alborán Island, it is quite abundant in the undergrowth of the *Laminaria* and *Saccorhiza* forests between 25 and 60 m (small colonies), but it can extend to deeper waters (down to about 200 m), where colonies are larger (Templado et al. 2006; Gofas et al. 2014). In the Seco de los Olivos, de la Torriente et al. (2018) found this gorgonian in the depth range of 75–450 m (more frequently in the range of 75–150 m).

The whip-like gorgonian *Viminella flagellum* is mainly an Atlantic species living in temperate and subtropical waters. Its occurrence in the Mediterranean Sea seems to be limited to its westernmost part (Alboran and Balearic Seas), with the exception of a record on the western coast of Corsica (Giusti et al. 2012, 2017). This gorgonian is characterized by monopodial colonies up to 3 m high with only one or few side branches. It may form dense meadows, especially over seamount summit plateaux, and may reach great depths (down to about 1000 m). In Alboran and Balearic Seas, the species has been recorded at a depth range of 90–400 m, generally on rocky substrata arising from detritic bottoms, where it achieves high densities over large areas (Aguilar et al. 2006; Grinyó et al. 2016). Nevertheless, *V. flagellum* is considered a near threatened species by IUCN Red List (García et al. 2015). Another whip-like gorgonian is the West African species *Eunicella filiformis*, only recorded in the Mediterranean from the Strait of Gibraltar (Carpine and Grasshoff 1975) and some areas of the Alboran Sea, such as Xauen Bank and Alboran Ridge (Templado et al. 2006; Gofas et al. 2014), and off the coast of Malaga and Granada (Templado et al. 1993; Ocaña et al. 2000), in the depth range of 60–300 m.

Small aggregations of the alcyonacean *Chironephthya mediterranea* (Fig. 10.10), recently described by López-González et al. (2015) in the Balearic Islands at a depth range of 115–200 m, have been recorded in some places accompanying *V. flagellum*. This alcyonacean was later found along the south Sardinian continental margin (Cau et al. 2017), in the Seco de los Olivos between 90 and 180 m (de la Torriente et al. 2018) and in the Cabliers Coral Mound between 300 and 400 m (Corbera et al. 2019).

The large Atlanto-Mediterranean gorgonian *Callogorgia verticillata* forms dense forests that can begin in the deep shelf and extend to a depth of more than 1000 m. This species generally dominates on gently sloping silted rocky bottoms in areas characterized by high sedimentation rates, often forming mixed gardens with other gorgonians and sponges. In the Alboran Sea, *C. verticillata* is very common in bottoms between 70 and 400 m (Templado et al. 2006; Gofas et al. 2014; de la Torriente et al. 2018).

Acanthogorgia hirsuta has been recorded in some areas of the northeast Atlantic and in some scattered western Mediterranean locations. This species is frequent in some areas of the Alboran Sea, such as the Alboran Ridge (Templado et al. 2006), El

Fig. 10.10 The recently described alcyonacean *Chironephthya mediterranea* has been found in the Seco de los Olivos in the depth range of 90–180 m [Ricardo Aguilar, Oceana]

Idrissi Bank and the so-called Melilla Mounds (Hebbeln et al. 2009), Seco de los Olivos (de la Torriente et al. 2018) and Cabliers Bank (Ocaña et al. 2017), usually on lightly silted rocky substrates of the shelf edge and upper slope between 150 and 400 m depth.

Paramuricea macrospina is an endemic Mediterranean gorgonian found mainly on rocky bottoms between 50 and 200 m depth and has recently been reported as one of the most abundant species in shelf and shelf edge environments, mainly in northwestern Mediterranean (Grinyó et al. 2016; Pica et al. 2018). In the Menorca Channel (western Mediterranean), *P. macrospina* is the dominant gorgonian species at 65–90 m depth, but it is also commonly found on the shelf-edge associated with other gorgonians at 110–160 m depth (Grinyó et al. 2016). Recently, the species has been found in the Seco de los Olivos around 120–130 m depth. This gorgonian has been included in the IUCN Red List of Threatened Species (Aguilar et al. 2015).

Some small-sized gorgonians are also widespread along the shelf edge and upper slope, being *Swiftia pallida*, *Bebryce mollis* and *Villogorgia bebrycoides* the most frequent species. They can create a sort of “underbrush” together with sponges living at the base of larger species, although they may form important monospecific thickets in the upper bathyal zone, usually between 200 and 700 m (Aguilar and Marín 2013). All these small gorgonians are well represented in several locations of the Alboran Sea (Templado et al. 2004; de la Torriente et al. 2014).

Isidella elongata, known as bamboo coral, is the main tree-like species on deep bathyal compact muds (it characterizes a facies together with the sea pen *Funiculina quadrangularis*) between about 500 and 1200 m depth (occasionally shallower) on relatively flat bottoms with a gentle slope (Cartes et al. 2013; Mastrototaro et al. 2017). The bamboo coral (with colonies up to 70 cm height) is almost exclusively restricted to the Mediterranean Sea, but it can extend to the adjacent Gulf of Cadiz and North Morocco. Maynou and Cartes (2012) pointed out that some fish and decapod crustaceans reach maximum abundance in bottoms where *I. elongata* reaches a high density, such as the deep-water shrimps *Aristeus antennatus* and *Plesionika martia*, both of high commercial interest. In fact, this deep-water coral is increasingly rare in the Mediterranean due to intense fishing pressure from trawlers targeting the red shrimp (*Aristeus antennatus*) at continental slope depths, so nowadays the species is considered Critically Endangered (Otero et al. 2017; Pierdomenico et al. 2018). In the Alboran Sea has been recorded in the Djibouti, Cabliers and Chella Banks, with a maximum density in the depth range of 400–500 m (de la Torriente et al. 2014).

All gorgonian species mentioned above are considered to be the most frequent in the Strait of Gibraltar and Alboran Sea, but there are also a number of other gorgonian species that have been recorded sporadically in this area, such as *Filigorgia guineensis* (Ocaña et al. 2000), *Paramuricea grayi* (Ocaña et al. 2009), *Dendrobrachia bonsai*, *Placogorgia coronata* (de la Torriente et al. 2014), *Placogorgia massiliensis*, *Spinimuricea atlantica* or *Nicella granifera* (Ocaña et al. 2017).

Regarding species conservation, three gorgonians (*Savalia savaglia*, *Callogorgia verticillata* and *Ellisella paraplexauroides*) have been recently included in Annex II of the Barcelona Convention.

10.3.3 Red Coral

The emblematic Mediterranean red coral *Corallium rubrum* belongs to the same group as gorgonians (order Alcyonacea, formerly Gorgonacea), but unlike the gorgonians (suborder Holaxonia), which have a flexible skeleton of a corneous nature, in *C. rubrum* (suborder Scleraxonia), the skeleton is hard calcified. It is a typical Mediterranean species widely distributed throughout the basin and into the neighbouring Atlantic Ocean from Portugal to Moroccan coasts (Boavida et al. 2016), and there are some scattered records in Canary Islands and Cape Verde Islands (Brito and Ocaña 2004).

The red coral is a sciaphilous long-lived species (a colony can live for more than 100 years) with low growth and reproductive rates and a very restricted dispersion ability (Cau et al. 2013). It inhabits a wide depth range from shallow-water caves in the infralittoral zone to depths greater than 1000 m in the bathyal zone (Rossi et al. 2008; Costantini et al. 2010; Taviani et al. 2010; Knittweis et al. 2016) although more commonly at 30–200 m. Although it may form single-species forests on rocky bottoms or be the predominant species on escarpments and in caves, it has also been found as part of mixed forests associated with large gorgonians as an important component of Mediterranean "coralligenous" assemblages. Furthermore, in the deepest bathymetric levels, it may appear associated with the white coral communities (Freiwald et al. 2009; Taviani et al. 2010). In shallow waters (between about 15 and 70 m), *C. rubrum* colonies (most of them less than 5 cm tall) grow in caves, crevices, overhangs and other protected interstices in crowded patches. In deeper waters, between about 70 and 130 m, coral colonies tend to be larger and more dispersed and typically settle on open surfaces. Below 130 m, colonies tend to be even larger and less dense.

In the Alboran Sea, *Corallium rubrum* is a typical component of the deeper part of the circalittoral rocky bottoms, and it is widespread in seamounts and rocky outcrops, where reaches its maximum densities below 100 m depth. In the Alboran Ridge, the red coral has been found mainly between 60 and 300 m (Templado et al. 2006; Gofas et al. 2014), and in the Seco de los Olivos, it has been found below 100 m (de la Torriente et al. 2014). In this area, shallow populations (15–50 m) of the red coral are only known in the Strait of Gibraltar (López-González 1993; Ocaña et al. 2009), while the presence of this species has not been detected in the Chafarinas Islands.

Because of their high economic value, the precious red coral has been heavily exploited in the Mediterranean Sea since ancient times. Its long history of intensive commercial harvesting has resulted in a well-documented decline of its stocks throughout the Mediterranean Sea, becoming especially apparent during the last decades with clear evidence of overexploitation (Santangelo et al. 2010; Tsounis et al. 2010). Due to this, several Mediterranean countries have developed national legislation to regulate red coral fishing in their territorial waters or adopted the regulations by the General Fisheries Commission for the Mediterranean (GFCM). According to these recommendations, the populations (down to 50 m depth) should be fully protected from exploitation, allowing their extremely slow recovery, and a minimum harvest colony size (7 mm of colony basal diameter) corresponding to an age of 30–35 years (Priori et al. 2013) should be established.

Regarding the Alboran Sea, the discovery in the mid-1980s of rich red coral banks led to their uncontrolled harvesting and to a consequent rapid depletion by fishermen from Sicily. Red coral was decimated by the usage of the so-called "Italian bar", a device formed by a heavy cross and tangle nets dragged over the bottom (Santangelo et al. 2010). This prompted the Instituto Español de Oceanografía to target cruises around the Alboran Island and Seco de los Olivos for evaluation of the resource and the impact on it. The results of these researches were gathered in a monographic volume of the Boletín Español de Oceanografia (1986) dedicated to different topics on the red coral. In 1984, the Spanish government authorized four fishing boats from Almería to extract coral on the Alboran Ridge using an "Italian bar" modified under the control of researchers from IEO. This type of fishing proved to be equally harmful to the environment and was banned in 1986. Since this date, and for some years, the extraction of coral by divers was allowed down to 100 m. On the other hand, at that time, the French-made submarine Nerée 201 was authorized to collect coral. Finally, the fishing of red coral was totally forbidden in this area. Exploitation of new areas is believed to occur in the short term off Morocco and Algeria (Cau et al. 2013).

In the Mediterranean, the protection of the red coral is strategic and should be more strictly protected not only by regional and national laws but also by international conventions. Recently, *Corallium rubrum* has been included in the IUCN Red List as an "Endangered" species (Garrabou et al. 2015; Otero et al. 2017), and it is also listed in Appendix III (protected fauna species) of Bern Convention. Nonetheless, it is still only included in Annex III (species whose exploitation is regulated) of Barcelona Convention and in Appendix V (species whose exploitation may be subject to management measures) of the EU Habitats Directive. Proposals for the inclusion of *Corallium rubrum* in the CITES Appendix II (species not necessarily threatened with extinction but that may become so unless trade is closely controlled) were started in 1987. Successive proposals in 2007 and 2010 for including in that Appendix all the *Corallium* species and the whole family Coralliidae were rejected by CITES Parties, after the FAO Expert Advisory Panel concluded that the available evidence did not support such proposals (Tsounis et al. 2010; Cannas et al. 2019). Up to now, all these efforts have resulted in only four species of *Corallium* currently listed under Appendix III (that regulates trade in the included species and needs the cooperation of other countries to prevent unsustainable or illegal exploitation) by China (CITES 2019) and adaptive management plans for red coral fisheries in the Mediterranean (Bruckner 2016). Apparently, Coralliidae in general and *Corallium rubrum* in particular remain excluded from CITES because the currently available data are still insufficient to quantify the decline of populations (Bruckner 2009; Santangelo and Bramanti 2010; Santangelo et al. 2010; Cannas et al. 2019). However, one may also wonder if this is really justified by insufficient knowledge (and the non-application of the precautionary principle in this case) to manage a resource which is just as unnecessary for human well-being as black corals, hawksbill turtle shells or sperm whale ivory, or it if is influenced by the red coral industry lobby.

10.3.4 Black Corals

Antipatharians, commonly known as black corals, have been recognized in the last decade as important components of Mediterranean deep coral gardens (Bo et al. 2009) and are frequently found associated to deep gorgonian assemblages, where quite often they are the dominant species, mainly on the deeper rocky shoals located on the upper continental slope (Bo et al. 2014, 2015). Black corals are extremely long-lived and slow-growing organisms; therefore, the presence of large colonies is an indicative of well-preserved environments (Bo et al. 2015).

Four species are the primary components of the Mediterranean antipatharian fauna: *Antipathes dichotoma*, *Parantipathes larix*, *Leiopathes glaberrima* and *Antipathella subpinnata* (Bo et al. 2018). A fifth species typical of the Macaronesian islands, *Antipathella wollastoni*, has been reported in the Gibraltar Strait (Ocaña

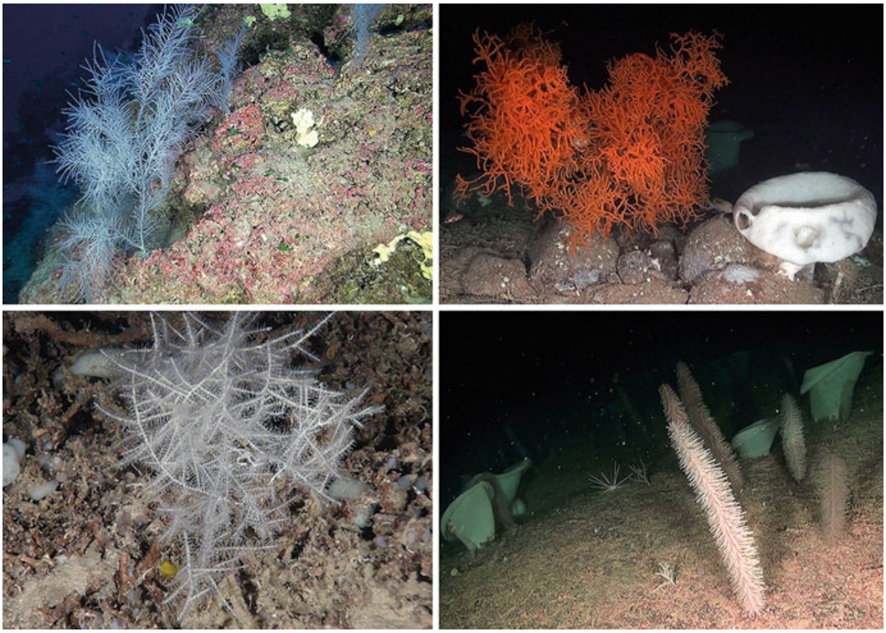

Fig. 10.11 Four black corals found in the Alboran Sea. From left to right and from top to bottom, *Antipathella subpinnata* (Seco de los Olivos, about 100 m depth), *Leiopathes glaberrima* (Seco de los Olivos, 290 m depth, next to the sponge *Asconema setubalense*), *Phanopathes rigida* (Cabliers Coral Mound, around 400 m depth) and *Parantipathes larix* (Cabliers Coral Mound, 470 m depth, next to *A. setubalense*) [Ricardo Aguilar, Oceana]

et al. 2006b) and is likely to be present in the Alboran Sea. Furthermore, the West Atlantic species *Phanopathes rigida* (Fig. 10.11) has been recently observed in the Cabliers Coral Mound, where it is abundant and dominates in its northern sector mainly in the depth range of 300–440 m (Corbera et al. 2019).

Antipatharians were rarely found shallower than 50 m, while the majority occurs in the depth range between 100 and 300 m, only on rocky slopes and isolated shoals. The large (up to 1.5 m tall), white, branched *Antipathella subpinnata* (Fig. 10.11) is a common component of the lower fringe of the circalittoral (60–150 m) and is the most widespread species with an Atlanto-Mediterranean distribution (Bo et al. 2008). It is able to form dense meadows starting at 60 m, sometimes mixed with *Paramuricea clavata*, and has been occasionally recorded down to 500 m associated with white coral mounds, but records of *A. subpinnata* below 100 m are sporadic. In the Alboran Sea, this species has been observed on steep rocky bottoms (Gofas et al. 2014) and seamount summits (de la Torriente et al. 2014). In Chafarinas Islands, *A. subpinnata* has been detected at a very shallow depth (26–32 m) compared with what is usual in all the distribution area of this species (Sánchez-Tocino et al. 2014; Sánchez-Tocino pers. obs.).

The large arborescent *Leiopathes glaberrima* (Fig. 10.11) forms bright orange colonies up to 2 m tall. It is widespread, known from the Pacific and the northeastern Atlantic Oceans (Macaronesian Archipelago and Bay of Biscay) and in the Mediterranean Sea, mainly in its central part (Massi et al. 2018). This species occurs in a broad bathymetric range (known depth range between 70 and 790 m) on rocky shoals, moderately silted, under low to moderate currents. It has proved to be an optimal indicator of the stability of the deep marine environments found at such depths (Deidun et al. 2015), being one of the most long-lived organisms known, reaching an age of up to 4000 years (Roark et al. 2006). In the Alboran Sea has been recorded in the Cabliers (Pardo et al. 2011; Corbera et al. 2019) and Seco de los Olivos Banks (de la Torriente et al. 2018) between 200 and 400 m depth.

Antipathes dichotoma is an Atlanto-Mediterranean species characterized by tall arborescent colonies with loose, long, flexible branches and large polyps. This species has a wide bathymetric distribution range and typically occurs on isolated rocky habitats surrounded by detritic or muddy seafloors under moderate currents and high sedimentation rates (Bo et al. 2011). In the Alboran Sea, there are records from the Cabliers and Algarrobo Banks (350–400 m) (Pardo et al. 2011; Corbera et al. 2019) and Seco de los Olivos (70–250 m) (de la Torriente et al. 2018).

Parantipathes larix (Fig. 10.11) is a monopodial or sparsely branched black coral up to 2 m tall showing a characteristic bottle-brush pinnulation pattern. This Atlanto-Mediterranean species lives on rocky bottoms both along the continental shelf and in deeper waters, usually between 200 and 700 m in isolate banks, often very sparsely distributed (Angiolillo and Canese 2018). Exceptional forests dominated by dense monospecific populations of *P. larix* were recorded only off the Island of Montecristo (Tuscan Archipelago, Tyrrhenian Sea) (Bo et al. 2014). In the Alboran Sea, it has been recorded in the Cabliers Bank at about 400 m depth (Pardo et al. 2011; Corbera et al. 2019) and in the Seco de los Olivos between 200 and 500 m (de la Torriente et al. 2018).

Unlike what occurs with red and pink corals (Coralliidae), all species of black corals (Antipatharia) are already included in CITES Appendix II (CITES 2019), and five Mediterranean species are listed in Annex II of Barcelona Convention.

10.3.5 Sea Pens

The anthozoans of the order Pennatulacea are commonly known as sea pens and are typical representatives of soft bottoms, where they bury part of the colony in the substrate. About a dozen species are known to occur in the Mediterranean Sea. Pennatulaceans, together with the alcyonaceans of the family Isididae (commonly known as bamboo corals), are the main components of forest-like habitats on soft bottoms. These habitats are considered key sites of aggregation for biodiversity and sustain a high abundance of species of commercial interest. The sea pen fields have been listed as vulnerable marine ecosystems worldwide (Otero et al. 2017). Despite their ecological value, pennatulacean habitats have been overlooked compared with cold-water coral ecosystems (order Scleractinia), or those characterized by sea fans or soft corals (order Alcyonacea) (Ruiz-Pico et al. 2017).

Veretillum cynomorium is a very common Atlanto-Mediterranean species found on muddy, sandy and detritic beds in shallow bottoms, but it can extend to greater depths throughout the continental shelf. Another Atlanto-Mediterranean species is *Cavernularia pusilla*, recorded from the Bay of Biscay to Senegal and sparsely distributed throughout the Mediterranean. It inhabits coarse detritic bottoms and "maërl" beds, reaching highest densities between 30 and 60 m depth and decreasing in density below this range (Altuna et al. 2006). López-González (1993) recorded this species in the Strait of Gibraltar between 14 (shallower known record) and 74 m, with abundances of 4–5 ind. m^{-2}, and it has been also found in the Alboran Sea in the Sabinar Bank (also named "Avenzoar Bank") (Pardo et al. 2011) and near the Alboran Island (IUCN 2012).

Virgularia mirabilis have also a wide bathymetric and geographical distribution. It inhabits muddy-sandy bottoms, from the infralittoral to the bathyal zones, sometimes also mixing with other pennatulaceans or forming monospecific communities (Aguilar et al. 2017).

The sea pens of the genera *Pteroeides* and *Pennatula* are widely distributed and can form mixed communities on the shelf edges and the beginning of the slope. *Pennatula rubra* and *Pteroeides griseum* are more abundant from 30 to 160 m on sandy-muddy bottoms, reaching densities of ≤ 10 specimens m^{-2} (Porporato et al. 2014), while *Pennatula aculeata* and especially *Pennatula phosphorea* prefer deeper, muddy bottoms. All these species are widely distributed throughout the whole Mediterranean Sea, except *P. aculeata*, a North Atlantic species with only a few records in the western Mediterranean, including the Granada coast in the Alboran Sea (Ocaña et al. 2000).

Funiculina quadrangularis has a worldwide range, being common throughout the North Atlantic and the Mediterranean Sea. It inhabits both sandy and muddy bottoms over a wide depth range, although it is more common on compact bathyal muds, where it can reach high densities and may appear in mixed communities with other pennatulaceans, bamboo corals or other soft-bottom species (de la Torriente et al. 2014). These assemblages provide an essential habitat for some commercial crustaceans, such as *Parapenaeus longirostris* and *Nephrops norvegicus* (Mastrototaro et al. 2017).

Kophobelemnon stelliferum (Fig. 10.12) normally lives on muddy bottoms below 400 metres, where it can occur in large aggregations, and also appears mixed with *Isidella elongata* or, in some cases, with *Funiculina quadrangularis* and *Pennatula phosphorea* (Mastrototaro et al. 2013). It has been found on some seamounts of the Alboran Sea, such as Avempace, Cabliers or Seco de los Olivos Banks (Pardo et al. 2011; de la Torriente et al. 2018).

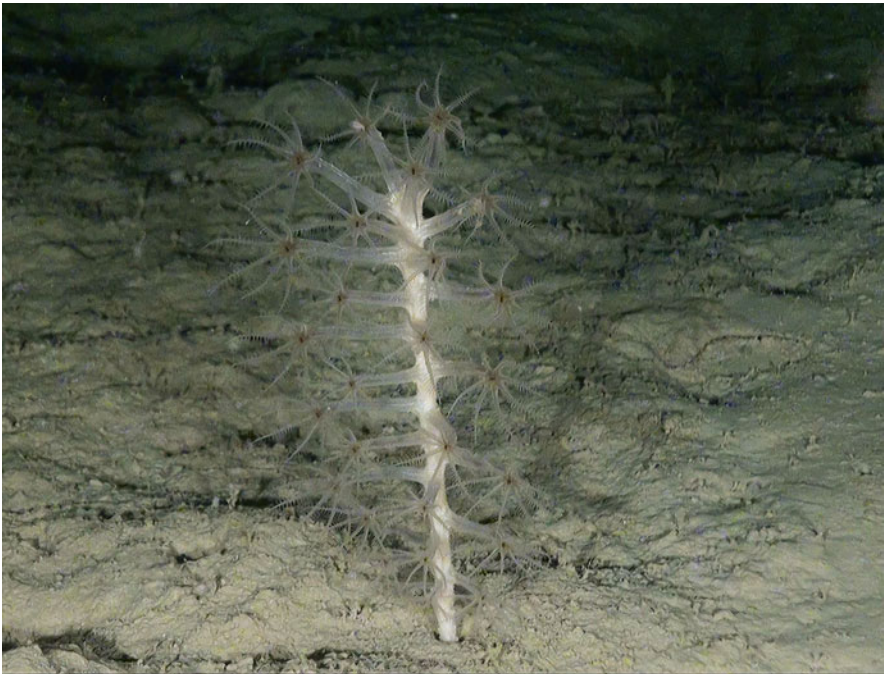

Fig. 10.12 The sea pen *Kophobelemnon stelliferum* on a muddy bottom of the Cabliers Bank (about 450 m depth) [Ricardo Aguilar, Oceana]

10.3.6 Deep Reef-Building Corals

Biogenic reefs are any durable hard structure built by living organisms that rises from the bottom, can increase in volume or thickness through the progressive stratification of successive generations of organisms and generate special habitats. Deep reefs in the Alboran Sea are mainly formed by stony corals or deep-sea oysters.

The so-called white coral or cold-water coral community (CWC) is dominated in the Mediterranean Sea by the azooxanthellate colonial species *Desmophyllum pertusum* (formerly known as *Lophelia pertusa*) and *Madrepora oculata* and the solitary coral *Desmophyllum dianthus*. A recent study (Adamo et al. 2016) shows a surprising genetic identity between *Desmophyllum pertusum* and *D. dianthus* and suggests the potential conspecificity of both species. This consequently leads, in any case, to ascribe both taxa under the generic name *Desmophyllum* (which has priority over *Lophelia* by date of publication). These corals are usually found below the photic zone at upper bathyal depths between 180 and 1000 m, where they can build large three-dimensional structures (Freiwald et al. 2009).

Until recent times, these deep-water corals were mostly recorded in the Mediterranean as Pleistocene fossils, with just a few records of living specimens, and it has been suggested that the postglacial conditions could cause their sharp decline

(Zibrowius 1980; Taviani et al. 2005). However, the advent of the new deep-sea exploration technologies has highlighted the richness of the Mediterranean deep-sea environments (Angiolillo and Canese 2018). As a result, large and highly structured CWC communities characterized by a significant coral growth and colonies density have been found in specific areas, such as the northern Ionian Sea, the Southwestern Adriatic Sea, the Strait of Sicily, the Sardinia Channel, the most westerly part of the Gulf of Lions submarine canyon system and the Alboran Sea (Orejas et al. 2009; Chimienti et al. 2018).

Radiocarbon ages of these reef-forming coral species revealed that they proliferated in the Alboran Sea during the last glacial-interglacial transition and the Early Holocene (ca.13–10 ka BP) with pronounced growth periods (Fink et al. 2013). After a subsequent period of coral absence, cold-water corals recolonized this basin during the Mid-Holocene (about 5.4 ka BP). According to Fink et al. (2013), that period of sustained cold-water coral growth in this area was closely linked to phases of high marine productivity. In more recent times, changes in hydrodynamic conditions have produced a shift from a CWC community dominated by *Desmophyllum pertusum* to other dominated by *Madrepora oculata* and dendrophylliid corals (Stalder et al. 2015). These authors pointed that their data suggest that *M. oculata*, and in particular dendrophylliids, show a higher tolerance to environmental changes than *D. pertusum*, whose upper limit of thermal tolerance is near 15 °C (Gori et al. 2014).

According to Pardo et al. (2011), nowadays white cold-water corals generate three distinct habitats widespread along the Alboran Sea: reefs and colonies of live corals, dead coral reefs and extensive bottoms covered with coral debris (rubbles), allowing the existence and settlement of different species and biocenosis. Dead corals predominate, while small reef patches of living colonies appear scattered in seamounts and escarpments, mainly observed from ca. 200–600 m depth, with the dominance of *Madrepora oculata* on most of the locations. Specifically, up to date, living CWC have been observed in the following sites of the Alboran Sea:

- Avempace Bank: isolated, living colonies of *M. oculata* at 350–360 m depth (Pardo et al. 2011).
- El Idrissi Bank: isolated colonies of *M. oculata* at about 400 m depth (Hebbeln et al. 2009).
- Alboran Ridge: living colonies of *M. oculata* deeper than 400 m (Templado et al. 2006).
- Seco de los Olivos: living colonies of *Desmophyllum pertusum*, *M. oculata* and specimens of *D. dianthus* below 220 m depth (Pardo et al. 2011). The highest densities were found between 300 and 500 m on rocky walls with steep slopes, but they extend down to 650 m (de la Torriente et al. 2018). These cold-water corals appeared intermixed with diverse communities where occur other scleractinians as *Dendrophyllia cornigera*, *Caryophyllia calveri* or the Atlantic species *Anomocora fecunda*.
- Catifas Bank (W Cabliers): living colonies of *M. oculata* and *D. pertusum* at about 360–460 m in depth (Pardo et al. 2011).

- Cabliers Bank: abundant dead reefs with living colonies up to 1 m tall at about 320 m depth (Pardo et al. 2011). These authors highlighted a reef south of the bank that extends over an area of about 10 ha. Likewise Lo Iacono et al. (2014a) and Corbera et al. (2019) pointed out an extremely dense and constant reef with large colonies of *D. pertusum* and *M. oculata* over a considerable extension about 300 m depth in its northern sector.
- Banc de Provençaux: individual living colonies of *M. oculata* and *D. pertusum* growing on the dead coral framework in the southerly ridges of the bank at 310 m depth (Hebbeln et al. 2009).
- West Melilla Mounds Field: frequent *D. pertusum* and *M. oculata*, below 350 m, with the latter species dominating the shallower areas (Lo Iacono et al. 2014a, b).
- Strait of Gibraltar: remarkable quantities of living *Desmophyllum pertusum* and to a lesser extent *Madrepora oculata* associated with large dead coral fragments at the depth range of 150–330 m (Álvarez-Pérez et al. 2005).

Other stony corals that form important marine habitats are the so-called "yellow tree corals" of the genus *Dendrophyllia*, represented in the Mediterranean by two species: *D. cornigera* and *D. ramea* (Fig. 10.13). Both are also present in the northeastern Atlantic and form large branched colonies but differ significantly in morphology, geographical distribution and ecology (Salomidi et al. 2010). *Dendrophyllia cornigera* extends further north than *D. ramea*, and its northern limit is the Celtic Sea, whereas *D. ramea* does not range further north than the Iberian Peninsula. Both species are common along the Atlantic coast of Morocco and occur further south along the African coast. A third smaller species of this genus, *D. laboreli*, is distributed along the Atlantic coasts of northwest Africa, reaching the Strait of Gibraltar (López-González et al. 2010), and isolated colonies have been found at Cabo Negro, on the Moroccan coast of the Alboran Sea (Ocaña et al. 2011).

The tree-like colonies of *D. ramea* reach up to 1 m high and 20 cm in diameter at the trunk base. In the Mediterranean, it was considered to be limited to the southwestern part of the Mediterranean Sea, but recently it has been found in the southern Croatian islands, Adriatic Sea (Kružić et al. 2002), from Greek waters in the southwest Korinthiakos Gulf (Salomidi et al. 2010) and off Cyprus in the Levantine Sea (Orejas et al. 2017). This coral is distributed in circalittoral rocky bottoms and can be observed within scuba diving depths, as shallow as 30–40 m in the Strait of Gibraltar (Ocaña et al. 2009) and in some localities of the Alboran Sea, such as the coast of Granada (Ocaña et al. 2000) or Chafarinas Islands (Maldonado et al. 2011). In the Alboran Ridge, Templado et al. (2006) and Gofas et al. (2014) found this coral deeper, between 90 and 115 m. Likewise, huge populations of *D. ramea* were recently discovered in the northern coast of Sicily between 80 and 120 m depth (Aguilar et al. 2017), around 130 depth off Cyprus (Orejas et al. 2017) and in submarine canyons off Lebanon (Ricardo Aguilar pers. obs.). This coral is common in the Canary Islands, forming banks between 60 and 150 m (Brito and Ocaña 2004).

The tree-like colonies of *Dendrophyllia cornigera* reach up to 60 cm high (normally it does not exceed 30–40 cm) and 10 cm in diameter at the trunk base (Brito and Ocaña 2004). This coral typically occurs deeper than *D. ramea*, at deep

Fig. 10.13 Colonies of *Dendrophyllia ramea* (above, Punta de la Mona, Granada, 35 m depth) and *Dendrophyllia cornigera* (below, Catifas Bank, 390 m depth) [Luis Sánchez Tocino and Ricardo Aguilar, Oceana, respectively]

circalittoral and bathyal rocky bottoms, mainly in the slope habitats where it may co-occur with *Madrepora oculata* and *Desmophyllum pertusum.* In the Bay of Biscay, *D. cornigera* can be found shallower and locally forms dense monospecific aggregations between 50 and 620 m (Reveillaud et al. 2008; Sánchez et al. 2009). Around the Canary Islands and nearby seamounts, it is the dominant coral between 200 and 600 m depth (Brito and Ocaña 2004; Almón et al. 2014a, b). In the Alboran Sea, *D. cornigera* is widespread on different seamounts mainly in the 150–600 m bathymetric range (Templado et al. 2006; Hebbeln et al. 2009; Pardo et al. 2011), but places with dense populations are rare.

The hydrocorals belonging to the family Stylasteridae are important components of deep coral communities, and they are worldwide distributed from shallow to deep waters. *Errina aspera* is the only stylasterid known from the Mediterranean, and its current occurrence has been confirmed only in the Straits of Messina and Gibraltar and the Atlantic coast of Morocco (Zibrowius and Cairns 1992). The colonies of this species reach up to 20 cm, generally show a bidimensional, fan-shaped morphology (more rarely as bush-like colonies) and growth on rocky bottoms exposed to strong currents (Salvati et al. 2010).

According to Salvati et al. (2010), the abundant population of *E. aspera* in the Messina Strait is located between 110 and 230 m depth. In the Gibraltar Strait, this hydrocoral has been found in a wide bathymetric range (61–443 m), but it is particularly abundant between 150 and 330 m (Álvarez-Pérez et al. 2005). *Errina aspera* has been frequently recorded in association with the giant barnacle *Pachylasma giganteum*, and the gastropod *Pedicularia sicula* is always associated with this hydrocoral (Zibrowius and Cairns 1992).

The scleractinians *Desmophyllum pertusum* and *Madrepora oculata* and the stylasterid *Errina aspera* are currently included in Annex II of the Barcelona Convention. The latter species is also included in Appendix II of Bern Convention.

10.3.7 Deep-Sea Oysters

Two species of the genus *Neopycnodonte* (family Gryphaeidae), *N. cochlear* (Fig. 10.14) and *N. zibrowii*, form dense aggregations along the European shelf and slope.

Neopycnodonte cochlear is distributed worldwide, both in ancient and modern environments (Van Rooij et al. 2010). In the Mediterranean, this oyster characterizes some areas of the continental shelf in rock outcrops and deep bioclastic gravels. Conglomerates of *N. cochlear* are widespread throughout the continental shelf of the Alboran Sea and in the Alboran Ridge between 50–300 m depth (Templado et al. 1993, 2006; Gofas et al. 2011).

The giant deep-sea oyster *Neopycnodonte zibrowii* was recently described from deep water in the Azores and Bay of Biscay between 420 and 450 m depth (Wisshak et al. 2009), but its geographical range extends from the Celtic Sea to Anna Ridge off Angola (Beuck et al. 2016). This oyster was found thriving concealed under

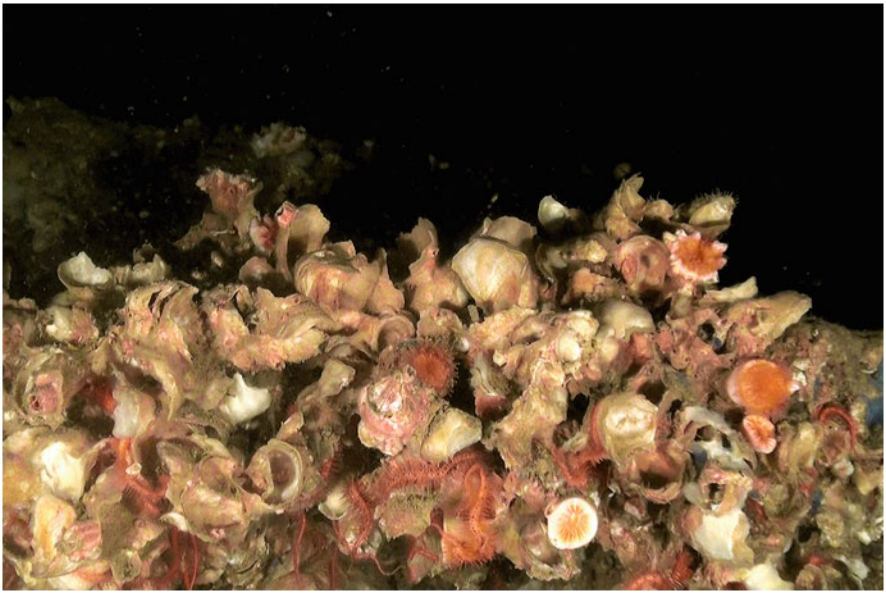

Fig. 10.14 Conglomerates of *Neopycnodonte cochlear* are widespread throughout the continental shelf of the Alboran Sea (off Punta de Calaburras, Malaga, 130 m depth) [Ricardo Aguilar, Oceana]

overhangs in high densities. Van Rooij et al. (2010) observed living *N. zibrowii* in the Bay of Biscay in depths from 540 to 846 m, colonizing overhanging banks or escarpments protruding from steep canyon flanks. Further, Johnson et al. (2013) described a biotope of vertical surfaces and overhangs at depths between 633 and 762 m covered by the bivalves *Acesta excavata* and *N. zibrowii* in one of the major submarine canyons along the Celtic margin. Likewise, Gofas et al. (2010) reported the occurrence of living *Neopycnodonte zibrowii* between 680 and 730 m, on the slope of the Hespérides Mud Volcano Complex located in the central part of the Gulf of Cadiz.

This “living fossil” oyster has an extensive lifespan that may exceed 500 years (placing it among the longest-lived molluscs known to date) and grows to more than fourfold the size of large *N. cochlear*, up to 30 cm (Wisshak et al. 2009; Beuck et al. 2016). Its occurrence, either living or subfossil, has been noted in scattered locations in the eastern Atlantic (living) and the Mediterranean (mainly as subfossil) (Taviani et al. 2007; Gofas et al. 2010). By that time, Hebbeln et al. (2009) also reported the presence of living specimens of *N. zibrowii* in steep cliffs of El Idrissi Bank, southeast of the Djibouti complex (Alboran Sea) at 490 m among abundant fossil oysters. Further, de la Torriente et al. (2014, 2018) found dense clusters of this species at the base of rocky walls down to 462 m depth in the Seco de los Olivos. Zibrowius (pers. comm.) observed dense aggregates on the south wall of Alboran platform, on video footages by submersible “Cyana” taken in 1993 and never released.

10.4 The Invertebrates of the Water Column

10.4.1 Planktonic Invertebrates

The peculiar and contrasting hydrological characteristics of the Alboran Sea are reflected in the structure and dynamics of plankton communities, which have been the object of many researches and publications. Several articles concern the specific composition and population assemblages of zooplankton in the Alboran Sea (e.g. Vives et al. 1975; Rodríguez 1983; Greze et al. 1985; Champalbert 1996; Youssara and Gaudy 2001; Andersen et al. 2004; Siokou-Frangou et al. 2010). In fact, nearly 30 years ago, a literature review and field guide of zooplankton of this area was already published by the Woods Hole Oceanographic Institution (Madin 1991).

While microzooplankton is mainly composed by protists (flagellates, dinoflagellates, ciliates, radiolarians, foraminiferans, among others), the invertebrates are the main component of mesozooplankton (size range of 0.2–2 mm) and macroplankton (organisms visible to the naked eye). Epipelagic mesozooplankton is highly diversified in terms of taxonomic composition. In addition to the strictly planktonic groups (holozooplankton), the pelagic larval phases of many invertebrates which are benthic in their adult phase are also incorporated to the plankton (merozooplankton). As elsewhere, copepods represent the largest group in the Alboran Sea both in terms of abundance and biomass (about 60% of the biomass), followed by cladocerans (near 20%) and larvae of various groups (about 12%, mainly crustaceans and molluscs).

More than 250 species of copepods have been recorded in the Alboran Sea. A few small-sized and species-rich genera of calanoids (*Clausocalanus*, *Calocalanus*, *Pleuromamma* and *Temora*, together with *Ctenocalanus vanus*) and cyclopoids (*Oithona*, *Oncaea*) account for the bulk of copepod abundance and biomass in epipelagic layers (Seguin et al. 1994; Youssara and Gaudy 2001; Siokou-Frangou et al. 2010). According to Rodríguez (1983), the most abundant copepods reported in spring in the upper layer were *Paracalanus parvus*, *Clausocalanus arcuicornis*, *Centropages chierchiae*, *Acartia clausi*, *Temora stylifera*, *Oithona similis*, *O. nana* and *Oncaea* spp. Some species seem particularly linked to Atlantic waters, such as *Pleuromamma borealis*, *Subeucalanus crassus*, *Eucalanus elongatus* or *Triconia dentipes* (Youssara and Gaudy 2001). Otherwise, two copepod species were described from the Alboran Sea by Shmeleva (1979): *Oncaea alboranica* and *Calocalanus alboranus.*

In the neuston layer, pontellids often constitute the major diurnal biomass. Among the most abundant species, *Anomalocera patersoni*, *Pontella lobiancoi*, *P. atlantica* and *Pontellopsis regalis* have an Atlantic origin and are abundant in oceanic waters, whereas *Pontella mediterranea* and *Labidocera wollastoni* are rather neritic species (Champalbert 1996).

Across the Almería-Oran Front area, three species of *Pleuromamma* were found in large numbers: *P. borealis*, the most abundant, followed by *P. abdominalis* and to a lower extent by *P. gracilis* (Andersen et al. 2004). Other abundant copepods recorded by these authors around this front are *Subeucalanus monachus*, *Eucalanus hyalinus*, *Clausocalanus furcatus* and *Centropages typicus.*

Cladocerans, which exhibit a seasonal and/or aggregative distribution, are represented by few species, but they can be very abundant in coastal waters, such as *Penilia avirostris*, *Pseudevadne tergestina*, *Evadne spinifera* and *E. nordmanni* (Rodríguez 1983). On the other hand, ostracods, which are not numerous in the mesozooplankton communities at temperate latitudes, are more abundant in deep waters than in the epipelagic zone (Siokou-Frangou et al. 2010).

The macroplankton of the Alboran Sea consists essentially of euphausiids, chaetognaths and gelatinous zooplankton. According to Madin (1991), the dominant euphausiid species occurring were *Euphausia krohnii*, *Nematoscelis megalops*, *Stylocheiron abbreviatum* and *S. suhmi*, with maximum abundances in summer.

Chaetognaths are active predators and an important component of zooplankton. They are well represented in the Alboran Sea by more than a dozen species (Camiñas 1985) that become very abundant in areas of higher biomass, such as in the vicinity of the Almería-Oran Front. According to this author, the most abundant chaetognaths in the area are *Parasagitta friderici*, *Serratosagitta tasmanica*, *Pterosagitta draco*, *Flacisagitta enflata* and *Decipisagitta decipiens.*

Three main phyla, the carnivorous Cnidaria and Ctenophora and the filter-feeding Tunicata, dominate the gelatinous macroplankton (Fig. 10.15). These holoplanktonic organisms exhibit important seasonal and interannual variations, both in biomass and specific composition. As evidence of the species richness of gelatinous plankton in the Alboran Sea, 58 species of planktonic Cnidaria and Ctenophora were observed during a cruise in April 1991 off the North Moroccan coast: 12 hydromedusae, 18 siphonophores, 6 scyphomedusae and 22 ctenophores (Mills et al. 1996). The most abundant species in surface waters were *Pandea conica* and *Solmaris leucostyla* (hydromedusae); *Nanomia bijuga*, *Lensia conoidea* and *Abylopsis tetragona* (siphonophores); and *Haeckelia beehleri*, *Pleurobrachia rhodopis*, *Bolinopsis vitrea*, *Ocyropsis maculata* and *Beroe ovata* (ctenophores). The mesopelagic *Solmissus albescens* (Narcomedusae) was the most numerous jellyfish in a wide bathymetric range capable of migrating to the surface at night. A few species, such as the coronate scyphozoans *Periphylla periphylla* and *Paraphyllina ransoni* and the siphonophore *Rhizophysa filiformis*, seemed to occur mainly near the bottom (Mills et al. 1996). These authors have also noted a very rich mesopelagic ctenophore fauna. Among them, *Bathocyroe fosteri* and *Thalassocalyce inconstans*, originally known from the Atlantic, have been reported in this westernmost area of the Mediterranean (Madin 1991).

The ubiquitous and troublesome scyphozoan *Pelagia noctiluca* (Fig. 10.15), which appears to be blooming with increased frequency (Brotz and Pauly 2012), deserves special mention. This holoplanktonic jellyfish inhabits oceanic as well as coastal areas, being responsible for the majority of the stings suffered by bathers (Canepa et al. 2014). Blooms of this medusa have been persistent in recent years in the Andalusian coast, resulting in a large number of stings and in the temporary closure of many beaches.

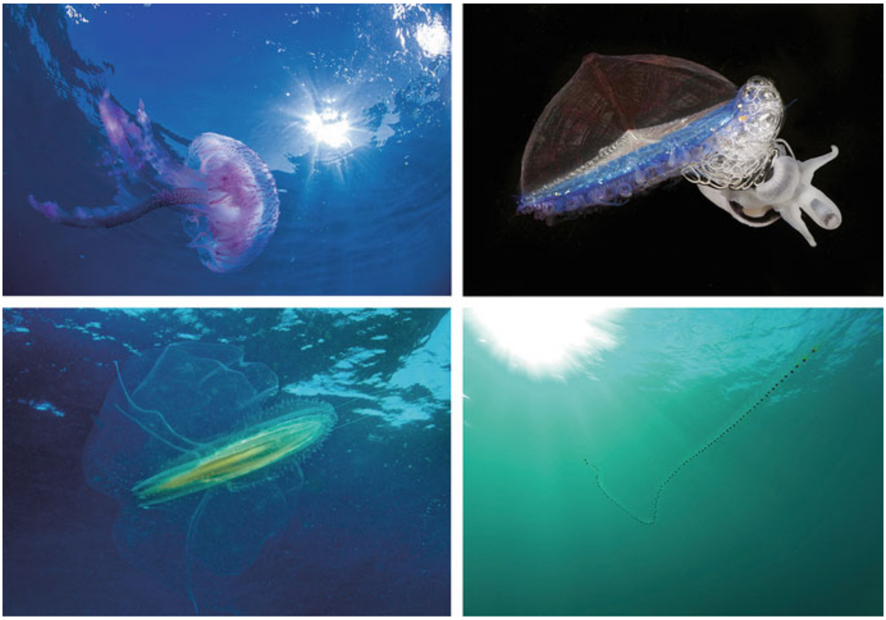

Fig. 10.15 Some common representatives of gelatinous macroplankton in the Alboran Sea. From left to right and from top to bottom, the scyphozoan *Pelagia noctiluca* (Punta de la Mona, Granada, 3 m depth), the siphonophoran *Velella velella* with the gastropod *Janthina pallida* attached (Playazo de Rodalquilar, Almería, 0 m depth), the ctenophoran *Leucothea multicornis* (Villaricos, Almería, 2 m depth) and a salp chain probably of *Thalia democratica* (Carboneras Island, Almería, 3 m depth) [Luis Sánchez Tocino, upper left, and Diego Moreno]

Pelagic filter-feeding tunicates are also an important component of gelatinous plankton and comprise four groups: appendicularians (class Appendicularia) and salps, pyrosomes and doliolids (class Thaliacea), all represented in the Alboran Sea. They often form large swarms after the upwelling of cool, nutrient-rich water promoting blooms of phytoplankton. The appendicularians are the predominant pelagic tunicates, mainly the genera *Oikopleura* during summer and *Fritillaria* during winter (Champalbert 1996). In turn, the species of salps, pyrosomes and doliolids that occur sporadically in swarms are mostly *Thalia democratica*, *Pyrosoma atlanticum* and *Doliolium nationalis*.

10.4.2 Nektonic Invertebrates

Most nektonic animals are vertebrates, mainly fish, whereas invertebrates are only represented by cephalopods (squids) and some crustaceans (larger euphausiids, shrimps, prawns and swimming crabs), many of them being commercially important marine species.

The cephalopods are the largest nektonic invertebrates. Some common species in the Alboran Sea are *Loligo vulgaris*, *L. forbesii*, *Alloteuthis media*, *Abralia verany*, *Illex coindetii*, *Todarodes sagittatus*, *Ommastrephes bartramii*, *Sthenoteuthis pteropus*, *Brachioteuthis riisei* and *Ancistroteuthis lichtensteinii* (Guerra 1992; Templado et al. 1993; González and Sánchez 2002; Quetglas et al. 2013). They are important predators and are also agents for the transfer of nutrients from the pelagic community to higher trophic levels.

Among the decapod crustaceans, a good number of caridean (suborder Dendrobranchiata) and penaoidean species (suborder Pleocyemata) form a characteristic trophic guild of macroplankton-epibenthic feeders that mainly dwell near the bottom (nektobentonic species) but have sharp diel vertical migrations into upper water layers during the night (Judkins 2014). These migrations behaviour have an important role in the transfer of matter and energy from the upper primary productive layers of the sea, where these species come up to feed during the night, down to the epibenthic community of the continental slope, where they dwell during the day (Simão et al. 2015).

The Alboran Sea is characterized by the dominance of caridean pandalid shrimps, which reach in this area the highest values of abundance and show a trend to have a shallower distribution compared with other areas (Carbonell and Abelló 1998; Fanelli and Cartes 2004). The most common Alboran pandalids are *Chlorotocus crassicornis*, *Plesionika acanthonotus*, *P. heterocarpus* and *P. martia.* Two very common shrimps of the suborder Pleocyemata are the pasiphaeids *Pasiphaea sivado* and *P. multidentata* (Simão et al. 2015). Both species also show a shallower bathymetric range in the westernmost region of the Algerian shore than in other sectors, linked to the occurrence of upwelling areas on the northwestern edges of the Alboran Sea.

The other important group of benthopelagic shrimps is that formed by species of Sergestoidea and Penaeoidea, also well represented in the Alboran Sea. The most common are the penaeoideans *Gennadas elegans* and *Funchalia villosa* and the sergestoideans *Robustosergia robusta*, *Sergia japonica*, *Allosergestes sargassi*, *Parasergestes vigilax* and *Eusergestes arcticus* (García Raso 1982; García Raso et al. 2018).

Among the swimming crabs, the portunid *Polybius henslowii* deserves special mention by its uncommon behaviour. It is a benthopelagic species distributed along the eastern Atlantic coasts from the British Islands to the Alboran Sea and southern Morocco. Usually of benthic habits, this crab moves periodically to surface waters, forming large pelagic swarms mainly composed of females, which excludes a reproductive migration and might be related to feeding. During this pelagic period, this species feeds on fish, squids or other crustaceans (Signa et al. 2008). Some of these surface swarms have been observed off the Moroccan coast near the Strait of Gibraltar from May to August (Ocaña et al. 2006a). These authors pointed out that the large concentrations of *P. henslowii* are the main source for the diet of the loggerhead turtles in this area and for a number of other species including gulls and pelagic and benthopelagic fishes.

10.5 Threatened Species

The protocol concerning Specially Protected Areas (SPA) and Biological Diversity in the Mediterranean (Barcelona Convention) established lists of endangered or threatened marine species (Annex II) and of species whose exploitation is regulated (Annex III) (Templado et al. 2004). Many of them were previously included in the Annexes of the Bern Convention. In addition, only a handful of marine invertebrates appear in other international conventions (Habitat Directive 92/43/CEE; CITES) (Ramos et al. 2001) or international Red Lists (IUCN) (Otero et al. 2017). The majority of the marine invertebrates included in these conventions and lists of the Mediterranean Sea are present in the Alboran Sea (66 species, see Table 10.1).

The SPA and Biodiversity Protocol was signed in 1995 by most of the Mediterranean countries and entered into force in 1999 in Spain and in 2009 in Morocco. The last Amendments to Annexes II and III entered into force in both countries in 2015. The initial list of Annex II was mainly composed of molluscs, with some sponges and a few cnidarians, crustaceans and echinoderms. That is why the modification of Annexes was proposed in 2013 during the SPA Focal Points meeting in order to improve the representativeness of deep-sea corals (Aguilar and Marín 2013). As a result, the last amendment of 2015 incorporated 11 cnidarians, among which there are several species of black corals; the gorgonians *Ellisella pareplexauroides*, *Callogorgia verticillata* and *Eunicella verrucosa*; and the scleractinians *Cladocora caespitosa*, *C. debilis*, *Madrepora oculata* and *Desmophyllum pertusum*. At the same time, the IUCN promoted a regional workshop on Mediterranean anthozoans Red List (September–October 2014), as a result of which new species of cnidarians were included in the IUCN Red List (Otero et al. 2017). Among the species not included in previous agreements stands out the bamboo coral *Isidella elongata*, listed as “critically endangered”. Further, the scleractinian corals *Desmophyllum dianthus* and *Dendrophyllia cornigera* were listed as “endangered”, and the gorgonian *Paramuricea clavata*, the coral *Dendrophyllia ramea* and the sea pens *Funiculina quadrangularis, Pennatula rubra*, *P. phosphorea* and *Pteroeides griseum* as “vulnerable”. Consequently, the cnidarians is the group with the highest number of protected or regulated species in the Alboran Sea, with 24 species (23 anthozoans and 1 hydrozoan), followed by molluscs with 20 species (14 gastropods and 6 bivalves), sponges (9 species), crustaceans (8 species) and echinoderms (5 species) (see Table 10.1).

Few of the threatened species live in the intertidal fringe, such as the gastropods *Patella ferruginea*, a critically endangered limpet with its best populations in the Alboran Sea, and the vermetid *Dendropoma lebeche*, which builds singular reefs in association with calcareous algae. Most of the protected species are subtidal and can live in different habitats and substrates, such as rocks or caves (as the coral *Astroides calycularis*) or seagrass meadows (*Pinna nobilis*). For these four species, included in the Spanish Catalogue of Endangered Species, the Alboran Sea constitutes the western limit of distribution since they do not extend to the Atlantic Ocean or are only found in areas close to the Strait of Gibraltar. *Pinna nobilis* has been declared as

Table 10.1 Marine invertebrates present in the Alboran Sea and included in International Conventions and Lists of endangered species or whose exploitation is regulated (nomenclature according to WoRMS 2019). The name of the taxonomic group and the number of species by group of each Convention or List are shown. Bern Convention (1986) included the Annexes II (strictly protected fauna species; status in force since 2018) and III (protected fauna species; status in force since 2002). Barcelona Convention (1995) included the last amendments of 2015 of Annexes II (endangered or threatened species) and III (species whose exploitation is regulated). The Habitat Directive (92/43/CEE) included the Annexes IV (species in need of strict protection) and V (species whose catch from the wild can be restricted by European law). The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) included all the species of scleractinians or hard corals (cnidarians), but here only those that are present in other Conventions and Lists are cited. The IUCN Red List includes the categories CR (Critically Endangered), EN (Endangered), VU (Vulnerable), NT (Near Threatened), LC (Least Concern), DD (Data Deficient) and LR/nt (Lower Risk/near threatened). In Spain the current Catalogue of Endangered Species and the List of Wild Species with Special Protection was published in 2011, with successive modifications in 2012, 2015, 2016, 2019 and 2020, and the equivalent of Andalusia in 2012. The categories in the Catalogue are EN (in danger of extinction) and VU (vulnerable). In 2018, the Spanish government declared critically endangered (CR) the bivalve *Pinna nobilis*, inside the EN category. This species has been subsequently included in 2019 as critically endangered in the IUCN Red List. Other abbreviations: Med, Mediterranean populations

Group/species	Bern Convention 1986 Annex	Barcelona Convention 1999 Annex	Habitat Directive 1992 Annex	CITES Annex	IUCN Red List	Spanish catalogue and list 2011+added (category or population)	Andalusian catalogue and list 2012 (category or population)	Observations
PORIFERA	**5**	**10**	**0**	**0**	**0**	**6**	**3**	
Aplysina spp.	II	II				Med		Only *Aplysina cavernicola* included in Bern Convention
Axinella polypoides	II	II				Med	Yes	
Spongia agaricina		III						
Tethya spp.		II				Med		There are still no species of the genus included in Bern Convention
Geodia cydonium		II				Med	Yes	
Sarcotragus foetidus		II				Med		*Ircinia foetida* is a synonym
Sarcotragus pipetta		II				Med	Yes	*Ircinia pipetta* is a synonym
Hippospongia communis	III	III						
Spongia lamella	III	III						*Spongia agaricina* is a synonym

(continued)

Table 10.1 (continued)

Group/species	Bern Convention 1986 Annex	Barcelona Convention 1999 Annex	Habitat Directive 1992 Annex	CITES Annex	IUCN Red List	Spanish catalogue and list 2011+added (category or population)	Andalusian catalogue and list 2012 (category or population)	Observations
Spongia officinalis	III	III						
CNIDARIA Anthozoa	**3**	**13**	**1**	**5**	**23**	**11**	**2**	
Antipathella subpinnata		II			NT	Med		Recently (2019) included in the Spanish List
Antipathes dichotoma		II			NT	Med		Recently (2019) included in the Spanish List
Leiopathes glaberrima		II			EN	Med		Recently (2019) included in the Spanish List
Parantipathes larix		II			NT	Med		Recently (2019) included in the Spanish List
Callogorgia verticillata		II			NT	Med		Recently (2019) included in the Spanish List
Eunicella verrucosa					VU			
Paramuricea clavata					VU			
Ellisella paraplexauroides		II			VU	Med		Recently (2019) included in the Spanish List
Isidella elongata					CR			
Corallium rubrum	III	III	V		EN			
Funiculina quadrangularis					VU			
Pennatula phosphorea					VU			
Pennatula rubra					VU			
Pteroeides griseum					VU			*Ptereoides spinosum* is a synonym

Savalia savaglia	II	II			NT	Med	Yes	
Cladocora caespitosa		II		II	EN	All areas		Recently (2019) included in the Spanish List
Cladocora debilis		II		II	DD			
Desmophyllum dianthus					EN			
Desmophyllum pertusum		II		II	EN	Med		Recently (2019) included (as *Lophelia pertusa*) in the Spanish List
Madrepora oculata		II		II	EN	Med		Recently (2019) included in the Spanish List
Dendrophyllia cornigera					EN			
Dendrophyllia ramea					VU			
Astroides calycularis	II	II		II	LC	VU	VU	
CNIDARIA Hydrozoa	**1**	**1**	**0**	**0**	**0**	**1**	**1**	
Errina aspera	II	II				Med	Yes	
MOLLUSCA Gastropoda	**12**	**12**	**1**	**0**	**3**	**13**	**13**	
Patella ferruginea	II	II	IV			EN	EN	
Cymbula safiana	II	II				Med	Yes	Included as *Patella nigra* in Bern and Barcelona Conventions
Dendropoma lebeche	II	II				VU	VU	Included as *Dendropoma petraeum* in Bern and Barcelona Conventions
Naria spurca	II	II				Med	Yes	Included as *Erosaria spurca* in Barcelona Convention

(continued)

Table 10.1 (continued)

Group/species	Bern Convention 1986 Annex	Barcelona Convention 1999 Annex	Habitat Directive 1992 Annex	CITES Annex	IUCN Red List	Spanish catalogue and list 2011+added (category or population)	Andalusian catalogue and list 2012 (category or population)	Observations
Luria lurida	II	II				Med	Yes	
Schilderia achatidea	II	II				Med	Yes	
Zonaria pyrum	II	II				Med	Yes	
Tonna galea	II	II				Med	Yes	
Ranella olearia	II	II			LR/nt	Med	Yes	
Monoplex parthenopeus					LR/nt			Included as *Ranella parthenopaeum* in IUCN Red List
Charonia lampas	II	II				VU	VU	
Charonia variegata	II	II				Med	Yes	Included as *Charonia tritonis variegata* in Barcelona Convention
Babelomurex cariniferus					LR/nt			Included as *Latiaxis babelis* in IUCN Red List
Tritia tingitana						VU	VU	Recently (2020) included in the Catalogues from the Red Book (2008, as *Nassarius tingitanus*)
Mitra zonata	II	II				Med	Yes	
MOLLUSCA Bivalvia	**4**	**4**	**2**	**0**	**1**	**4**	**6**	
Lithophaga lithophaga	II	II	IV			Med	Yes	
Modiolus lulat							Yes	Included in the Andalusian List from the Red Book (2008)
Pinna nobilis	II	II	IV		CR	CR	VU	Critically endangered (Spanish Catalogue) since 2018 and IUCN Red List since 2019

Pinna rudis	II	II				Med	Yes	Included as *Pinna pernula* in Bern Convention
Pholas dactylus	II	II				Med	Yes	
Barnea candida							Yes	Included in the List of Andalusia from the Red Book (2008)
ARTHROPODA Crustacea	**6**	**6**	**1**	**0**	**0**	**1**	**1**	
Pachylasma giganteum		II				Med	Yes	
Palinurus elephas	III	III						
Scyllarides latus	III	III	V					
Scyllarides pygmaeus	III							
Scyllarus arctus	III	III						
Homarus gammarus	III	III						
Maja squinado	III	III						
ECHINODERMATA	**3**	**3**	**1**	**0**	**0**	**3**	**4**	
Ophidiaster ophidianus	II	II				Med	Yes	
Hacelia attenuata							Yes	Included in the List of Andalusia from the Red Book (2008)
Asterina pancerii	II	II				Med	Yes	The species living in Andalusia is *A. phylactica* (López-Márquez et al., 2018)
Centrostephanus longispinus	II	II	IV			Med	Yes	
Paracentrotus lividus		III						
Total taxa:	**34**	**49**	**6**	**5**	**27**	**39**	**30**	

Fig. 10.16 A female of the threatened gastropod *Zonaria pyrum* on its egg cluster. This is the rarest of the four Mediterranean cowries, all of them included in annex II of Bern and Barcelona Conventions (Calahonda, Granada, 14 m depth) [Antonio Rodríguez-Medel]

critically endangered (CR) in 2018 by the Spanish government and then included in 2019 in the same category in the IUCN Red List, after the massive mortality event of recent years (see Sect. 10.7). Recently, some deep-water species have been included in the Annex II of the Barcelona Convention, such as the corals *Madrepora oculata*, *Desmophyllum pertusum* and *Callogorgia verticillata*, or in the IUCN Red List, such as *Desmophyllum dianthus* and *Dendrophyllia cornigera*.

Some species present in the Alboran Sea are of West African origin and present their only European populations in this area. Examples are the limpet *Cymbula safiana* and the bivalve *Modiolus lulat*, the latter species included in the Andalusian Red List of endangered species. Other Mediterranean protected molluscs, such as the four species of cowries (Fig. 10.16), have a wider distribution that includes the West African coast but become increasingly rare in the Mediterranean.

The set of protected species is in any case scarce relative to the invertebrate diversity and richness of the Alboran Sea. For example, some endemic species or with restricted distribution are still not protected, such as some molluscs living in the Strait of Gibraltar (Gofas 1998; Gofas et al. 2011), except for the recently protected (2020) gastropod *Tritia tingitana*, as well as other invertebrates that are suffering an alarming decline in their populations. Among the additional species that should be protected in the Alboran Sea, we consider at least the following taxa: the sponges

Fig. 10.17 Four of the species here proposed to be protected. From left to right and from top to bottom, the sponge *Petrosia ficiformis* with two specimens of the nudibranch gastropod *Peltodoris atromaculata* (Cerro Gordo, Malaga, 8 m depth), the anthozoan *Phyllangia americana mouchezii* (Calahonda, Granada, 16 m depth), the bivalve *Donacilla cornea* (Torregarcía, Almería, 0 m depth) and a couple of the decapod crustacean *Stenopus spinosus* in a crevice together with a conger (*Conger conger*) and the holothurian *Holothuria arguinensis* (Calahonda, Granada, 21 m depth) [Luis Sánchez Tocino, upper left; Antonio Rodríguez-Medel, upper and bottom right; Diego Moreno, bottom left]

Calyx nicaeensis and *Petrosia ficiformis* (that has suffered some events of mortality, Garrabou et al. 2009; Fig. 10.17); the gorgonians *Eunicella gazella* and *E. labiata*; the scleractinians *Phyllangia americana mouchezii* (Fig. 10.17), *Pourtalosmilia anthophyllites* and *Dendrophyllia laboreli*; the gastropods *Monoplex corrugatus*, *Bursa scrobilator* and *Tarantinaea lignaria*; the bivalves *Spondylus gaederopus* (that has suffered some events of mortality, see Sect. 10.7 and Fig. 10.19), *Donacilla cornea* (Fig. 10.17) and *Ungulina rubra*; the crustaceans *Pollicipes pollicipes* and *Stenopus spinosus* (Fig. 10.17); and the echinoderms *Asterina gibbosa* and *Astrospartus mediterraneus*. In addition, some invertebrates of groups that have not traditionally been included in threatened species lists should be protected, such as the sipunculans *Sipunculus nudus*, the polychaete *Sabellaria alveolata*, the bryozoans *Pentapora fascialis* and *Reteporella* spp., and the tunicate *Halocynthia papillosa*. Most of them were included and evaluated in the *Red Book of Invertebrates of Andalusia* (Barea-Azcón et al. 2008). Protective measures should also be considered for large holothurians of the genus *Holothuria* and for *Parastichopus regalis*, which are now heavily harvested in the Mediterranean for the export to Asia (González-Wangüemert et al. 2018).

On the other hand, some of the species traditionally considered of interest for fisheries and included in Annex III (species whose exploitation is regulated) of the Barcelona Convention should be moved to Annex II and be considered as threatened. This should apply especially for large exploited crustaceans that are increasingly scarce in the Alboran Sea, such as *Palinurus elephas* and *Homarus gammarus*, or those that have practically disappeared from this Mediterranean area, such as *Scyllarides latus* and *Scyllarus arctus*.

10.6 Species Originally Described from the Alboran Sea

The overview on the Mediterranean Sea biodiversity compiled by Coll et al. (2010) pointed out that the Alboran Sea displays the highest values of species richness of the basin. This was also suggested by Templado et al. (2006), García Raso et al. (2010) or Aguilar et al. (2011a) and makes this area a biodiversity hotspot, within the wider hotspot that the Mediterranean Sea represents globally. The Alboran Sea represents a transition zone between the Atlantic Ocean and the Mediterranean Sea where co-exist warm-water (from Atlantic North Africa), cold- and temperate-water (from the northeast Atlantic) and Mediterranean species, plus some endemic species restricted to this zone. Only the insular shelf of Alborán Island hosts more than a quarter (26.87%, 1636 species) of the total Mediterranean species richness of 11 benthic groups (Gofas et al. 2014). As another example, the megadiverse Mollusca, a good proxy indicator for total marine species richness, comprises in Spanish waters of the Alboran Sea and Gibraltar Strait 1245 species, about 52.5% of the total diversity of this phylum in the entire Spanish waters, including the Canary Islands (Gofas et al. 2017).

All said above is reflected in the sustained description of new species from the Alboran Sea during the past four decades. According to the non-exhaustive review listed in Table 10.2, no less than 154 new species have been described since 1980 in the Alboran Sea and the Strait of Gibraltar (18 Porifera, 6 Cnidaria, 5 Platyhelminthes, 1 Kinorhyncha, 2 Entoprocta, 8 Polychaeta, 1 Nemertea, 1 Tardigrada, 25 Crustacea, 1 Pycnogonida, 75 Mollusca, and 11 Bryozoa) (Fig. 10.18). The highest number of new species were described from the Strait of Gibraltar (89) on both African and European sides, followed by the Alboran Island (28) and other localities within the Alboran Sea (28) and the Chafarinas Islands (9).

10.7 Mass Mortality Events

Events of mass mortality related to climatic anomalies (storms, high water temperature or oxygen deficiency episodes) and mainly affecting filter-feeding benthic invertebrates (sponges, corals, gorgonians, bivalves, ascidians, etc.) have become

Table 10.2 Species originally described in the Strait of Gibraltar and Alboran Sea since 1980 (SG, Strait of Gibraltar; AI, Alboran Island, CH, Chafarinas Islands; OT, other localities within the Alboran Sea). Those species that have fallen into synonymy have been excluded (nomenclature according to WoRMS 2019)

Species	SG	AI	CH	OT
Porifera				
Axinella alborana Sitjà and Maldonado 2014		+		
Axinella estacioi Carballo and García-Gómez, 1995	+			
Axinella spatula Sitjà and Maldonado 2014		+		
Axinyssa diversicolor (Carballo, 2000)	+			
Cerbaris alborani (Boury-Esnault et al. 1994)				+
Coelosphaera cryosi (Boury-Esnault et al. 1994)				+
Crambe tuberosa Maldonado and Benito, 1991		+		
Delectona alboranensis Rosell, 1996		+		
Dotona mediterranea Rosell and Uriz, 2002		+		
Endectyon filiformis Sitjà and Maldonado 2014		+		
Forcepia megachela (Maldonado 1992)		+		
Haliclona palmonensis Carballo and García-Gómez, 1995	+			
Halichondria almae (Carballo, Uriz and García-Gómez, 1996)	+			
Plakinastrella mixta Maldonado 1992		+		
Pleraplysilla reticulata Maldonado and Uriz, 1999		+		
Scleranthelia microsclera López-González, Ocaña and García-Gómez, 1995	+			
Scopalina ceutensis Blanquer and Uriz, 2008	+			
Vulcanella aberrans (Maldonado and Uriz, 1996)		+		
Cnidaria				
Antennella ansini Peña-Cantero and García-Carrascosa, 2002			+	
Cordagalma bimaculatum Pugh, 2016				+
Eudendrium moulouyensis Marques, Peña-Cantero and Vervoort, 2000			+	
Filellum disaggregatum Peña Cantero, García-Carrascosa and Vervoort, 1998			+	
Merona ibera Medel, García-Gómez and Bouillon, 1993	+			
Scleranthelia microsclera López-González, Ocaña and García-Gómez, 1995	+			
Platyhelminthes				
Parotoplana cucullata Delogu, Casu and Curini-Galletti, 2008	+			
Parotoplana fretigaditani Delogu, Casu and Curini-Galletti, 2008	+			
Parotoplana mastigophora Delogu, Casu and Curini-Galletti, 2008				+
Parotoplana varispinosa Delogu, Casu and Curini-Galletti, 2008				+
Phaenoplana caetaria Pérez-García, Noreña and Cervera, 2018	+			
Kinorhyncha				
Pycnophyes almansae Sánchez, Herranz, Benito and Pardos, 2014				+
Entoprocta				
Loxosomella almugnecarensis Tierno de Figueroa and Sánchez-Tocino, 2009				+

(continued)

Table 10.2 (continued)

Species	SG	AI	CH	OT
Loxosomella ameliae Sánchez-Tocino and Tierno de Figueroa, 2009				+
Polychaeta				
Amphicorina triangulata López and Tena, 1999			+	
Bispira primaoculata Cepeda and Lattig, 2017				+
Exogone acerata San Martín and Parapar, 1990	+			
Myrianida longoprimicirratus (López, San Martín and Jiménez, 1996)			+	
Ophryotrocha alborana Paxton and Åkesson, 2011	+			
Ophryotrocha rubra Paxton and Åkesson, 2010	+			
Opisthodonta serratisetosa (López, San Martín and Jiménez, 1996)			+	
Salvatoria celiae (Parapar and San Martín, 1992)	+			
Nemertea				
Prosorhochmus chafarinensis Frutos et al. 1998			+	
Tardigrada				
Halechiniscus chafarinensis de Zio Grimaldi and Villora-Moreno 1995			+	
Crustacea				
Anapagurus alboranensis García-Gómez, 1994				+
Anthessius arcuatus López-González, Conradi, Naranjo and García-Gómez, 1992	+			
Astacilla cingulata Castelló and Carballo, 2000	+			
Astacilla paucisaetosa Castelló and Carballo, 2000	+			
Botryllophilus conicus Conradi, López-González and García-Gómez, 1994	+			
Caprella caulerpensis Guerra-García, Sánchez-Moyano and García-Gómez, 2002	+			
Caprella ceutae Guerra-García and Takeuchi, 2002	+			
Caprella monai Guerra-García, Sánchez-Moyano and García-Gómez, 2001	+			
Caprella paramitis Guerra-García, Sánchez-Moyano and García-Gómez, 2001	+			
Caprella pseudorapax Guerra-García, Sánchez-Moyano and García-Gómez, 2001	+			
Caprella sabulensis Guerra-García, Sánchez-Moyano and García-Gómez, 2001	+			
Caprella santosrosai Sánchez-Moyano, Jiménez-Martín and García-Gómez, 1995	+			
Caprella takeuchii Guerra-García, Sánchez-Moyano and García-Gómez, 2001	+			
Doridicola comai Conradi, Megina and López-González, 2004	+			
Enterocola africanus López-González, Conradi and García-Gómez, 1993	+			
Eriopisella ruffoi Martí and Villora-Moreno, 1996			+	
Heteranthessius hoi López-González and Conradi, 1995	+			
Leptocheirus alboranensis Ortiz and Jimeno, 2006		+		
Limnoria turae Castelló, 2011		+		

(continued)

Table 10.2 (continued)

Species	SG	AI	CH	OT
Mychophilus palmatus López-González and Conradi, 1996	+			
Pagurus pseudosculptimanus García Muñoz, Cuesta and García Raso, 2014				+
Pedoculina garciagomezi Sánchez-Moyano, Carballo and Estacio, 1995	+			
Stenosoma albertoi (Castellanos and Junoy, 2005)	+			
Stenosoma raquelae (Hedo and Junoy, 1999)	+			
Urothoe hesperiae Conradi, López-González and Bellan-Santini, 1995	+			
Pycnogonida				
Hannonia stocki Munilla, 1993	+			
Mollusca				
Alexandromenia avempacensis Pedrouzo and Cobo, 2014				+
Alvania alboranensis Peñas and Rolán, 2006		+		
Alvania nestaresi Oliverio and Amati, 1990				+
Alvania vermaasi Aartsen, Menkhorst and Gittenberger, 1984	+			
Aphanitoma mariottinii Smriglio, Rufini and Martín Pérez, 2001		+		
Baenopsis baetica (García-Gómez, 1984)	+			
Bittium circa Moreno, 2006		+		
Calliostoma gubbiolii Nofroni, 1984				+
Cassiella abylensis Gofas, 1987	+			
Cerithiopsis tarruellasi Peñas and Rolán, 2006		+		
Chauvetia dentifera Gofas and Oliver, 2010	+			
Chauvetia taeniata Gofas and Oliver, 2010	+			
Crisilla aartseni Verduin, 1984	+			
Curveulima beneitoi Peñas and Rolán, 2006		+		
Dikoleps marianae Rubio, Dantart and Luque, 1998				+
Dikoleps templadoi Rubio, Dantart and Luque, 2004	+			
Dizoniopsis abylensis Bouchet et al. 2010	+			
Dizoniopsis aspicienda Bouchet et al. 2010	+			
Doto alidrisi Ortea, Moro and Ocaña, 2010	+			
Doto caballa Ortea, Moro and Bacallado, 2010	+			
Doto furva García-Gómez and Ortea, 1984	+			
Doto unguis Ortea and Rodríguez, 1989				+
Eatonina matildae Rubio and Rodríguez Babio, 1996	+			
Eubranchus linensis García-Gómez, Cervera and García, 1990	+			
Eulimella carminae Peñas and Micali, 1999				+
Eulimella oliveri Peñas and Rolán, 2006		+		
Facelinopsis pacodelucia Ortea, Moro and Caballer, 2014	+			
Fjordia insolita (García-Gómez and Cervera, 1990)	+			
Gibberula jansseni van Aartsen, Menkhorst and Gittenberger, 1984	+			
Granulina gubbiolii Smriglio and Mariottini, 1999				+
Granulina torosa Gofas, 1992	+			
Granulina vanhareni (van Aartsen, Menkhorst and Gittenberger, 1984)	+			
Graphis pruinosa Gofas and Rueda, 2014				+

(continued)

Table 10.2 (continued)

Species	SG	AI	CH	OT
Jujubinus alboranensis Smriglio, Mariottini and Oliverio, 2015		+		
Jujubinus dispar Curini-Galletti, 1982	+			
Lepidochitona severianoi Carmona Zalvide and García García, 2000	+			
Leptochiton xanthus Kaas and van Belle, 1985	+			
Macellomenia adenota Salvini-Plawen, 2003	+			
Macromphalus abylensis Warén and Bouchet, 1988	+			
Melanella scarifata Gofas and Rueda, 2014				+
Mitrella bruggeni van Aartsen, Menkhorst and Gittenberger, 1984	+			
Mitrella templadoi Gofas, Luque and Urra, 2019	+			
Mitromorpha wilhelminae (van Aartsen, Menkhorst and Gittenberger, 1984)	+			
Monophorus alboranensis Rolán and Peñas, 2001		+		
Odostomia kromi Aartsen, Menkhorst and Gittenberger, 1984	+			
Odostomia sorianoi Peñas and Rolán, 2006		+		
Okenia hispanica Valdés and Ortea, 1995				+
Onchodia valeriae (Giusti Fr., 1987)				+
Onoba guzmani Hoenselaar and Moolenbeek, 1987	+			
Onoba josae Moolenbeek and Hoenselaar, 1987	+			
Onoba tarifensis Hoenselaar and Moolenbeek, 1987	+			
Parvicardium vroomi van Aartsen, Menkhorst and Gittenberger, 1984	+			
Parviturbo alboranensis Peñas and Rolán, 2006		+		
Pogonodon pseudocanaricus (Bouchet, 1995)				+
Pseudosimnia angusta Celzard, 2017	+			
Rugulina monterosatoi (van Aartsen and Bogi, 1987)				+
Runcina bahiensis Cervera, García-Gómez and García, 1991	+			
Runcina macrodenticulata García-Gómez and López de la Cuadra, 1990	+			
Setia alboranensis Peñas and Rolán, 2006		+		
Setia anselmoi (van Aartsen and Engl, 1999)	+			
Setia bruggeni (Verduin, 1984)	+			
Setia lacourti (Verduin, 1984)	+			
Setia slikorum (Verduin, 1984)	+			
Similiphora triclotae Bouchet, 1997	+			
Simnia jacintoi Fehse and Trigo, 2015	+			
Tambja ceutae García-Gómez and Ortea, 1985	+			
Tambja marbellensis Schick and Cervera, 1998				+
Trapania hispalensis Cervera and García-Gómez, 1990	+			
Trenchia anselmoi Rubio and Rolán, 2013		+		
Tricolia deschampsi Gofas, 1993	+			
Tricolia entomocheila Gofas, 1993	+			
Tricolia tingitana Gofas, 1993	+			
Trophonopsis alboranensis (Smriglio, Mariottini and Bonfitto, 1997)		+		
Tyrannodoris europaea (García-Gómez, 1988)	+			

(continued)

Table 10.2 (continued)

Species	SG	AI	CH	OT
Bryozoa				
Bicrisia gibraltarensis Harmelin, 1990	+			
Crepis harmelini Reverter-Gil, Souto and Fernández-Pulpeiro, 2011	+			
Disporella alboranensis Álvarez, 1992		+		
Disporella piramidata Álvarez, 1992				+
Disporella robusta Álvarez, 1992		+		
Fenestrulina barrosoi Álvarez, 1993		+		
Hemicyclopora dentata López de la Cuadra and García Gómez, 1991	+			
Patinella distincta (Álvarez, 1993)	+			
Puellina pseudoradiata Harmelin and Arístegui, 1988				+
Schizomavella rectangularis Reverter-Gil, Berning and Souto, 2015	+			
Sessibugula barrosoi López de la Cuadra and García-Gómez, 1994	+			

Fig. 10.18 Two species originally described from the Alboran Sea, the shelled gastropod *Alvania nestaresi* (left, Los Escullos, Almería, 5 m depth) and the nudibranch *Tyrannodoris europaea* (right, Almería Port, 14 m depth) [Diego Moreno]

frequent in the last three decades across the Mediterranean Sea (e.g. Stachowitsch 1984; Cerrano et al. 2000; Perez et al. 2000; Garrabou et al. 2009; Bensoussan et al. 2010; Lejeusne et al. 2010; Crisci et al. 2011; Rivetti et al. 2014; Di Camillo and Cerrano 2015; Rubio-Portillo et al. 2016). These events can cause massive damage or death to those species by (i) thermal stress (that makes them more susceptible to infections and diseases); (ii) decrease in the efficacy of defence mechanisms; (iii) damages by hypoxia; (iv) increasing populations of pathogenic organisms as fungi, bacteria or protists (or increasing their virulence); (v) favouring the arrival and settlement of thermophilic species to the detriment of the most sensitive to high temperatures; and (vi) inducing coral bleaching or the breakdown of the cyanobacteria-sponge symbiosis (Stachowitsch 1984; Kushmaro et al. 1998; Cerrano et al. 2000; Perez et al. 2000; Coma et al. 2009; Lejeusne et al. 2010; Maldonado et al. 2010; Cebrián et al. 2011; Sánchez-Tocino and Tierno de Figueroa 2016). In fact, as referred by Lejeusne et al. (2010), the Mediterranean Sea is one of the most affected seas by the global warming and by the extreme events derived from the current climate change. Moreover, the increases of temperatures act synergistically with other anthropogenic disturbances, which also cause mass mortalities. Different types of professional and recreational fishing impact mainly invertebrates on rocky bottoms (corals, bryozoans, sponges and gorgonians), whereas trawling on soft bottoms affect sea pens, echinoderms and many other benthic animals. Coastal degradation, biological invasions and pollution added to high temperatures and pathogens cause serious conservation problems for marine species in the Mediterranean Sea and hamper the recovery of their populations (Lejeusne et al. 2010; Templado 2014).

Several events of mass mortality have been detected in the Alboran Sea in recent years, affecting different invertebrates, such as sponges, cnidarians, molluscs and echinoderms. Maldonado et al. (2010) found disease outbreak in sponge populations of the genus *Ircinia* from the Granada coast and the Chafarinas Islands and pointed that epidemic outbreaks could recur periodically at the end of summer and early autumn probably favoured by short periods of abnormally high water temperatures in August. Their study in 2008 and 2009 showed that, although 27% of the sponges died, the sponge immune system could successfully resist the disease in many cases. More recently, in 2016 late summer, a new mass mortality event was reported for the sponges *Ircinia variabilis* and *Sarcotragus fasciculatus* in the Granada coast coinciding with abnormally high seawater temperatures (Sánchez-Tocino and Tierno de Figueroa 2016). In this study, diseased sponges ranged from 7.2% to 81%, and dead ones ranged from 0% to 92.8%. Authors detected an effect of the coast topography and thermocline position on the degree of mortality or disease, as had been previously reported for the anthozoan *Corallium rubrum* in the Mediterranean Sea (Garrabou et al. 2001). Necrosis in *Petrosia ficiformis* related with environmental stress was recorded in Liguria (Cerrano et al. 2001) and recently observed in Almería (Moreno pers. obs., Fig. 10.19).

Sánchez-Tocino et al. (2017) pointed out that the moderate to low recruitment (previously reported by Maldonado et al. 2013) of the anthozoan *Ellisella paraplexauroides* populations in the Chafarinas Islands, the impacts of fishing and the particular shallow distribution of this species in this archipelago could have an important negative effect in its conservation. These authors also highlighted that mass mortality events caused by high temperatures, such as those affecting other species of gorgonians in the Mediterranean (e.g., Cerrano et al. 2000; Linares et al. 2008b; Cupido et al. 2009), could also have contributed to the preoccupying conservation status of this population. In relation to this, de la Linde Rubio et al. (2018) reported a mortality episode of the gorgonians *Eunicella singularis* and *Paramuricea clavata* in Chafarinas Islands also after a high temperature event in summer 2014. On average, 43% of the colonies of *E. singularis* were found dead and 21% damaged, while in *P. clavata* none of the studied colonies was dead but only half of them were completely healthy. Unlike other mass mortality events in the Mediterranean (Crisci et al. 2011), *P. clavata* was apparently not so affected in the Chafarinas Islands. Nevertheless, recent observations showed mortality in the colonies of *P. clavata* from the shallower areas of these islands (Sánchez-Tocino et al.

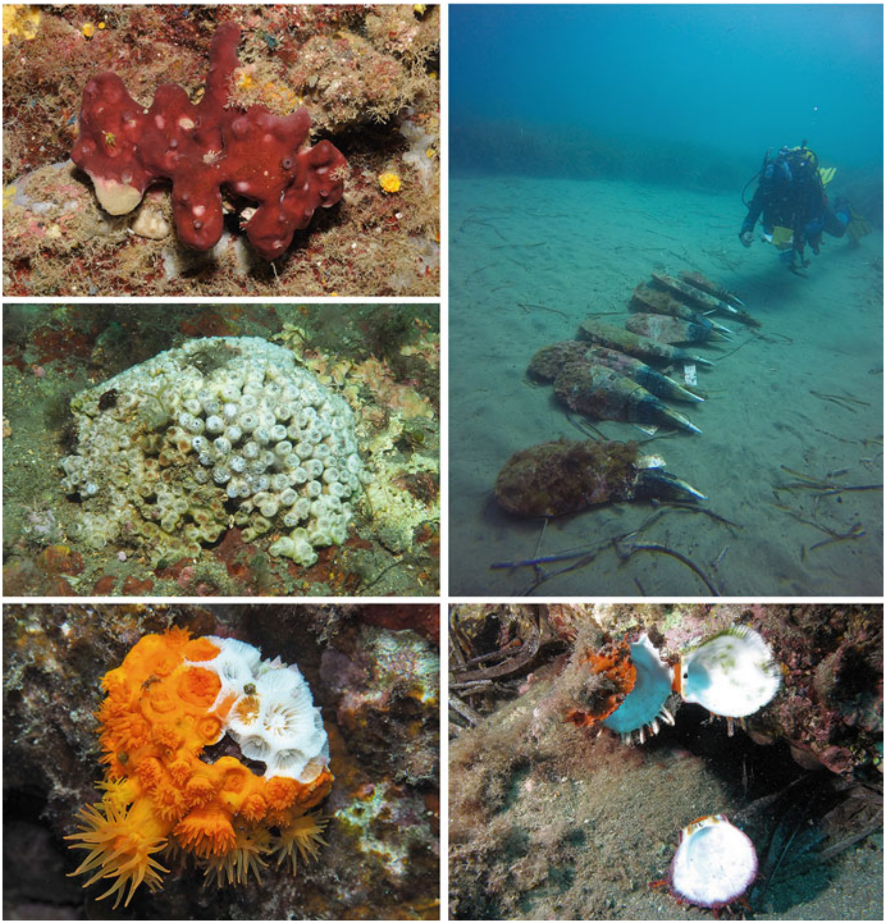

Fig. 10.19 Mortality events. From top to bottom and from left to right, necrosis (white patches) in the sponge *Petrosia ficiformis* (Carboneras Island, Almería, 17 m depth), partially dead colonies of the scleractinian corals *Cladocora caespitosa* (Balanegra, Almería, 15 m depth) and *Astroides calycularis* (San José, Almería, 3 m depth), cemetery of marked specimens of *Pinna nobilis* (Carboneras Island, Almería, 10 m depth, 2016) and two dead specimens of *Spondylus gaederopus* (Carboneras Island, Almería, 8 m depth) [Diego Moreno/Sustainable Marine Environment Management Program/Junta Andalusia, three photos on the left; Agustín Barrajón Domenech/Sustainable Marine Environment Management Program/Junta Andalusia, two photos on the right]

2019). Furthermore, punctual episodes of mass mortality of the anthozoan *Parazoanthus axinellae* have been observed in the Granada coast at the end of particularly warm summers (personal observations), coinciding with that detected in the Ligurian Sea (Cerrano et al. 2006).

Other anthozoans, such as the Mediterranean endemic scleractinians *Cladocora caespitosa* and *Astroides calycularis* (Fig. 10.19), may suffer massive mortalities.

The first species is the sole zooxanthellate scleractinian reef-builder of the Mediterranean and has been affected by bleaching events in the last years due to seawater warming (Kersting et al. 2013). Gambi et al. (2010) reported local mass mortality events of the thermophilic azooxanthellate orange coral *Astroides calycularis* also related to high water surface temperatures. Both species support a high biodiversity (Pitacco et al. 2017; Terrón-Sigler et al. 2014).

Among molluscs, the better known cases of mass mortalities are the recurrent events suffered by the bivalve *Spondylus gaederopus* since the 1980s and the more recent mortality that have severely affected *Pinna nobilis* populations in the western Mediterranean. The European thorny oyster (*S. gaederopus*), which lives attached by the lower (right) valve to more or less vertical rock walls and other hard substrates, suffered the first known case of mass mortality in 1981 in France for causes yet unknown (Meinesz and Mercier 1983). Similar mortality events were observed in this species in the Alboran Sea since 1990, and subsequently there have been mortalities in 2005 and later years, detected in the Granada coast (personal observations) and, particularly, in the Chafarinas Islands (Sánchez-Tocino et al. 2009). Mass mortalities of *S. gaederopus* are easy to detect since this species loses the flat upper (left) valve when it die and the white inside of the convex lower valve that remains attached to the rock can be seen by divers from a distance of several meters (Fig. 10.19). Observed mortalities of *S. gaederopus* often coincide with a number higher than usual of empty shells of other bivalves that live attached with the byssus to rocky bottoms, such as *Arca noae* and *Barbatia barbata* (personal observations). For the former species, a massive mortality has been recently reported in the Strait of Messina (Bottari et al. 2017). Currently, *Spondylus gaederopus* is still present in many localities in the Alboran Sea, but it is uncommon, and its abundance has never been the same since the recorded mortalities (Moreno et al. 2008b).

Nevertheless, the most drastic and surprising mass mortality event that has affected any invertebrate species in the Alboran Sea and the whole Mediterranean is that first detected in October 2016 in southeastern Spain (Fig. 10.19) affecting the Mediterranean endemic and threatened fan mussel *Pinna nobilis*, one of the world's largest bivalves, which lives associated to seagrass meadows. By the end of 2016, between 70% and 90% of the specimens died, and in the spring of 2017, practically 100% of the population died in most of the southern Spanish coasts including the Alboran Sea. Vázquez-Luis et al. (2017) found in the Spanish Mediterranean Sea mortality values of 100% in the North part of the Alboran Sea and of 90–99% in the Chafarinas Islands. These authors and Darriba (2017) pointed out a haplosporidian-like parasite detected in dying individuals as the very likely cause of this mortality. The parasite associated to this mortality (the protist *Haplosporidium pinnae*) was subsequently described in 2018 (Catanese et al. 2018) and infects the vital organs of the bivalve causing its death. It seems to be a very specific pathogen because it does not affect the closely related species *Pinna rudis*, somewhat smaller and that prefers rocky substrates, although it is also found in *Posidonia* meadows. By 2019, the mortality of *Pinna nobilis* affects populations of other Mediterranean countries (France, Italy, Malta, Greece, Croatia, Turkey, Cyprus, Tunisia and Morocco), according to IUCN (2019). According to Cabanellas-Reboredo et al. (2019), the haplosporidian has probably dispersed regionally by surface currents, and the disease expression seems to be closely related to temperatures above 13.5 °C and to a salinity range between 36.5 and 39.7 psu. *Pinna nobilis* has been recently included in the IUCN Red List as a critically endangered species (Kersting et al. 2019).

Finally, a mass mortality episode of echinoderms was detected in August 2009 affecting to the starfish *Astropecten aranciacus* and the sea urchins *Spatangus purpureus*, *Paracentrotus lividus* and *Sphaerechinus granularis* in Almuñécar, Granada coast (Tierno de Figueroa and Sánchez-Tocino 2010). This event coincided with a sudden increase in sea temperature, reaching values higher than those ever registered in the previous 25 years.

Effects of mass mortalities may extend from the directly affected species to other invertebrates linked by trophic or symbiotic relationships. *Pinna nobilis*, for example, may host three symbiotic, commensal or mutualistic, decapod crustaceans: the shrimp *Pontonia pinnophylax* and the crabs *Nepinnotheres pinnotheres* and *Pinnotheres pisum* (Rabaoui et al. 2008; Trigos and Vicente 2018). *Pontonia pinnophylax* is a Mediterranean species that could also live in association with sponges and ascidians (Trigos and Vicente 2018), *Nepinnotheres pinnotheres* may live also in ascidians, and *Pinnotheres pisum* lives also in mussels, oysters and other bivalves (Rabaoui et al. 2008; Becker and Türkay 2017). Local extinction of the fan mussel predictably carries at least a population decline of these decapod species or even their local extinction (co-extinction). This is especially so for *Pontonia pinnophylax*, since Calafiore et al. (1991) revealed that the larval development of this shrimp is stopped in the zoea phase in the absence of *Pinna nobilis* (Trigos and Vicente 2018). Similar effects are predictable for specialized gastropods preying on sponges. For example, the doridoidean nudibranch *Peltodoris atromaculata* (Fig. 10.17) feeds on *Petrosia ficiformis* (Ros 1978) and *Paradoris indecora* on *Ircinia variabilis* (Marín et al. 1997), whereas *Trapania maculata* and *T. hispalensis* (Fig. 10.20) are common on *I. variabilis* and *Sarcotragus spinosulus* but feed on Entoprocta of the genus *Loxosomella* living on the sponges (Sánchez Tocino and Cervera 2006). Many other doridoideans feed on sponges (e.g., Megina et al. 2002; Gemballa and Schermutzki 2004), as also do gastropods belonging to the families Triphoridae or Cerithiopsidae (Wells 1998; Bouchet et al. 2010). Similarly, other gastropods are more or less specific predators of anthozoans, such as Ovulidae (Fig. 10.20), which feed on several species of octocorals (Fehse et al. 2010; Priori et al. 2014); Coralliophilinae (Muricidae, Fig. 10.20), which prey on stony corals, sea anemones, antipatharians or octocorals (Richter and Luque 2002, 2004); or Epitoniidae that only feed on stony corals or sea anemones (Richter and Luque 2004). Some nudibranchs also feed on diverse anthozoans including gorgonians (McDonald and Nybakken 1997, 1999; Goodheart et al. 2017). Finally, echinoderm mass mortalities may affect, among others, to the specialized parasitic gastropods of the family Eulimidae (Fig. 10.20) that feed on many species of this group (Warén 1983).

Fig. 10.20 Four examples of gastropods linked by trophic relationships to species that may suffer mass mortalities. From left to right and from top to bottom: the ovulid *Simnia spelta* on the gorgonian *Leptogorgia sarmentosa* (Cantarriján, Granada, 13 m depth), may also feed on species of the genera *Eunicella* and *Paramuricea*; the eulimid *Pelseneeria minor* (arrows), on the sea urchin *Psammechinus microtuberculatus* (La Rábita, Granada, 150 m depth), may also feed on other sea urchins; the coralliophiline muricid *Babelomurex cariniferus* (arrow), here feeding on the orange coral *Astroides calycularis* (Almuñécar, Granada, 15 m depth), may also feed on *Cladocora caespitosa*; and the doridacean nudibranch *Trapania hispalensis*, which feeds on entoprocts of the genus *Loxosomella*, on the sponge *Sarcotragus spinosulus* (Punta de la Mona, Granada, 14 m depth) [Luis Sánchez Tocino]

10.8 Some Aims for Present and Future Research

At least from the taxonomic point of view, the main groups of marine invertebrates of the Alboran Sea (e.g. sponges, anthozoans, molluscs, decapod crustaceans, echinoderms) are reasonably well known, but knowledge on most of minor groups, and also on polychaetes and non-decapod crustaceans, is much scarcer and needs to be improved. However, research work on basic scientific issues, such as taxonomy, systematics or biogeography, seems to be currently unfashionable for funding agencies. Qualified and constantly updated systematic inventories of all the components of biodiversity are necessary since they provide a permanent scientific record for documenting patterns of diversity, endemism and alien species. Small cryptic invertebrates are numerically dominant in most marine ecosystems, but the inventory of these species requires the participation of trained taxonomists (those experts able to identify, describe and classify species). Regrettably, expertise in biodiversity is being lost and needs to be urgently reinforced. Moreover, the available information is unbalanced between the north and south shores of the Alboran Sea, with the latter much less known. Thus, it would be necessary to increase research efforts in Moroccan and Algerian waters to have a more complete and updated overview of the biodiversity of this Mediterranean basin.

On the other hand, the biological traits and the role of the species in the maintenance of biodiversity, functionality and resilience of ecosystems remain poorly understood, particularly for the vast majority of rare species. Thus, besides the necessary basic research on taxonomy, investigations must be also focused on the species ecological features (mainly on trophic interactions) and on its reproductive biology, larval development, settlement and recruitment. Moreover, and especially for the threatened species, it is also essential to understand the environmental factors that modulate their distribution and, in the current context of global change, their thermal tolerance limits, acclimatization capacities and resilience under other human impacts and diseases. Finally, genetic data (such as population genetic variability and the extent of connectivity), associated with ecological studies, are of primary importance to detect when a population is threatened and to predict the influence of environmental changes on individual species. All these issues will determine "winners" and "losers", and such knowledge is necessary for successful management and effective protection.

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Chapter 11
Biogeographical and Macroecological Context of the Alboran Sea

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11.1 Introduction

Biogeography refers to the distribution of living beings in space and time (Brown and Gibson 1983), and includes the description of distribution patterns, the formulation and testing of hypotheses about the processes (either historical, ecological, or anthropogenic) responsible for creating, maintaining, and modifying these patterns, and the elaboration of predictions about the future course of species distribution according to different ecological or human-behaviour scenarios. Here we are going to highlight the main distribution patterns of marine species currently discernible in the Alboran Sea, and the causes of these patterns, with particular emphasis on the groups that are exploited as natural resources. Some of the drivers are rooted in past

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events, which have been described in detail in other chapters of this book; we will only briefly mention the most important events related to the historical relationship of the Alboran biota with those of other parts of the world.

With the word macroecology, we mean the study of ecological processes that occur at geographical, temporal, and taxonomical scales beyond the scope of experimental tests, normally approaching relationships between organisms and their environment in a regional or global context (Brown and Maurer 1989). The study of the effect of the regional climatic variability in the distribution pattern of species is part of macroecology, as it is also the analyses of the several large-scale gradients in species diversity. We will address the main internal geographical trends in species richness, mainly the bathymetrical gradient, but also the less significant longitudinal and latitudinal ones. The effect of large-scale macroclimatic patterns, such as those derived from the North Atlantic Oscillation and the Arctic Oscillation, on Alboran waters and their consequences for living beings and fishing activities will be also addressed here. The analyses of recent changes in Alboran biota, resulting from the invasion of alien species, are also of interest from a macroecological and biogeographical point of view.

In spite of the importance of the Alboran Sea from a biogeographic and macroecological point of view, there are no integrating works of the entire biota. This is crucial, since species are typically interrelated, and it is necessary to approach the biogeography and macroecology of the complete flora and fauna in order to obtain comprehensive descriptive, explanatory, and predictive conceptual models of Alboran biodiversity, ecosystems, and natural resources.

11.2 Historical Biogeography: Where Do the Biota of the Alboran Sea Come From?

The current patterns of biodiversity in the Alboran Sea can only be understood in the light of the very complex geological history of the Mediterranean Sea as a whole. The early history of this sea may be considered to start in the Mesozoic era, some 150 My BP, when the supercontinent of Gondwana, then migrating to the Southern Hemisphere, was separated from Eurasia by a large ocean named Tethys by geologists. As a result of the breakup of the Gondwana landmass, Africa separated from South America about 100 My BP, started moving towards Eurasia, and the large Tethys Ocean went consequently under compression, gradually becoming a Tethys Sea. The current configuration of the biota in the Alboran Sea and adjacent waters is the result of how this common Tethyan heritage was overcome by later events.

The essential point, from a biogeographical perspective, is that throughout the Cretaceous (145–66 My BP) and the Paleogene (66–23 My BP) periods the tropical and subtropical world ocean had easy and permanent East-West communication. The part of the Tethys Sea corresponding to the present-day Mediterranean communicated eastwards with the Indian Ocean through the current Middle East, Mesopotamia, and the Persian Gulf. To the West, there was a broad communication towards the Atlantic. This contrasts sharply with the current setting, where strong North-South barriers separate the Pacific Ocean from the Atlantic, and the Atlantic-Mediterranean domain from the Indian Ocean. During the Eocene, the biota of the Tethys Ocean was a tropical-type community of warm waters whose current representatives are mostly found in coral reefs of the Indian and Pacific oceans. The Oligocene communities of Tethys differed, biogeographically, largely from those of the Eocene, due to the disappearance of a large number of genera and the appearance of others with Atlanto-Mediterranean affinities that we can find nowadays in the Mediterranean (Cappetta and Ledoux 1970). Vestiges of the fish fauna of this Tethys can be found in species that, geographically, currently occur both on the American, Mediterranean, or Asian coasts, such as *Blennius cristatus* and *Zeus faber* (together with their related species), as is also the case of the genera *Pagrus*, *Sparus*, *Echelus*, and *Cepola* (Quignard 1978).

The final closure of the Tethys seaway, called the Terminal Tethyan Event (TTE), took place during the first half of the Neogene period, approximately 12–18 My BP, affecting mainly the eastwards communication with the Indian Ocean, probably with recurrent re-establishment and interruptions of the connexion, and giving place to the Paleomediterranean Sea (Steininger and Rögl 1979). Although the Red Sea started opening about 24 My BP (Segev et al. 2017), when rifting occurred between the African and the Arabian plates, and received its first waters from the Tethys Sea, it seems to have never restored a seaway into the Paleomediterranean from the Indian Ocean, despite a tantalizing isthmus of only 13 m above sea level. The significant impact of the TTE on circumtropical biota has been widely recognized (Harzhauser et al. 2007).

To the West, reasonable communication with the Atlantic Ocean persisted for several million years after the TTE. The Paleomediterranean communicated with the Atlantic by two straits (Martín et al. 2014): the Betic Strait (occupying part of the current valley of the Guadalquivir) to the north and the Rifian Strait to the south of the Betic-Rif arc. The biotic composition of that sea was very different from now, with most of its flora and fauna still direct inheritances of the Tethys Sea, and with numerous fossil occurrences of coral reefs (Perrin and Bosellini 2013).

Continued compression and sedimentary infilling triggered the closure of these straits (Krijgsman et al. 1999; Rouchy and Caruso 2006; Martín et al. 2014), isolating the Paleomediterranean Sea from the World oceans in the Messinian (upper Miocene). The Mediterranean Sea started then as a concentration basin, i.e. the contributions of rivers and precipitation did not balance the evaporation losses. Therefore, a process of gradual and almost complete desiccation of the Mediterranean Sea occurred in less than thousand years. This is the renown but still not fully understood "Messinian Salinity Crisis", which affected the Mediterranean in a brief but drastic episode, dated 5.97–5.33 My BP. There is still no agreement as to whether the whole basin dried out (Hsü et al. 1973), or if the deposition of hundreds of metres of salt and gypsum layers occurred within a deep sea basin (see revision in Krijgsman et al. 2018), but in any case the impact on the biota could be so great as to wipe out the Tethyan heritage of biota across the whole basin. Pérès and Picard (1964) mention, however, the existence of a relic

Fig. 11.1 Exquisitely preserved shells of Lago Mare fauna, from a late Messinian outcrop near Málaga. Top row: snails of the genus *Theodoxus*, middle row and below left: three species of lymnocardiine cockles; below right, a *Dreissena*, remote relative of the modern Zebra mussel

Paleomediterranean population, which adapted and persisted during this salinity crisis and that may have participated in the repopulation of the current Mediterranean since the Pliocene.

At the very end of the salinity crisis, prior to the restoration of normal marine conditions, there were several brief episodes, known as "Lago Mare", where sedimentary deposits close to current sea level contain strange brackish-water faunas similar to those living nowadays in the Caspian Sea and, in the Miocene epoch, in the Paratethys, a large body of shallow water spanning from the Vienna Basin to the Caspian Sea and Aral Sea (Steininger and Rögl 1979). An exquisitely preserved assemblage of this kind of fauna from this period has been found as far west as Málaga (Guerra-Merchán et al. 2010), well inside the Alboran Sea, and shows no evidence whatsoever of any of the marine organisms that now populate the basin (Fig. 11.1). Rivers and rainfall are unable to account for covering the whole Mediterranean with brackish water, and the best explanation is a massive overflow from the Paratethys, bringing hyposaline waters and, with them, the corresponding fauna.

Normal marine conditions were resumed at the beginning of the Pliocene, 5.3 My BP, with the establishment of the Strait of Gibraltar as we know it today, in what is called the Zanclian flood (but see Krijgsman et al. 2018 for the view that it should have started functioning earlier, during the salinity crisis). Geomorphological studies suggest that the Strait of Gibraltar originates from an eastwards flowing stream, which drained the eastern slope of an emergent Gibraltar Isthmus to the Mediterranean Basin at the end of the Messinian. Consequent canyons are still found in the marine topography towards the Alboran Sea. The present Spartel and Camarinal Sills both originated from the coeval mass sliding of the northern bank of the strait (Blanc 2002).

This narrative leads to thinking that the bulk of the Mediterranean biota has been received from the Eastern Atlantic through the Strait of Gibraltar, populating a basin whose flora and fauna may have been practically eliminated by the Messinian Salinity Crisis. The idea that all Mediterranean biotic elements should proceed from the Atlantic was first put forward by Paul Pallary, a schoolteacher in Oran who published extensive work on the Mollusca of North Africa. Without being aware of the salinity crisis, Pallary (1907) wrote (in translation) that “the Mediterranean having received its population from the Ocean, there is no such thing as a Mediterranean fauna”.

Nonetheless, some aspects of the Mediterranean biogeography are discordant with this scenario. The rate of endemism in the Mediterranean Sea is high, contrary to what would be expected in a subset of the Atlantic biota. The overall rate of endemism is more than 20% (Bianchi et al. 2012) and a good number of endemic Mediterranean species are paleoendemics, not recently segregated from an Atlantic ancestor but with a relict distribution limited to the Mediterranean. The most spectacular example is the marine seagrass, *Posidonia oceanica*, a flagship species of Mediterranean biota, which has its westernmost populations in the Alboran Sea and its nearest relatives in Australia. Other species have a still more puzzling distribution, as is for example the case of the small gastropod *Homalopoma sanguineum* (Fig. 11.2), which has no close relatives in the Atlantic and avoids even the Alboran Sea. The history of these Mediterranean endemics and paleoendemics is still far from being understood (Ekman 1953). Where were those species during the salinity crisis? The adjacent Paratethys was reduced, in its western part, to the brackish Lake Pannon, which could only harbour a fauna similar to that of the “Lago-Mare” episode. Two possibilities are left: either some parts of the Mediterranean proper were neither evaporated nor brackish and could give refuge to *Posidonia* and other marine biota, or the adjacent part of the Atlantic could provide a suitable habitat. The first alternative is not supported by any fossil record anywhere, and the second would suppose that the deep embayment of the southwestern Iberian Peninsula and Northwestern Morocco was then not so much sediment-clad as it is nowadays.

In any case, the species richness of the Mediterranean was fully restored during the Pliocene with many species that are now extinct or are restricted to more southern waters off northwestern Africa. At that moment the history of the Mediterranean biota was already linked to the populations of the Atlantic. Not so widely renowned as the Italian Pliocene (Monegatti and Raffi 2001), the outcrops around the Western part of the Alboran Sea near Estepona have provided an extremely diverse Pliocene fauna mostly studied for molluscs (see Landau et al. 2009 and references therein).

From there on, the biogeographic history of the Mediterranean is essentially the result of a series of climate changes, resulting in repeated biotic shifts. There were

Fig. 11.2 A Mediterranean paleoendemic, *Homalopoma sanguineum*, not present west of the Almeria Oran front. Specimens from the Mediterranean coast of France, about 8 mm in diametre

several episodes of colder and warmer climate during the glaciations of the last 700,000 years (Siddall et al. 2007), corresponding respectively with lower and upper limits of the sea level. The best documented are the last interglacial period including the warm "Marine Isotope Stage 5e", between 116,000 and 122,000 years ago with a highstand of sea level leaving deposits above the current shoreline, and the Last Glacial Maximum, between 19,000 and 22,000 years ago with a coastline receding to the outer part of the continental shelf, now around 100 metres deep.

During the last interglacial, the Mediterranean fauna incorporated many thermophilous elements, the most conspicuous of which is the large strombid *Persististrombus latus* (also known as *Strombus bubonius*), sometimes abundant in marine terraces, and fish of the families Serranidae, Sparidae, or Labridae. This thermophilous fauna, which was first described on the coast of Sardinia (hence the name of "Tyrrhenian" given to those deposits), are recorded in the Alboran Sea, best exposed near Almería (Zazo et al. 2003) and to a lesser extent on the coast of Málaga (Lario et al. 1993).

The cold spells of the Pleistocene are scarcely recorded from the Alboran Sea, but this is mostly due to a lack of proper sampling. Remains of cold-water species like the whelk *Buccinum undatum* or the horse mussel *Modiolus modiolus* are routinely taken by commercial trawlers operating deeper than 100 m off the coasts of Málaga (Fig. 11.3). *Modiolus* was also found during the Pleistocene on the Alboran platform, then surrounding an island much larger than it is nowadays. Boreal fish species

Fig. 11.3 Shells of *Modiolus* and large *Mytilus* from a Pleistocene shoreline of the Alboran platform, collected during the INDEMARES project (photo Serge Gofas)

such as *Sprattus sprattus*, *Platichthys flesus*, or *Raja clavata* also occurred during the cold episodes.

At present, the Mediterranean biota is still changing, mainly due to the regional or global effects of human activity. Since 1869, new species of Indo-Pacific origin are arriving again through the Red Sea into the Mediterranean via the Suez Canal. These current migrations of species have been called Lessepsians, in honour of Ferdinand de Lesseps, an engineer who designed the Suez Canal. *Fistularia commersonii* is the first Indo-Pacific fish species cited in the Alboran Sea (Sánchez-Tocino et al. 2007), which spent years to colonize the entire Mediterranean, from the Sea Red to the Atlantic, since it was cited for the first time in the coasts of Israel in the year 2000 (Golani 2000).

11.3 The Alboran Sea as a Biogeographical Entity

The Alboran Sea is defined by the existence of geographical limits, at both sides of its longitudinal range, that work as permeable biogeographical barriers, mainly the Strait of Gibraltar and the hydrographic front between Oran and Almeria. They not only are geographic limits, but also affect the distribution of species and become the boundaries of a biogeographical area, the Alboran Sea.

The Strait of Gibraltar is known to be a barrier for certain species and a transition zone for many others. The Strait acts as a biogeographical frontier particularly for deep marine fishes, as the depth of the Gibraltar Strait, which is only 320 m, has made it an effective barrier to them (Fredj and Maurin 1987). This border sometimes functions as a semipermeable frontier, working more effectively at hindering the pass from east to west than vice versa, especially for species that make use of the superficial water, where the current is important and always flows eastwards. This is the case for the Loggerhead turtles, as turtle youngsters enter the Mediterranean but are unable to cross back the Strait, since they lack the strength to overcome the incoming current of Atlantic water until they reach a carapace size of at least 55 cm (Bellido et al. 2007, 2010, 2010; Revelles et al. 2007; Eckert et al. 2008).

In any case, this frontier is permeable, and the Strait of Gibraltar and the Alboran Sea constitute an important transition zone, particularly for highly migratory fish species and air-breathing vertebrates. The highly migratory species (HMS) have been listed in Annex 1 of UNCLOS (United Nations Convention of the Law of the Sea) and include the tunas, billfishes, oceanic sharks, and other migratory fishes (dolphin fishes, pomfrets, and sauries), in addition to cetaceans. On the other hand, cetaceans, sea turtles, and marine birds conform the group of marine air-breathing vertebrates, which are also highly migratory marine species. Currently, the Alboran Sea represents an important area for the distribution of many HMS and air-breathing vertebrate species, since it acts as the entry point to the Mediterranean from the Atlantic for migrating sharks (Megalofonou et al. 2005; Meléndez et al. 2015), cetaceans (de Stephanis et al. 2008), and sea turtles (Camiñas et al. 1992; Camiñas 1997). This affects vagrant or casual species such as, for example the pelagic sharks *Galeocerdo cuvier* and *Sphyrna mokarran*, which have been reported in the Alboran Sea (Pinto de la Rosa 1994; Denham et al. 2007), and groups of species that are known to migrate periodically eastward or westward through the Alboran Sea, which include large pelagic vertebrate fishes (tuna and others tuna-like species), chondrichthyans (sharks and batoidea), mammals, sea turtles (loggerhead and leatherback) and different species of sea birds.

This periodic and systematic transition through a strait and a narrow sea pathway, as is that represented by the Alboran Sea, imply predictable concentrations of individuals and densifications of passing populations that have been exploited by man since ancient times. The fishing gears mainly used to this aim were driftnets and trap nets, designed for improving the fishing yield mostly of tunas and swordfish (Silvani et al. 1999; Tudela et al. 2005). Nevertheless, driftnets gears have been proven to concentrate a high bycatch rate of other HMS species of conservation concern and, for this reason, they were recently banned (UNEP-MAP-RAC/SPA. 2015).

The highly mobile behaviour of these species, which is typical of large pelagic fishes, implies a link between the fishing stocks at both sides of the Strait of Gibraltar. However, recent studies revealed significant genetic differentiation between Mediterranean and Atlantic populations of certain fish species. As a consequence, the population of species such as, for instance, *Coryphaena hippurus*, within the Alboran Sea must be considered as a management unit different from those outside the Mediterranean (Sacco et al. 2017).

On the other hand, the hydrographic front between Oran and Almeria has been effective in maintaining a low presence of endemic Mediterranean species in the Alboran Sea, even though the Mediterranean as a whole house a large number of endemic species. For example, only 10 of the 248 infralittoral fish species reported in the Alboran Sea (Reina Hervás et al. 1982; Reina-Hervás 1987; Reina Hervás 1989; Reina Hervás and Serrano 1987a, b; Reina Hervás and Serrano 1993) are exclusive to the Mediterranean. Examples of endemic Mediterranean fish that are absent from the Alboran Sea are *Coelorinchus mediterraneus*, *Gouania willdenowi*, *Paralepis speciosa*, *Pegusa nasuta*, *Syngnathus tenuirostris*, and *Nansenia iberica* an Iberian mesopelagic endemism (500–800 m depth) that lives around the Balearic Islands and the Iberian Peninsula but not in the Alboran Sea. There are also Mediterranean endemics that avoid the Alboran sea or hardly penetrate there (e.g. the gastropod *Tricolia speciosa* in addition to the already mentioned *Homalopoma sanguineum*, or the bivalves *Cardites antiquatus* and *Glans trapezia*). Probably also due to the ecological characteristics of the Alboran basin, such as the scarce flow of the rivers, the fish endemic species *Aphanius iberus*, which have freshwater preferences but also inhabits marine habitats (e.g. estuaries and the Mar Menor) is also absent from Alboran (Crivelli 2006).

Consequently, the historical, geographical, and hydrographic characteristics of the Alboran Sea have affected both the internal composition of its biota and the relationship with that of the surrounding waters, which warrants the consideration of the Alboran Sea as a valid biogeographical entity. This has been particularly well established for certain groups of species, such as sponges (Maldonado and Uriz 1995). The biogeographical identity of the area is also recognized in the classification by Spalding et al. (2007) as an ecoregion independent of the rest of the Mediterranean.

Several internal biogeographical regionalizations have been also proposed for the Alboran Sea. Using checklists of macrophytes from Cádiz (Spain) to Italy on the European coast, and from Tangier to Tunis on the African coast, Conde (1989) identified two subsectors in the Alboran Sea, divided by an imaginary line that joins Calaburras (Málaga) with the border area between Morocco and Algeria, passing along Alboran Island. He pointed to several species as evidence of the presence of these subsectors, with *Posidonia oceanica* and *Rissoella verruculosa* occurring only in the oriental sector, and *Fucus guiryi* and some Laminariales in the Atlantic sector, and considered that the incoming Atlantic water was the main driver of the benthic macroalgae biogeography in the Alboran Sea.

In more recent studies, focused only on macrophytes of the littoral and upper sublittoral areas of the north coast of the Alboran Sea, three oceanographic and three biogeographic subregions were identified, exhibiting a “very good” or “excellent” correspondence between them (Bermejo et al. 2015, 2016). Biogeographic subregions were characterized by landscape and species composition. The western subregion spans from the Strait of Gibraltar to Calaburras, and is characterized by a flora with elements of very different affinities, but rich in Atlantic species, which reflects the fact that this subregion is immersed in a conjunction point of three ecoregions (Spalding et al. 2007). A quasi-permanent zone of upwelling influences the flora and landscape of this subregion, providing relatively stable environmental conditions. The central subregion spans from Calaburras to Punta Entinas (Almería), and lacks typical Atlantic or Mediterranean communities, besides holding the lowest species richness and a less differentiated flora. *Mytilus* beds are shared with the western subregion as an important element of its landscape and species composition, but combined with some other characteristic species of this subregion such as *Corallina* spp., *Gongolaria* spp., *Ericaria* spp. or *Halopteris scoparia*, and a great number of species with widespread distribution (Cebrián and Ballesteros 2004). Fluctuating temperature and nutrient availability, related to strong upwelling processes and incoming of Mediterranean surface waters, may explain the dominance of filter-feeder organisms (Vargas-Yáñez et al. 2002; Bermejo et al. 2015, 2016). As with other marine organisms in Alboran, this coastal section includes the distribution limits of both Atlantic and Mediterranean species, such as *F. guiryi* and *P. oceanica*, respectively. The eastern subregion covers from Punta Entinas to Cabo de Palos (Murcia) and shows a typical Mediterranean flora and marine landscape, characterized by slow-growing *Gongolaria* spp., *Ericaria* spp. and extended *P. oceanica* meadows, together with several Mediterranean endemics such as *Acetabularia acetabulum* or *Halimeda tuna* (Ballesteros and Pinedo 2004). This flora differs greatly from the two other subregions, due to the wider thermal amplitude along the year, and the prevalence of oligotrophic waters due to the dynamics of the water, which favours slow-growing species (Duarte 1995).

11.4 Patterns of Distribution of Species

The Alboran Sea is also notable for the diverse biogeographic relationship of its biota since it is a confluence area of the Lusitanian, Mauritanian, and Mediterranean biogeographical regions. In fact, several biotic elements are distinguishable within Alboran, namely the endemic Mediterranean, Atlanto-Mediterranean, African, and Boreal, with some species strictly endemic to the Alboran Sea.

Some species appear to be endemic to the Alboran Sea with very small distribution ranges (Fig. 11.4), such as the molluscs *Tritia tingitana* (Pallary 1901) and *Cassiella abylensis* (Gofas 1998) in the Strait of Gibraltar, or *Trophonopsis alboranensis* (Smriglio et al. 1997) on the Alboran platform. In other less thoroughly known groups, there are also species only recorded from the Alboran Sea (sometimes, only recorded from their type locality) but it is difficult to know if their range is indeed restricted, or it is an artefact created by a limited sampling range. For instance, although a fish species does exist with the specific name “alboranensis”, *Protogrammus alboranensis* (Farias et al. 2016), it has been posteriorly found outside the Alboran Sea.

Among the Mediterranean endemic biotic element, the most notable is the seagrass, *Posidonia oceanica*, which reaches its western limit in Estepona and has

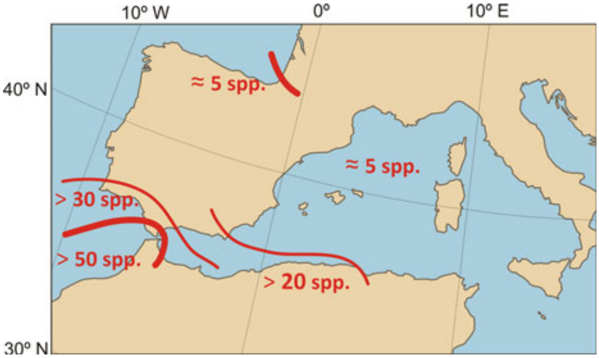

Fig. 11.4 Approximate numbers of thermophilous mollusc species with West African affinity present in the Mediterranean (redrawn from Gofas and Zenetos 2003)

its last important populations in Calahonda (Málaga). Ten infra-littoral fish species (*Raja asterias*, *Syngnathus abaster*, *Gobius strictus*, *Pomatoschistus kneri*, *P. quagga*, *Pseudaphya ferreri*, *Blennius incognitus*, *Symphodus rostratus*, *Opeatogenys gracilis*, and *Arnoglossus kessleri*) are endemic to the Mediterranean (Reina Hervás and Serrano 1987a, b; Reina Hervás and Serrano 1993). The Alboran Sea also hosts most of the populations of the *Patella ferruginea*, catalogued "in danger of extinction". This and other Mediterranean species (e.g. the intertidal gastropod *Phorcus richardi*) reach the Strait of Gibraltar but do not penetrate further into the Atlantic. However, the Alboran Sea is characterized by a low presence of Mediterranean endemics, probably due to the effect of the incoming Atlantic body of water, which forms a permanent gyre clockwise in Alboran that is separated from the rest of the western Mediterranean basin by the well-marked hydrographic front between Oran and Almeria. The Alboran Sea is also the core distribution area of the Mediterranean orange coral *Astroides calycularis*, which has a limited geographical distribution in the straits of Sicily and Messina, the Gulf of Naples and Malta, but mainly occurs in the Alboran Sea, from the Strait of Gibraltar to Cabo de Palos on the European coast and from Morocco to Tunisia on the African coast. Probably as a result of the currents that disperse the larvae from the Alboran Sea, there are also specimens in Cape Espartel (Morocco) and Cádiz (Spain) (Terrón-Sigler et al. 2015).

The most common pattern among species living in the Alboran sea is that of an Atlanto-Mediterranean range spanning both the Mediterranean (or most of it) and, in the Atlantic, the Ibero-Moroccan area or further. Nearly half of the molluscan species recorded by Urra et al. (2017) in the Calahonda Special Area of Conservation (Málaga) have this kind of distribution, as it is also the case of infralittoral fish, with 30% of them being Atlanto-Mediterranean and an additional 18% more strictly Ibero-Moroccan (Reina Hervás and Serrano 1987a, b, Reina Hervás and Serrano 1993). A majority of Cnidarians from the coast of Granada assessed by Ocaña et al. (2000) are also Atlanto-Mediterranean, as are other fish species such as *Galeus atlanticus* or *Squalus megalops*. During the last 30 years, there has been a growing presence of Atlantic species, mainly fish, on the coasts of the Alboran Sea. These presences would be favoured by an increase in the flow of water through the Strait and hydroclimatic modifications of the area. Psomadakis et al. (2012) quantified in

Fig. 11.5 Large kelps of the genera *Sacorrhiza* and *Laminaria* are a prominent feature of the surroundings of Alboran Island and are unique in the Mediterranean. (photo JC Moreno)

48 the Atlantic fish species that have penetrated the Strait of Gibraltar into the Mediterranean in recent years.

Another element that contributes notably to the richness of the area is the presence of African species, which reach in the Alboran sea their northern limit of distribution (Fig. 11.5), such as the limpet *Cymbula safiana*, the mussels *Perna perna* and *Modiolus lulat*, the gorgonians *Eunicella labiata* and *Leptogorgia guineensis* (Ocaña et al. 2000), the hermit crab *Pagurus mbizi* (García Raso et al. 2014), a high number of Atlantic subtropical fish species such as *Hyporthodus haifensis* and *Ephippion guttifer*, 24% of Alboran infralittoral fish, and many more.

Less prevalent are the elements of Atlantic boreal fauna that penetrate the westernmost Mediterranean but not further, as is the case, for example of the hagfish *Myxine glutinosa*. The most spectacular instances are to be found among brown algae, for example *Fucus guiryi* reaching eastwards to Calahonda (Málaga), *Laminaria ochroleuca*, and *Saccorhiza polyschides*, found around the Alboran platform (Fig. 11.6). Much of those have a very short range inside the Mediterranean and most of them, like the intertidal molluscs *Littorina saxatilis* and *Patella depressa*, do not extend further than the Strait proper. In addition, 21% of infralittoral fish belong to this biogeographic element.

An analysis of the internal biotic elements of the Alboran Sea derives from the study of the chorotypes (species sharing their spatio-temporal distribution) inferred from the data of the MEDITS survey. The MEDITS demersal fishing survey (Bertrand et al. 2002) was conducted by the Spanish Institute of Oceanography for 19 years, between 1994 and 2012, between 30 and 800 metres deep, and included the

Fig. 11.6 Some of the endemic molluscan species from the Strait of Gibraltar. Top row: *Tricolia tingitana*, *Granulina vanhareni*, *Gibberula jansseni*; bottom row: *Cassiella abylensis*, *Onoba josae*, *Pusillina testudae*; to the right, *Tritia tingitana*, the largest species about 1 cm high and known since 1901; all the others are minute and were discovered only in the 1980s

Alboran Sea together with other Spanish Mediterranean waters. Depth was the most influential factor to explain the distribution patterns of these fish species in the Alboran Sea. For example, a chorotype was composed of shallow species (71.2 m average depth), including *Arnoglossus thori, Diplodus vulgaris, Pagrus pagrus, Scorpaena notata, Serranus cabrilla, Spondyliosoma cantharus*, and *Trigloporus lastoviza.* These species live near the coasts and on the whole continental platform. They share rocky but also sandy and muddy habitats. There are years in which populations of these species are absent, or are less frequent in large areas, including the Alboran Sea. A second chorotype, however, was composed of *Gadiculus argenteus, Gaidropsarus biscayensis, Helicolenus dactylopterus, Lepidopus caudatus, Lophius budegassa, Micromesistius poutassou, Phycis blennoides, Scyliorhinus canicula* and *Symphurus nigrescens*, and occurs mostly at the limits between the continental shelf and the slope (300 m).

In recent years, a process of tropicalization of the ichthyofauna is evidenced by the northward range expansion of southern species which are either reported for the first time in the Mediterranean, as is the case of *Acanthurus monrovie* (Langeneck et al. 2015) and *Cantigaster capistratus* (Galeote 2001; Brito et al. 2007), or increase their number, as occurs with *Katsuwomus pelamis* (Saber et al. 2015) or *Thunnus obesus* (J.C. Báez, personal observation). This process could be due to a combination of increasing sea surface temperature and anthropogenic effects.

11.5 Species Richness

The Alboran Sea stands out for the richness of its biota, in part because of its location at the crossroads of the already mentioned Lusitanian, Mauritanian and Mediterranean marine biogeographical regions. This makes the area a place of confluence, blending Mediterranean species with others belonging to the subtropical fauna of North-West Africa or to the temperate biota of the European Atlantic. The consequence of this is that its waters are among the most species-rich of all European seas and are of foremost importance for the preservation of regional biodiversity. The knowledge about this richness is of importance to the commercial use of Alboran waters, and the scientific survey effort has been in part associated to this use.

With regard to fish, the general knowledge of Alboran species richness is based on a long tradition of using sea products of the Alboran Sea, mainly on the European coast. The Greek geographer Strabo (64 BC-23 AD), in his Geography, mentioned salted fish from Algeciras, Sexi (Almuñécar), and Malaka (Málaga). The mentioned salted products were not only tuna, but moray eels, sturgeons or mackerels, and smaller fish. In more recent times, numerous scientific authors documented a series of lists of fish that were used in the coasts of the Alboran Sea, especially in its Spanish slope, among them García de la Leña (which is a pseudonym for Cristobal Medina Conde) who in 1789 named 139 fish caught in the coasts of Málaga (García de la Leña [Medina Conde] 1789) and Steindachner (1868) who reported 203 species from the Spanish coasts of the Alboran Sea.

The investigations on the marine biodiversity of the south of the Alboran Sea did not start until the twentieth century, when the Biological-Marine Station of Málaga, from which derived the current Spanish Institute of Oceanography, was created in 1911 by Odón de Buen, according to his words, “due to the scientific importance of the Strait of Gibraltar”. He organized the first African biological expeditions along the Rif coast (Melilla-Chafarinas-Cabo Tres Forcas), between 1908 and 1912 (Camiñas 1997; Pérez de Rubín 2011). As a result, the first important works on the ichthyofauna of the Moroccan side of the Alboran Sea were published by Odón de Buen (de Buen 1912, 1913, 1926), reporting 127 species, and by Fage (1912), who collaborated with the taxonomic identification of 82 other species.

In total, 508 species of fish, of which 430 species are bony fish, 75 species are cartilaginous fish, and 3 species are agnatha, have been historically cited in the Alboran Sea. The recently published checklist of marine species in Spanish waters (MAGRAMA 2017) only considered species recently found in Alboran, and reduced these numbers to 465 species of fish, grouped into 133 families, of which 389 species are bony fish (108 families), 75 species of cartilaginous fish (24 families) and 1 species of agnatha (1 family). The MAGRAMA (2017) checklist recorded 5409 species of marine fauna and flora as occurring in the “Strait of Gibraltar and Alboran” demarcation, and another 169 “revisable” species whose presence requires confirmation. This represents, in a relatively small area, one-third of the total known species of the Mediterranean Sea (Coll et al. 2010).

A macroecological implication of the biogeographical role of the Strait of Gibraltar and the Alboran Sea as transition zone is that they give place to several spatial trends in species diversity. In general, marine species richness is known to decrease bathymetrically from the surface to the deep seabed, latitudinally from the equator to the poles, and longitudinally in many locally idiosyncratic ways and usually linked to historical processes (Gray 2001). Due to the effective barrier effect of the shallow Strait of Gibraltar for deep biota, the bathymetrical gradient in species richness is acute, and the deep sea diversity in the Alboran Sea is especially low in relation to the adjacent Atlantic Ocean (Coll et al. 2010). By contrast, the infralittoral biota, which refers to the area which is permanently submerged up to the depth with presence of photophilic marine algae and seagrass (normally, and depending on the quality of the waters, down to 20 or 30 metres deep, sometimes more than 60 m) is highly diverse. The community of fish inhabiting the infralittoral area is very important, as well as the variety of ecosystems or biocenoses found in it, particularly the seagrass communities of the genera *Zostera*, *Cymodocea*, and *Posidonia*. Studies carried out since 1980 (Reina Hervás et al. 1982; Reina Hervás and Nuñez 1985; Reina-Hervás 1987; Reina Hervás 1989; Reina Hervás and Serrano 1987a, b; Reina Hervás and Serrano 1993) on the infralittoral ichthyofauna (0–20 m deep) of the coast of Málaga reported a total of 248 species of fish that are considered frequent in this zone, belonging to 65 families, being *Bleniidae* with 22 species, *Labridae* with 21, *Gobiidae* with 20, and *Sparidae* with 19 species the most frequently represented.

Below the infralittoral zone, the Spanish Institute of Oceanography conducted several fishing surveys, both in Spanish and in Moroccan waters (Gil de Sola 1994; Gil de Sola et al. 2017). The MEDITS demersal fishing survey was the most extensively studied. Several studies of this faunistic database analyzed specifically the demersal ichthyofauna of the Alboran Sea (Lloris et al. 2000; Gaertner et al. 2013; García-Ruiz et al. 2015; Gil de Sola et al. 2017). A total of 186 species were inventoried in the Alboran Sea (27% of the total of those mentioned for the Mediterranean), encompassed in 3 classes, 24 orders, and 69 families. The values of total abundance were higher in the continental shelf than in the slope, decreasing sharply from it. The interval between 301 and 500 m. appeared as a transition zone where certain species, more abundant in the shelf, disappeared, and those that are typical of the slope showed up, with the exception of eight species considered as eurybathic (*Conger conger*, *Helicolenus dactylopterus*, *Lepidopus caudatus*, *Lophius budegassa*, *Merluccius merluccius smiridus*, *Pagellus acarne*, *Pagellus bogaraveo*, and *Symphurus nigrescens*), which were distributed throughout the bathymetric range studied.

On the contrary, due to the short latitudinal and longitudinal variation encompassed by the Alboran Sea, the species richness gradients associated to their respective geographical ranges are moderate. Latitudinal variations are observed in the Alboran Sea, although not very frequently. For example, the Scombridae *Orcynopsis unicolor* is frequently found in the landings at Moroccan Alboran ports, but it is rare in ports of the Spanish Alboran coast (UNEP-MAP-RAC/SPA 2015). Longitudinal distribution gradients in species richness also exist (Fig. 11.5), normally due to extinction-recolonization processes associated to the distance to the Strait of Gibraltar of the kind that have been used to explain the longitudinal gradient of chondrichthyes species richness in the Mediterranean Sea (Meléndez et al. 2017). There is also a longitudinal pattern of westward gradual substitution of the Mediterranean flora and fauna that makes them increasingly more similar to the Atlantic ones. The Atlantic character of the fish fauna of the Mediterranean is particularly high in the area of influence of the Atlantic, i.e. between Gibraltar and Malaga in the north and along the northern coast of Morocco in the south (especially between

200 and 400 m deep), while this character is decreasing eastwards. A total of 23 fish species or subspecies frequent in the Atlantic correspond to this type of distribution in the Mediterranean; 3 of which do not exceed the limits of the Alboran Sea.

11.6 Macroecological Patterns and Processes

Other macroecological studies have shown the effect of macroclimatic oscillations, captured in indices such as the North Atlantic Oscillation (NAO) or the Arctic Oscillation (AO), on the physical and biological characteristics of the Alboran Sea. These broad-scale atmospheric oscillations affect several climatic factors (e.g. water temperature, prevailing wind direction and speed, and precipitation) at more regional scales. This results in a macroecological teleconnection atmosphere–ocean–primary producers. The first step in this chain of effects was addressed in several oceanographic studies that described the effect of the NAO and AO on the sea surface temperature of the Alboran Sea. Báez et al. (2013), for example established that positive AO values before the summer imply a colder atmosphere in the Polar Regions, which could spell occasional cold waves over the Iberian Peninsula that, when coupled with precipitations favoured by negative NAO values, usually result in snow precipitation. This snow typically accumulates in the high peaks, particularly in the Sierra Nevada, and melt down in the next spring-summer season. As a consequence, summer runoff of freshwater to the Alboran Sea increases, which in turn triggers a diminution of sea surface salinity and density, and blocks the local upwelling of colder water, resulting in a higher sea surface temperature (SST) in the Alboran Sea. Finally, many embryonic and larval phases of algae and animals are correlated with high sea temperatures (Vargas-Yáñez et al. 2009) which have an impact on whole populations.

This kind of teleconnections has been shown to affect, in particular, the physical condition of pre-reproductive bluefin tuna (Báez et al. 2013) or the fishery yields of the blackspot seabream *Pagellus bogaraveo* (Báez et al. 2014) from the Strait of Gibraltar, and the presence or absence of the brown seaweed *Fucus guiryi* in the Alboran Sea (Melero-Jiménez et al. 2017). It has been also related to the incidence of jellyfish swarms on the beaches of the province of Málaga, in the northern coast of the Alboran Sea (Bellido et al. 2020).

In a good example of macroecological study, Melero-Jiménez et al. (2017) demonstrated, based on a survey extending over 26 years (from 1990 to 2015), that the survival of the thalli of *F. guiryi* at Punta Calaburras (North Alboran Sea) in midsummer correlates with the overall mean NAO value recorded from April to June. The presence of the species was clearly favoured under positive NAO, whereas the algae did not survive or did not develop from microscopic stages under negative overall mean NAO values from April to June. The sequence of events for the persistence until midsummer of *F. guiryi* thalli at Punta Calaburras could imply the growth from microscopic, cryptic stages, as well as the arrival of few-celled embryos originating from the populations located on the shores of the Strait of

Gibraltar in winter-spring, followed by growth of young thalli if the SST remains relatively low, which is macroecologically affected by the NAO. However, the survival of the thalli could be also favoured by the effects of the NAO over the Atlantic Jet (AJ). The position of the AJ coming from the Atlantic Ocean into the Mediterranean Sea is variable (Vargas-Yáñez et al. 2002; Macías et al. 2016) with a north-south migration pattern (Sarhan et al. 2000). The speed of the incoming AJ increases at low pressure over the western Mediterranean (Timplis and Josey 2001; García-Lafuente et al. 2002). Increasing velocity enhances the Coriolis force and separates the AJ from the Spanish coast, facilitating the upwelling of cold Mediterranean water (14 °C to 17 °C) at the Spanish coast and, consequently, allowing the survival of *F. guiryi* thalli. A similar pattern was suggested by Lourenço et al. (2016) in other locations where this species appears associated with an upwelling. In contrast, under negative NAO index, the AJ velocity might decrease and the Western Alboran gyre, characterized by warmer water, migrates northward and may reach the coast at Punta Calaburras. This increases the probability of short-term periods of very warm water (up to 22 °C) that hinder survival of *F. guiryi* thalli under negative NAO index.

The occurrence of harmful algal blooms (HABs) is also a function of the physical and environmental controls acting on the HAB species and, for this reason, it must be considered as a macroecological phenomenon. Recent studies suggested that the occurrence in the Alboran Sea of the toxic dinoflagellates *Gymnodinium catenatum* (producer of the PSP toxin) could be modulated by the NAO of the previous 4 months, while the appearance of *Dinophysis acuminata* (producer of the DSP) could be linked to the AO from 3 months before. This implies a relationship between interannual and multidecadal-scale variability of atmospheric oscillations and HABs similar to that suggested for the northeast Atlantic (Edwards et al. 2006; Hinder et al. 2011).

This macroecological relationship between Alboran populations and macroclimate leads to thinking that climate warming and, more generally, global change is affecting both species composition and ecology. Future scenarios contemplating an increase of extreme values in atmospheric cycles due to climatic change have been proposed (Vicente-Serrano et al. 2011). It could therefore be hypothesized, for example, that toxic algal events will increase in association with increased extreme values of NAO and AO indices, taking into account the significant favourabilities already demonstrated for HAB in the marine systems of SW Europe. In fact, it has been proposed that HAB caused by dinoflagellates (Hallegraeff 2010; Philipparta et al. 2011; Fu et al. 2012) will increase as a result of climate change. Recent nesting events of loggerhead sea turtle (*Caretta caretta*) are also occurring periodically on the Spanish Mediterranean coast since the first reported nesting in Vera, northern Gata cape, in 2001 (Tomas et al. 2002) and the recent nesting in northern Alboran (Báez et al. 2020), in what seems to be an increasing trend in nesting of this species in this basin. This change in the nesting behaviour of this species seems to be related to changes in climate and beaches temperature. Clearly, more studies must be carried out on this matter. On the other hand, the effect of overfishing must also be considered, as it destroys funds and alters the structure of the communities of native species, leaving ecological "niches" available. In this sense, the introduced hermit *Pagurus mbizi* has been captured between 50 and 150 m (maximum frequency over 70 m), depths in which many of the trawlers in the area normally fish. In concurrence with this view, Froglia et al. (2017) pointed out that there are major changes in the structure of decapod crustacean communities in the Adriatic (in the western Meso-Adriatic depression) due to the synergistic action of fisheries and global change.

11.7 Alien Species

Compared to other parts of the Mediterranean such as the eastern basin, the Adriatic or the Gulf of Lion, the Alboran Sea has a low incidence of non-indigenous species. One possible reason lies precisely in the richness and diversity of its indigenous fauna and flora, which some scholars hold as a factor promoting resistance to biological invasions (Stachowicz et al. 1999; Kennedy et al. 2002). While about a thousand exotic species have been recorded in the Mediterranean, only a few (*Caprella scaura, Paracaprella pusilla, Godiva quadricolor, Anteaeolidiella cacaotica, Marginella glabella, Oculina patagonica, Aplidium lobatum*, and *Microcosmus squamiger*) are definitely established in the Alboran Sea according to the Spanish checklist (MAGRAMA 2017) (Fig. 11.7).

The coral *Oculina patagonica*, originally described as a fossil from South America, has been claimed, even recently, to be introduced in the Mediterranean. However, genetic data (Leydet and Hellberg 2015) indicate that the Mediterranean populations are not conspecific with those of the southwestern Atlantic and

Fig. 11.7 The alien sea slug *Godiva quadricolor*, first recorded around marine farming facilities in Granada and in a harbour environment in the Straits of Gibraltar. The animal is about 3 cm long

therefore, the species so-called exotic in the Mediterranean is likely to be native and to have been misidentified.

The spectacular West African gastropod *Marginella glabella*, reported in the fishing harbour of Málaga by Luque et al. (2012), was speculated to have been imported when the fishing fleet routinely operated on Saharan fishing grounds. The species persisted in the fishing harbour of Málaga, without spreading, at least for some years.

Another introduced species that comes from West Africa is the crab *Cryptosoma cristatum*, which was captured in Malaga in 1993 (García Raso 1993, as *Cycloes cristata*). However, the origin of the presence in Alboran of some African crustacean species is not clear, as they could be either introductions or the result of a natural advance. For example, *Synalpheus africanus*, which may come from the Atlantic or Mediterranean African coasts (García Raso 1984b), is a very coastal species that has been able to enter with ballast water from ships or transported (as larvae) by currents. *Acantharctus posteli* (= *Scyllarus posteli*) was first found in Europe in Cádiz and is most likely the result of an introduction (Pozuelo et al. 1976; García Raso 1982) but its presence in Alboran (Málaga) is the result of a natural progression. Another case would be the crab *Brachynotus atlanticus*, which was first cited for Europe in Alboran (Málaga) (García Raso 1984a) but, in European waters, only has well-established populations in the Gulf of Cádiz (García Raso 1985; unpublished data), so its presence in the Alboran Sea would be a case similar to that of *Acantharctus posteli*. Another more recent case is that of the pea crab *Afropinnotheres monodi*, which lives inside the mussel (*Mytilus galloprovincialis*), was first caught in the Bay of Cádiz and shows a progress towards the Mediterranean coasts (Pérez-Miguel et al. 2017).

In any case, the scarcity of studies on the coast of Mauritania and Morocco (especially in shallow areas) means that the actual distribution of many African species is not well known. This makes it uncertain whether the presence of a species in the South of Spain is due to human introductions or not. As examples, we may mention the prawn *Processa macrodactyla* (García Raso and Salas Casanova 1985), or more recently the hermit crab *Pagurus mbizi* (García Raso et al. 2014), whose northernmost known location before its capture in Alboran was the coast of Senegal.

Since the publication of the MAGRAMA checklist, several additions have been made to the alien fauna. The Alboran Sea is far away from the Suez Canal and, thus, more difficult to reach by the Lessepsian migrants that entered the Mediterranean through this waterway. Still, the record of a Lessepsian migrant *Bursatella leachii,* a sea-hare, in the Alboran sea was made very recently (March 2018, J.D. Moreno, pers. comm.) at Marina del Este (Granada). Another recent addition is the sponge *Paraleucilla magna*, reported as spreading fast inside the Mediterranean including the Alboran Sea (Guardiola et al. 2016). In relation to decapod crustaceans, the only strictly invasive alien species is *Percnon gibbesi*, which entered the Suez Canal into the Mediterranean in 1999 (Katsanevakis et al. 2010; IUCN–MedPAN 2012) and whose most recent and western location is in the Alboran Sea, in 2017 on the coast of Almeria (near the border with the province of Granada). Nonetheless, the Alboran Sea seems to resist invasions better than other marine areas of Europe. Azzurro et al.

(2013), for example provided an environmental model of the invasion of the Lessepsian fish *Fistularia commersonii* and found the Alboran Sea to be one of the least favourable areas for this invasion.

Few species of fish have been reported as alien in the Alboran Sea, and none of them seems to be related to anthropogenic causes. This contrasts with, for example the Catalan coasts, where two highly invasive species (*Zebrasoma flavescens* and *Balistoides conspicillum*) have been reported (Weitzmann et al. 2015), resulting from an aquarium release. However, several species are considered to be casual o alien in the Alboran Sea, among them *Fistularia petimba*, *Galeocerdo cuvier*, *Gephyroberyx darwini*, and *Microchirus boscanion* (Massutí et al. 2002; Zenetos et al. 2005).

Among the most impacting alien species are the marine algae. In the last 20 years, both coasts of the Alboran Sea have been suffering the successive invasion of three Pacific seaweeds (in order of report *Asparagopsis taxiformis*, *Caulerpa cylindracea*, and *Rugulopteryx okamurae*), which are deeply altering lower subtidal communities (Altamirano et al. 2008, 2014, 2017). Maritime transport is suspected to be the main vector for introducing these species, both from the Strait of Gibraltar and from the oriental region of the Mediterranean Sea (Boudouresque et al. 2017). The relationship between these invasions and climate change is not clear yet, although some evidence exists that changes in SST may produce changes in distributional patterns of these species (Zanolla et al. 2018). The green alga *C. cylindracea* forms continuous meadows in the Cabo de Gata National Park, and until the recent proliferation of *R. okamurae*, also close to the Strait of Gibraltar (Altamirano et al. 2014; Altamirano et al. 2017). Both species compete with photophilic lower subtidal communities, such as forests of *Gongolaria* spp. and *Ericaria* spp., in both sides of the Strait of Gibraltar, homogenizing the community to only one species and, in the case of *R. okamurae*, producing massive drifted material that hinders the recreational use of the beaches (Altamirano et al. 2017).

Continuous incoming of propagules of allochthonous species of macroalgae, transported by merchant ships arriving to the Alboran Sea from the coasts of Pacific East Asia, together with very weakened native communities due to previous invasions, may presage an increase in the frequency of invasion events in the Alboran Sea, which may become a driver of transformation of the marine biota in this unique corner of the Mediterranean. There are impacts from alien species also in the plankton community. The dinoflagellate *Gymnodinium catenatum*, originally described from the Gulf of California (Mexico) and responsible for Paralytic Shellfish Poisoning has become an established species in the Alboran Sea where it causes frequent toxic events (Calbet et al. 2002).

Researchers from the Spanish Institute of Oceanography (Massuti et al. 2010) have reported the recent arrival of non-native fish species in the Mediterranean Sea, in a phenomenon known as “tropicalization”, which may be changing the identity of the Mediterranean. Their data suggest that in the western Mediterranean, where an increase in water temperature has been observed during the second half of the twentieth century, global warming has affected the composition of fish populations. However, these changes do not occur only due to changes in climate. The variations that occur in marine habitats also has an influence, since each species requires certain conditions of temperature, salinity etc. The presence of tropical and subtropical fish in the western Mediterranean has almost tripled in the last three decades, going from the 12 or 15 species that scientists reported in the 1980s to the 38 catalogued in 2010. Almost all of these species come from the subtropical and tropical Atlantic, and entered the Mediterranean through the Strait of Gibraltar. It is difficult to know if any of these new species have formed stable populations, although they do seem to be expanding towards the north and east of the Mediterranean, reaching its eastern basin. Such is the case of the fish species of Atlantic origin *Carcharhinus altimus*, *Acanthurus monroviae*, *Pisodonophis semicinctus*, *Sphoeroides pachygaster*, *Pagellus bellottii*, and *Seriola fasciata*, which have recently entered the Mediterranean through the Strait of Gibraltar, and have already reached the coasts of the Eastern Mediterranean.

An example of progressive advance from Africa for crustaceans is the hermit *P. mbizi*, which was captured in 2006, 2007, and 2009 in the westernmost area of the Alboran Sea (Málaga: Estepona, Marbella), later in 2010–2011 in the central zone (coast of Granada) and later, from 2010 to 2013, specimens were already captured in the eastern sector (Almería: Adra, Almerimar near Roquetas de Mar).

Consequently, the biota of the region keeps changing and the Alboran Sea stands as a critical area for monitoring changes in species distribution.

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Chapter 12
Biophysical Processes Determining the Connectivity of the Alboran Sea Fish Populations

Jesus Garcia-Lafuente, Jose C. Sanchez-Garrido, Alberto Garcia, Manuel Hidalgo, Simone Sammartino, and Raul Laiz

12.1 A Short Review on Connectivity Issues

Hydrodynamics is an essential ingredient for the vital developmental rates conditioning the survival of fish populations. This is of special relevance in regions such as the Alboran Sea—Strait of Gibraltar-Gulf of Cadiz area, where the inflow of Atlantic waters through the Strait features a strong surface current in the Alboran Sea that plays a key role in the advection of propagules, either by propitiating their west-to-east transport or by hampering the north-to-south conveyance. A thorough understanding of the physical oceanography of the region is therefore essential for a comprehensive interdisciplinary approach to the study of the early life history and biology of the involved species. Two main concepts arise when dealing with the topic dynamics-of-population: dispersal and connectivity. The former describes the mechanism employed to disperse early life stages of the biological cycle (spores,

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eggs, larvae for benthic or pelagic species, and also juveniles for pelagic ones) and aims at maximizing the spread and at expanding the distribution of the species over the maximum geographical range (Cowen and Sponaugle, Annu Rev Mar Sci 1:443–466, 2009). Marine propagule dispersal relies basically on the environmental dynamics, where turbulence, advection, and diffusion acting at different scales determine the connections or separation of different (sub-) populations of both benthic and pelagic taxa (Dubois et al., Glob Ecol Biogeogr 25:503–515, 2016). The patterns of linkage or isolation, which determine the very development and abundance of certain species in certain areas, are summarized under the concept of connectivity. Two main concepts arise when dealing with the topic dynamics-of-population: dispersal and connectivity. The former describes the mechanism employed to disperse early life stages of the biological cycle (spores, eggs, larvae for benthic or pelagic species, and also juveniles for pelagic ones) and aims at maximizing the spread and at expanding the distribution of the species over the maximum geographical range (Cowen and Sponaugle 2009). Marine propagule dispersal relies basically on the environmental dynamics, where turbulence, advection, and diffusion acting at different scales determine the connections or separation of different (sub-) populations of both benthic and pelagic taxa (Dubois et al. 2016). The patterns of linkage or isolation, which determine the very development and abundance of certain species in certain areas, are summarized under the concept of connectivity.

Connectivity is the result of the interaction of the biological cycle of a species with the dynamic conditions of the marine environment, acting differently according to the size and the age of the propagule, and the scale of the physical phenomenon involved. In fish species with pelagic larval stages, hydrodynamics is fundamental for connecting populations (Cowen et al. 2006). Ocean currents condition the plankton distribution through mesoscale and submesoscale processes that disperse or retain live and inert particles, which are pivotal processes for surviving at early life stages. The study of marine connectivity is essential for a comprehensive understanding of the dynamics of population of fish species, the management of fishing resources in fisheries optimization (Falcini et al. 2015; Patti et al. 2018) as well as the design of Marine Protected Areas (Andrello et al. 2013; Shanks et al. 2003; Rossi et al. 2014). Beyond the exchange of organisms, the connectivity processes can also influence ecological functions and ecosystem services, such as benthopelagic coupling and food web implications across latitudinal and longitudinal gradients, which is often referred to as “functional connectivity” (Gerber et al. 2014). Physical barriers and corridors are critical elements deeply affecting the feeding, reproduction, spawning, and recruitment success of numerous migratory species (CIESM 2016), and natural or anthropogenic alteration of these structures can seriously compromise the presence and abundance of the involved species (e.g., the case of the Atlantic bluefin tuna, Fromentin et al. 2013). The introduction and spread of alien species is a typical example of artificial connectivity prompted by human activities (“impacts connectivity”): ballast water and hull fouling in shipping traffic, aquaculture, and civil structures (stepping stones) can act as artificial substrate capable to improve the transfer of alien species to new habitats (CIESM 2016). Connectivity also works at different time scales: Long-term (evolutionary) connectivity is, with the exception of very coastal and benthic species, generally high in regions of limited geographical extension (low genetic differentiation). However, for the ecosystems management and fisheries assessment perspective, the connectivity at short and middle temporal scale (i.e., within a year) is more variable and relevant influencing the population dynamics (demographic connectivity) and the long-term populations' persistence. Connectivity research implies the development of varied research tools, ranging from biophysical modelling, population genetics, tag and recapture, and otolith microchemistry.

Hydrodynamic connectivity, understood as the capability of a flow to connect separated areas by exchanging water parcels and their eventual biogeochemical content, depends on the circulation patterns and their variability. Stable currents, as the inflow of Atlantic water in the Mediterranean Sea through the Strait of Gibraltar, promote the exchange of nonresident species among adjacent basins without human intervention (Rodriguez et al. 1982; Whitehead et al. 1986). However, due to the highly unpredictable nature of geophysical flows, in which turbulence, mixing processes, and a wide spectrum of spatial and temporal scales are involved, understanding and addressing this connectivity is one of the main challenges in modern ecology. Despite the many limitations due to the number of spatial scales resolved and the unavoidably simplified role of the biotic component, numerical models are affordable tools that provide reliable results to delineate the main patterns of connectivity (CIESM 2016; Werner et al. 2001; Conklin et al. 2018). Models must increase resolution in coastal areas and resolve at least the mesoscale satisfactorily (and as much submesoscale as possible) since these processes are essential for connectivity. Thus, previous knowledge of the hydrodynamics, the circulation patterns, and their variability become fundamental issues to build up models in a given region. Biological traits and life history of the fish species concerned, especially those impacting the early life stages, are equally important. These issues are the focus of this chapter.

12.2 Hydrodynamic Connectivity and the Alboran Sea Circulation

12.2.1 Mean Circulation Pattern and Mesoscale and Seasonal Variability

Regarding the surface circulation of the Mediterranean Sea, the Alborán Sea may be seen as a zonal-oriented basin that conveys the inflow of Atlantic water through the Strait of Gibraltar toward the interior of the Mediterranean (Vargas-Yañez, this book). This eastward flow, with typical speed of 1 m/s, is a meandering stream (the Atlantic Jet, AJ hereinafter) that usually encircles two medium-sized anticyclonic gyres (referred to as WAG and EAG for Western and Eastern Alboran Gyres hereinafter, see sketch in Fig. 12.1) where newly arrived Atlantic water accumulates (Parrilla and Kinder 1987; Viudez et al. 1998; Vargas-Yañez, this book). They are

Fig. 12.1 Sketch of the average surface circulation of the Alboran Sea and Gulf of Cadiz overlying the MODIS image of January 25, 2003 (NASA Goddard Space Flight Center, EOS Project Science Office). Solid thick lines outline the two anticyclonic gyres (Western and Eastern Alboran Gyres, WAG and EAG, respectively, and the Atlantic Jet, AJ). Dashed line is the Central Cyclonic Gyre (CCG). Some locations (in white) and geographical features (deep yellow) are labelled

separated by a cyclonic structure, referred to as Central Cyclonic Gyre, CCG (Renault et al. 2012). This ensemble of mesoscale structures represents the widely accepted mean pattern of surface circulation in the Alboran Sea. Such a pattern, with the AJ flowing along the middle of the basin, favors the isolation of north and south shore ecosystems or, at least, establishes a considerable obstacle for their hydrodynamic connection.

Intermediate and bottom circulation consist of waters of Mediterranean origin moving sluggishly toward the Strait underneath the surface Atlantic layer (Vargas-Yañez, this book). A spatial differentiation is found in that Levantine and other Intermediate waters flow closer to the Spanish shore whereas Western Mediterranean deepwater moves along the African coast (Naranjo et al. 2015; Garcia-Lafuente et al. 2017). All they overflow the main sill of the Strait and spread into the Atlantic Ocean. Except for the Strait area itself, their typical speed is one order of magnitude less than the surface counterpart. Its seasonal variability is more reduced and linked to the formation of deep water in the Gulf of Lions (Garcia-Lafuente et al. 2009). In a regional scenario where the average upper layer flow is to the east, the intermediate-deep circulation provides a chance for hydrodynamic connection in the opposite direction.

12.2.2 *Short-term Variability: Instabilities*

The previous description suggests mesoscale scenarios simpler than those actually found in the Alboran Sea. The AJ and the surface circulation are full of submesoscale

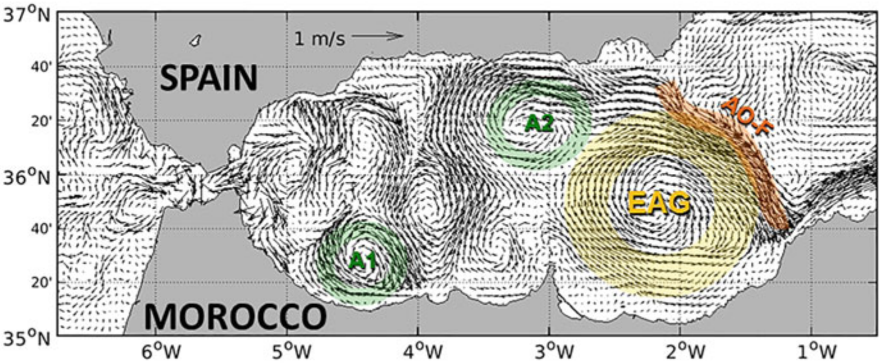

Fig. 12.2 Hindcast of the surface velocity field at 17:45 on March 17, 2004, produced by the numerical model employed by Sanchez-Garrido et al. (2013). The WAG is not present and has been replaced by a number of submesoscale eddies. The snapshot shows a well-developed EAG and Almeria-Oran front (AO-F) in contact with a medium-size anticyclonic gyre (A2) that could well correspond with a declining old WAG and that seems about to be merged with the EAG. Another smaller anticyclonic gyre (A1), which is probably the seed of a future WAG, is attached to the southeast coast of the basin. The time scale for this unorganized submesoscale field is of the order of days

structures (in the order of few km) displaying submesoscale variability (in the order of days or, even, hours). Fig. 12.2 is a realization of the surface circulation produced by a high-resolution numerical model (Sanchez-Garrido et al. 2013) that highlights the richness of submesoscale structures in the western Alboran Sea. In this case, the EAG emerges as a well-defined structure bounded at the east by the Almeria-Oran front, whereas the area that should be occupied by the WAG displays seven submesoscale eddies at least, either cyclonic or anticyclonic, which will last for several days before disappearing or merging together selectively in order to form an incipient new WAG.

The origin of submesoscale and, also, mesoscale structures as well as their variability lies partially in the properties of the AJ as it enters the Alboran basin. In particular, the generation of relative vorticity in the Strait which is subsequently advected into the Alboran Sea by the AJ seems to play a relevant role (Sanchez-Garrido et al. 2013), as discussed below in this chapter. Other physical mechanisms such as local wind stress, enhanced vertical shear, short-term variability of the Atlantic inflow, internal dynamics (hydraulics) of the exchange through the Strait or, even, baroclinic instabilities have been pointed out as possible causes of the submesoscale variability (Heburn and La Violette 1990; Viudez et al. 1998; Sanchez-Garrido et al. 2013). Most likely, several of these processes are at play concomitantly. Whatever the cause, these time fluctuations open wider the opportunity windows for cross-basin transport.

12.3 The Zonal (East-to-West) Connectivity

The main circulation pattern favors the zonal connectivity, which includes the inter-basin connection Gulf of Cadiz—Alboran Sea through the Strait. Their feasibility and accomplishment depend on the stability of the flow patterns, which suggests two different breakdowns of the topic: the aforementioned inter-basin connectivity that involves a rather permanent flow structure, the AJ, and intra-basin connectivity between different areas of the Alboran Sea, which implies more variable mesoscale scenarios.

12.3.1 Interbasin Connectivity: Gulf of Cadiz-Alboran Sea

The ultimate origin of the Atlantic inflow is the hydric deficit of the Mediterranean Sea and, therefore, the east-going AJ is a rather permanent feature. It enables an intuitive west-to-east surface connectivity between the Gulf of Cadiz and the Alboran Sea, which makes the former basin a potential source of biological material for the Alboran Sea. This material, among which spawning products are particularly relevant for establishing one-direction connected fish stocks, can be displaced downstream with few obstacles. And it happens in a very steady manner due to the permanence of the AJ. Such surface layer connectivity was pointed out by Muñoz et al. (2015), who used geostrophic currents deduced from altimetry in order to track corridors for connectivity in terms of time. Surface connectivity in the opposite direction from the Alboran Sea to the Gulf of Cadiz, is highly improbable as it implies transport against the east-going AJ. Exceptionally, however, under strong meteorological forcing the AJ can be halted or, even, temporarily reversed (Garcia-Lafuente et al. 2002), which gives a little chance for this otherwise highly improbable surface connectivity. According to these authors, the north shore of the Strait is the suitable place for this process to happen since the AJ starts reversing at this shore and then the reversal progresses southwards. If the meteorological forcing is strong enough, the reversal reaches the south coast and the inflow interruption is fully achieved. If it is not, the AJ still keeps on flowing eastwards as a weak narrow stream attached to the African shore. Tides may increase the chances of the short-lasting reversal if the peak of meteorological forcing coincides with the flood (rising tide) tidal current, a realization suggested by trajectories of drifting buoys under the rarely achieved simultaneity of these conditions that have been further confirmed by numerical simulation (Sanchez-Garrido et al. 2014).

Although the surface east-to-west connection is feasible, yet exceptional, biological connectivity would be even more exceptional, as it requires the presence of spawning events at the time of the flow reversal. Such connection, however, is achievable in intermediate and deep layers (i.e., below 150–200 m depth) where the prevailing motion of the Mediterranean waters is to the west. The genuine hydrodynamic connectivity within this depth range is from the Alboran Sea to the Gulf of Cadiz, although a successful biological connectivity depends again on the availability of spawning products at the depths concerned. For fish species that reproduce and breed in depth (i.e., European hake) whose larvae do not migrate to the surface layers, connectivity at depth is a challenging issue that has not been successfully addressed yet (O'Leary and Roberts 2018).

A difference with foreseeable biological consequences between west-to-east surface layer and east-to-west intermediate/deep layer hydrodynamic connectivity arises as for the time a water parcel needs to get through the Strait of Gibraltar from one basin into the other. It is of only 1–2 days for the surface layer because of the high speed of the AJ, and of several days, even weeks, for the lower layer as the speed of the outflow is substantially lower in most of the Strait domain. The difference obviously affects the potential motility of the spawning products in transit through the Strait, which in turn is conditioned by the pelagic larval duration before settlement, since those in the lower layer stay much longer in the zone.

12.3.2 Intra-basin Along Shore Connectivity

Connectivity of different regions in the north shore of the Alboran Sea is favored by the mean surface circulation (Fig. 12.1). The same applies to the south shore. The prevailing zonal circulation does not establish significant hydrodynamic barriers for connectivity, although the variability of the surface pattern may change the direction in which connectivity would occur. Figure 12.3 sketches some of these patterns that have been reported in the Alboran Sea. Fig. 12.3a (it replicates Fig. 12.1) corresponds to the most stable mode of surface circulation, which prevails in summertime (Viudez et al. 1998; Renault al., 2012). In the north shore, it promotes west-to-east connections along the northern meanders of the AJ in the west and east parts of the basin and in the opposite direction in the central part. The direction of the flow along the southern edges of the WAG and EAG makes the east-to-west be the prevailing direction for connectivity in the southern shores of the basin. Obviously, these connectivity patterns change when the surface circulation does, which provides different scenarios in the same geographical area, as suggested by the snapshots in Fig. 12.3.

From this point of view, the relevant feature of zonal intra-basin hydrodynamic connectivity would be the time variability. The hydrodynamic situation that prevails when the biological (spawning) products are available for transport will become the most suitable pattern, if not the only one, for demographic connectivity. For instance, surface circulation in summertime matches the pattern sketched in Fig. 12.3a (Vargas-Yañez et al. 2002; Renault et al. 2012). Therefore, fish species spawning in this season would be prone to west-to-east connectivity along the northwestern sector of the Alboran Sea, which would result in quasi-stable patterns of connected fish stocks. The central area of the north shore, however, would be under the influence of a weak east-to-west transport coupled to a diminished and weak CCG, which would favor the enrichment of the Bay of Malaga and, eventually, endow it with retention characteristics linked to the slow cyclonic circulation of the CCG (Garcia et al. this book).

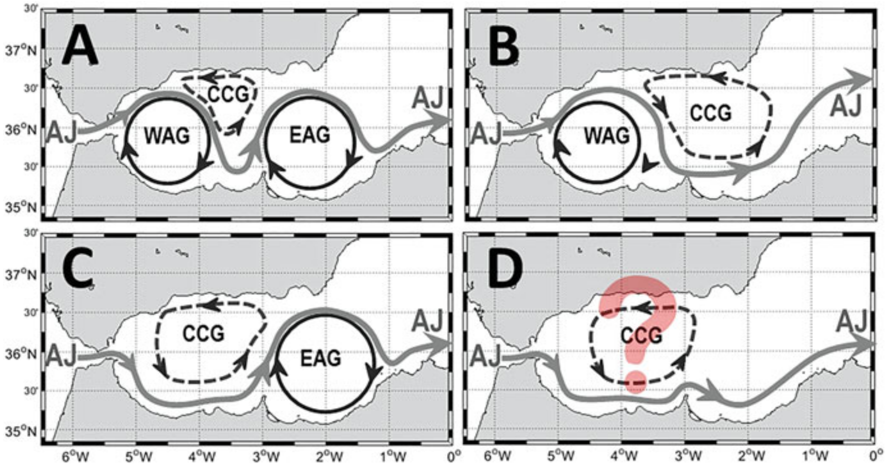

Fig. 12.3 Sketches of possible surface circulation patterns of the Alboran Sea (see caption of Fig. 12.1 for acronyms meaning). Panel **a** is the widely accepted prevailing pattern. In panel **b** the EAG is absent, which allows the eastward stretching of the CCG. Panel **c** is similar to the former but with a missing WAG, which allows for the westward stretching of the CCG. Panel **d** shows no gyres and an AJ behaving as a boundary current attached to the African shore. The presence of a CCG spanning the whole basin is uncertain in this situation (question mark)

12.4 The Meridional (North-to-South) Connectivity

12.4.1 The Atlantic Jet: a Hydrodynamic Barrier

Connectivity between the north and south shores of the Alboran Sea is a more complex issue. At a first glance, it might not be the case since the AJ heading south along the eastern edges of the gyres gives chances for north-to-south transport. And the opposite happens around the western edge of the gyres, which would propitiate south-to-north connection. However, whatever the mesoscale surface circulation, both shores still remain separated by the AJ (Fig. 12.3), and the possibility that biological products from a shore reach the other one depends on the chances that a water parcel containing the products has to go across the jet.

If the Alboran Sea circulation were strictly geostrophic, across-jet motions would not be possible and the AJ would be an insurmountable hydrodynamic barrier for the north-south connectivity. The geostrophic relative vorticity of the AJ, basically positive on the left side of the stream looking downstream, tends to keep water parcels on this side (see Fig. 12.4). In other words, it would prevent water parcels from crossing the AJ, a necessary requirement to connect both shores. The actual circulation, however, is not geostrophic and it offers mechanisms for surpassing the hydrodynamic barrier.

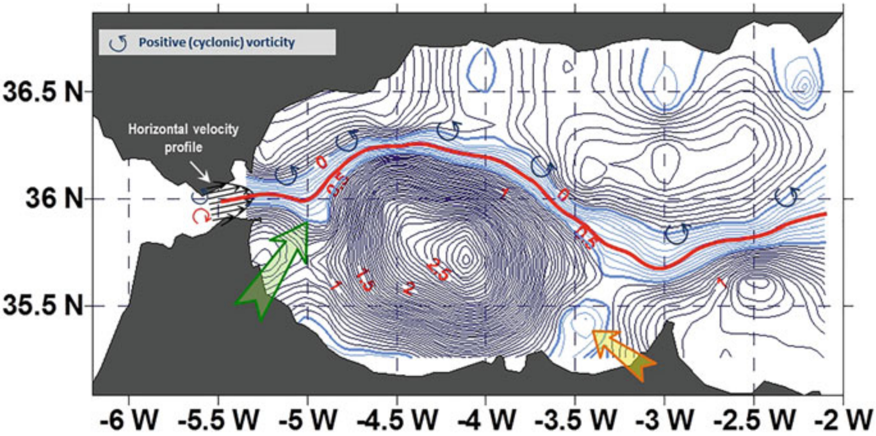

Fig. 12.4 Dynamic topography referred to 200-m depth (units in meters) in July 1993, adapted from Garcia-Lafuente et al. (1998). An idealized profile of the AJ horizontal velocity in the Strait has been plotted to illustrate the sign of relative vorticity. Thick red line indicates the core of the jet in the Alboran Sea and thick blue lines at either side depict the portion of the AJ that flows out the basin without recirculation. Curved deep blue arrows denote the positive relative vorticity on the left side of the AJ looking downstream. The green arrow marks the AJ–WAG junction, which leaves a pronounced meander in the topography (see text). The yellow arrow indicates the location of the cyclonic eddy discussed in the text and in Fig. 12.6. Notice that this situation corresponds to pattern B in Fig. 12.3

12.4.2 *Physical Processes to Overcome the Barrier*

Quasi-geostrophic theory, which addresses small departures from geostrophic balance, has been applied to the Alboran Sea in order to investigate vertical and horizontal ageostrophic motions (Tintore et al. 1991; Viudez et al. 1996, 1998; Allen et al. 2001). These motions have no null component of cross-stream velocity and, therefore, provide a mechanism for crossing the jet (Pollard and Regier 1992; Viudez et al. 1996). In the case of the Alboran Sea, however, the smallness of the ageostrophic velocities (1 cm/s) makes them inefficient to this aim since the time required for crossing the AJ at such a low speed is considerably greater than the time a water parcel advected by the AJ spends in the Alboran Sea basin.

A much more energetic ageostrophic process takes place where the AJ and the WAG meet each other at the entrance of the Alboran Sea. The coupling of both structures is not smooth, particularly if the WAG is well-developed and the direction of the AJ when it leaves the Strait is due east. Under these conditions, the AJ collides with the eastern rim of the WAG and injects large volumes of water in the interior of the gyre (Viudez et al. 1998). In the process, water parcels in the northern side of the AJ can cross the vorticity barrier and place themselves “in the other side” of the AJ, from where the south shore is easily available. Hints of this ageostrophic process are often revealed by the sharp meander of the AJ in maps of dynamic topography of the area built from hydrographic observations (green arrow in Fig. 12.4; see also Cano 1977; Tintore et al. 1991; Garcia-Lafuente et al. 1998).

The north-to-south drifts of the AJ in the northwestern part of the Alboran Sea as the jet enters the basin, linked to the variability of the internal hydraulics of the exchange through the Strait (Sarhan et al. 2000), is another mechanism able to transport sardine and other neritic larvae offshore, as reported by Vargas-Yañez and Sabates (2007). According to these authors, the same process could account for inshore transport and upwelling of larvae of mesopelagic species such as *Maurolicus muelleri* and *Benthosema glaciale*.

Instabilities associated with mesoscale and submesoscale fields are quite probably the most efficient mechanism for north-south hydrodynamic connectivity. Sanchez-Garrido et al. (2013) show that these instabilities are not sporadic processes but rather the consequence of the evolution of structures that are regularly fed by the energetic AJ. One of them is a small cyclonic eddy located in the northwestern area of the basin off Estepona (C1 in Fig. 12.5), whose origin is the separation of the AJ from the Spanish shore when it flows past Point Europa (Gibraltar Rock). According to Sanchez-Garrido et al. (2013), the lateral friction of the AJ with the north shore of the Strait generates positive relative vorticity, which is advected by the AJ. Part of it accumulates in the cyclonic eddy and makes it to increase in size (Fig. 12.5b and c) until it cannot grow anymore. In these circumstances, it becomes unstable and gets rid of the accumulated vorticity by releasing submesoscale cyclonic vortices that wander around the basin. They can even trigger longer spatial-scale disturbances that eventually lead to the WAG disappearance, as suggested by Fig. 12.5d. The wandering eddies last for days and have chances to end up on the southern shore of the Alboran Sea. Any biological material in their interior will have the same fate, in which case the vortices would establish an intermittent connection between both shores. Obviously, this intermittency does not guarantee the survival of larvae unless larval trophic resources are available during the vortex wandering.

Numerical simulations by Sanchez-Garrido et al. (2013) confirm the key role that tidal currents in the Strait play in triggering and enhancing the process, as they are first-class contributors to the generation of relative vorticity. If tides are removed in the simulation, the mechanism is still at work, but at a much slower pace. Spring tides are, therefore, preferred periods for this intermittent connection to happen. Propitious meteorological conditions are important to enhance the process as well. It is worth mentioning that such processes have been rarely documented by in situ observations. One of them, analyzed in Garcia-Lafuente et al. (1998), was reported to occur in the summer of the year 1993. The authors presented strong evidences of north-to-south transport of biological material, as they identified a small cyclonic eddy close to the southern shore of the Alboran Sea (see red arrow in Fig. 12.4) with indisputable biological content and hydrological properties of waters from the northern part of the basin (Fig. 12.6).

Wind stress is another external agent that propitiates migration of surface inshore waters offshore-ward. This is the case often found in upwelling systems such as the west Iberian Peninsula (Smyth et al. 2001; Alvarez-Salgado et al. 2001; Sanchez et al. 2008) or northwest Africa (Rodriguez et al. 2006; Sangra 2015) upwelling

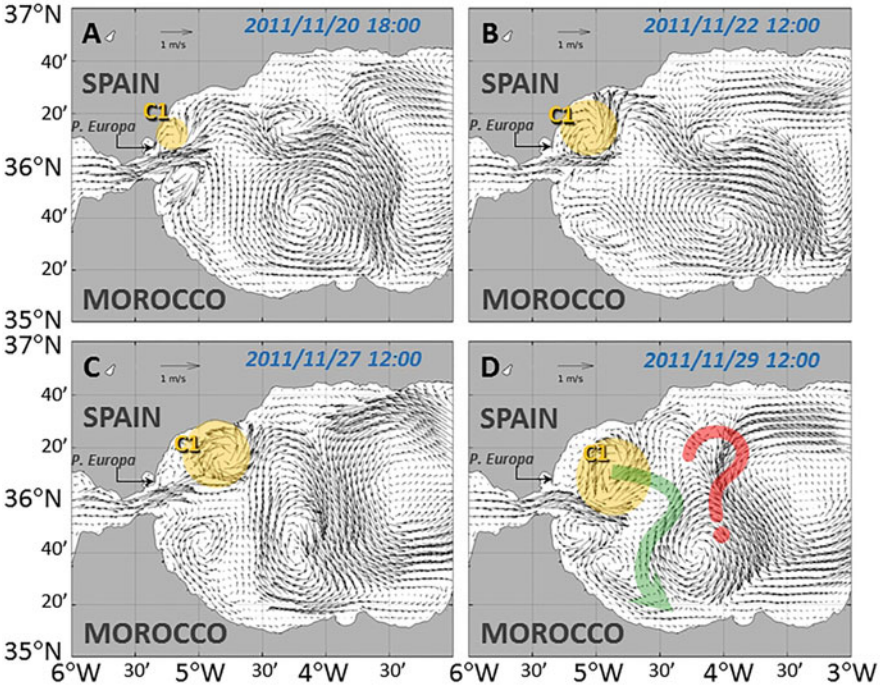

Fig. 12.5 Snapshots sequence of the evolution of the surface velocity field in the western Alboran basin in November 2011, adapted from Sanchez-Garrido et al. (2013). The focus in the sequence is the small cyclonic eddy C1 leeward of P. Europa (Gibraltar Rock). It forms when the AJ detaches from the coast (panel **a**). Fed with positive relative vorticity advected by the AJ, it grows bigger (panels **b** and **c**) until finally it becomes unstable and is released to follow a wandering path sketched by the green arrow in panel **d**. It well could end in the south shore. In the meanwhile, it has triggered the instability of the WAG which is about to disappear (panel **d**). See Sanchez-Garrido et al. (2013) for a comprehensive description of the full process

systems in the Atlantic, where filaments generated by favorable winds transport labile products from coastal areas offshore across the upwelling jet. Comparable processes have been modelled in the Strait of Sicily in the Mediterranean, where wind-induced upwelling can produce larval drifts across the Atlantic-Ionian stream, which is the prolongation of the Atlantic inflow (Falcini et al. 2015), allowing for chances of connecting north (Sicilian) and south (African) shores.

The vertical reach of the surface structures is 100–200 m, which is the typical thickness of the Atlantic layer in the Alboran Sea.[1] Below these depths, i.e., in the

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[1] Thickness changes markedly from place to place. Maximum thickness exceeds 250–300 m in the center of the WAG and EAG where Atlantic water accumulates. Minimum thickness is found near the shores where Mediterranean water is found few tens of meters below the surface. Geostrophy is the responsible.

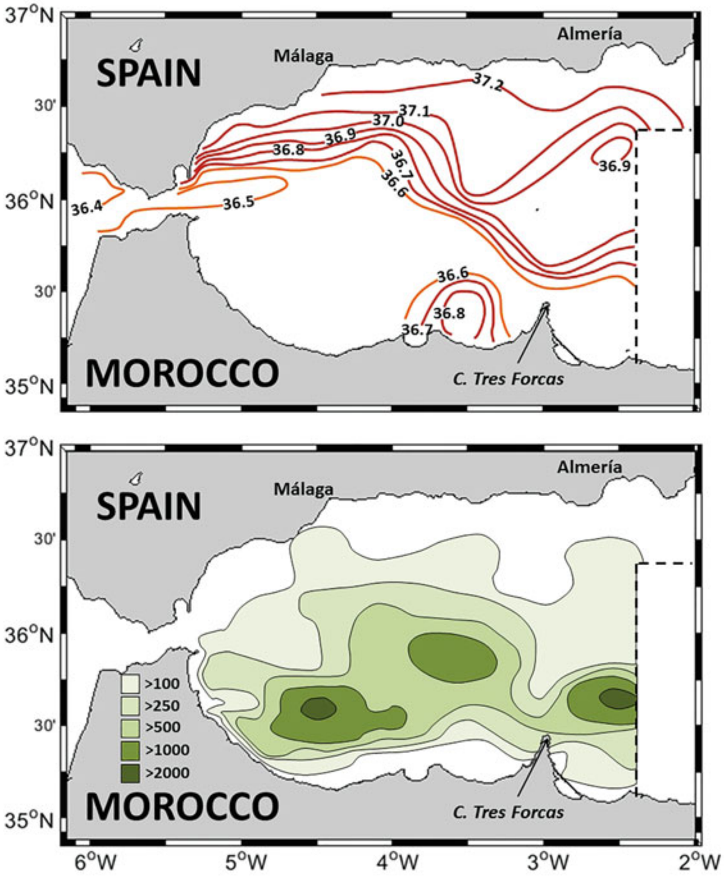

Fig. 12.6 Top panel: Surface salinity in July 1993. West of Cape Tres Forcas, in the same location occupied by the small cyclonic eddy indicated in Fig. 12.4, the salinity is anomalously high, with values of the northern part of the basin. Bottom panel: Spatial distribution of *Cerastocopelus maderensis* larval concentration (larvae/10 m^2). The species prevails in the southern half of the Alboran Sea, but the panel shows noticeably reduced values at the location of the eddy. These physical and biological indicators strongly point to the northern half of the basin as the source of the waters inside the eddy, which had to overcome the physical barrier of the AJ that is flowing east to the north of the eddy (cf. Figure 12.4). The mechanism by which the eddy reached this location is most probably the submesoscale instability discussed in the text. (Adapted from Garcia-Lafuente et al. (1998); see this article for more details)

lower layers, the north-south hydrodynamic connectivity could be more easily achievable since the AJ is no longer a constraining feature. However, velocities there are much smaller, one order magnitude less than in the surface layer, a fact that does not help connecting both shores: the sluggishness of the flow is the limiting factor in this case.

12.4.3 Role of Topography: Conveyor and Obstacle for the Connectivity

Coastline orientation, capes, islands, embayments, etc. are well-known topographic features that interact with the flow and result in hydrodynamic processes with often relevant consequences noticeably on the marine ecosystems. A pronounced cape on an otherwise straight-like coastline represents a serious obstacle for a coastal jet flowing along the shore, since it has the potential to disturb and destabilize the jet downstream the cape. There are examples of perturbations resembling Von Karman vortex streets generated by oceanic currents flowing through islands (Jimenez et al. 2008), which, moreover can trap patches of chlorophyll and become productive biological environments. Or flows deflected by the shoreline orientation that evolves in rather steady structures, etc.

The Gulf of Cadiz–Alboran Sea system holds a variety of such structures. One of them already cited is Point Europa, which causes the AJ separation from the shore and enables submesoscale instabilities with important consequences for hydrodynamic and biological connectivity. Cape Tres Forcas in the southern shore of the basin is a pronounced cape in a rather straight coastline that turns into a barrier that prevents east-to-west zonal connectivity in the south part of the Alboran Sea. It also hampers the west-to-east connection for different reasons. The geographical morphology of the cape facilitates the formation and growth of the EAG by deflecting the AJ in a cross-basin direction as it approaches the cape. Under these circumstances, the southern shore west of the cape would be more likely connected with the northeast Alboran shore than with the south shore east of the cape, as suggested by Muñoz et al. (2015). This connection relies, however, on the stability of the mesoscale, the permanency of the EAG in this case, which is affected by submesoscale variability.

Another relevant example of the influence and consequences of topography is illustrated in Fig. 12.7. Its oceanographic scope is the very Strait of Gibraltar, and it emphasizes the role played by the shoreline orientation to achieve connectivity between opposite shores separated by the energetic AJ. Several oceanographic processes are involved, among which tides stand out. The experiment presented in Fig. 12.7 shows the time evolution of passive drifters (virtual particles) initially released at the western approach of the Strait at two different locations. The strong tidal currents (see inset) result in a back-and-forth motion of the particles with prevailing net eastwards (along-AJ) displacements. No cross-jet (i.e., north-south) displacement is observed for the cases of particles initially released in the central and north part, which move following zonal trajectories. Things are different for particles released in the south, as a considerable fraction are seen crossing the eastern part of the Strait 20 hours after their release (Fig. 12.7f). The likely origin of such deflection is the coastline orientation west of Point Cires, which would allow for limited, but not negligible, south-to-north connectivity.

As a collateral result of Fig. 12.7, it is worth mentioning the fact that tidal currents can lead to a net westward transport if the passive drifters are located to the west of

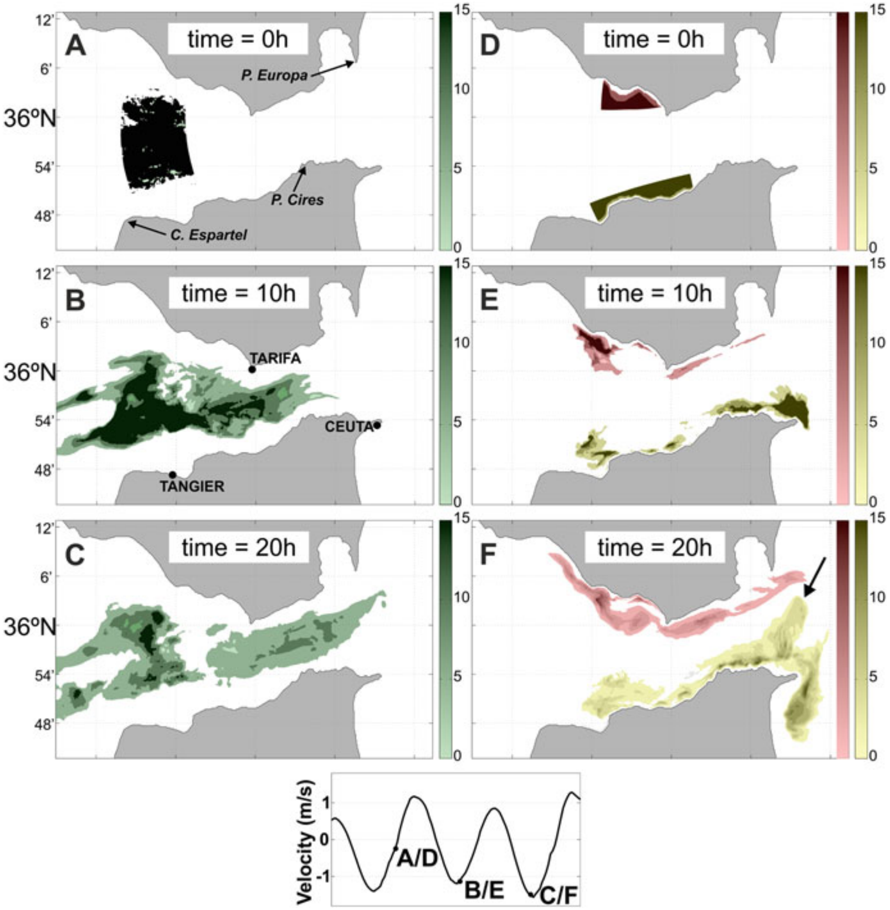

Fig. 12.7 Snapshots of the drift of surface passive tracers released at different locations in the western half of the Strait of Gibraltar, adapted from Garcia-Lafuente et al. (2013). Panels **a** and **d** represent the initial position and concentration (arbitrary relative units, see color scales) of the tracers. Panels on the left column show the results for virtual release of tracers in the central part of the Strait, whereas panels on the right do the same for a release in the north and south shores. Subsequent spreads of the initial patches (panels **a** and **d**) are presented in panels **b**–**c**, and **e**–**f**. The time of all snapshots, referred to as the tidal cycle of the barotropic velocity (positive values toward the east) is indicated in the bottom inset. Black arrow in panel F shows the northward conveying of the southern patch forced by the shoreline orientation west of P. Cires (see panel **a** for location)

Tarifa. Or in other words, any drifter able to reach this area (by, for instance, the unlike processes associated with the coeval of strong atmospheric forcing and suitable tidal conditions addressed previously in this chapter) increases its chances to progress westwards and achieve successfully the unlike east-to-west interbasin connectivity. The critical zone that would prevent such connectivity is the eastern half of the Strait where the much narrower topography (topography again) enhances the mean flow (Armi and Farmer 1985, 1988; Garcia-Lafuente et al. 2000) with the result of a quasi-permanent eastward direction of the AJ regardless the tidal conditions. West of Tarifa, where the Strait broadens, tidal currents overcome the mean flow and tidally induced reversals of the AJ are the rule.

12.5 Species Life History Effects and Constraints in the Connectivity Processes

12.5.1 Influence of Hydrographic Patterns at Early Life Stages of Fish

Hydrodynamics is pivotal in the fish egg and larval environmental scenario, most particularly in the case of pelagic species originating from adult fish, which are adapted to recurrent and permanent hydrographic patterns. Hydrodynamics causes the passive drifting of small pelagic offspring until finding areas where processes of enrichment, concentration, and retention confluence (the "Bakun triad", Bakun 1996). If these conditions are positionally retained in the form of a nursery ground, ontogenic development is favored until attaining early juvenile stages in which they can overcome the constraints imposed by local hydrography.

The Alboran Sea is a sharp trans-continental ecosystem with the potential of early life stages connecting European and African coasts, which are separated by the AJ. Another example of such an ecosystem in the Mediterranean is provided by the Strait of Sicily where a surface current of Atlantic origin too, the Atlantic Ionian Stream (AIS), may disengage the respective coastal marine ecosystems. Hydrodynamics there strongly conditions the life stages of small pelagics.

Establishing connectivity by the import of early life history stages (ELHSs) from one distant spawning ground to another site is crucial to incorporate vital developmental rates that condition survival probabilities at critical ontogenic stages. Garcia-Lafuente et al. (2002) analyzed the coupling of the AIS in the Strait of Sicily with the European anchovy (*Engraulis encrasicolus*) and showed spatially asymmetric distributions of eggs and larvae originated by the southeastwards alongshore advection of these products by the main branch of the AIS. The geostrophic front associated with the stream facilitates the pumping of nutrients and trophic resources for the alongshore drift of larvae until they concentrate in a cyclonic vortex off the southernmost Sicily, where they feed and grow in favorable conditions provided by upwelling linked to the vortex (Garcia-Lafuente et al. 2002). Biological evidence of this transport is supported by the estimated daily ages and sizes of larvae, which significantly increases as larvae drift southeast. Larvae of 11 mm have an estimated age of 14 days, a sufficient pelagic larval duration (PLD) for reaching the vortex from the northern spawning grounds. But the AIS apparently represents a hydrographic barrier for the exchange of ELHS individuals between the Tunisian and Sicilian shores. In fact, lagrangian simulations confirm that high mortality rates at

ELHS does not support the connectivity hypothesis between either side of the Sicilian Channel, even though as much as 20% exchange rate of particles between both coastlines is possible (Patti et al. 2018).

Permanent hydrographic patterns create conditions that pelagic fish species recognize and, in doing so, adopt a homing behavior for reproduction and ontogenic development. Brochier et al. (2009) analyzed the environmental cues for sardine and anchovy on the basis of retention or dispersion constraints that may determine a homing behavior in small pelagic stocks of major eastern boundary current, such as the Canary and Humbold upwelling systems. They concluded that rather than natal homing, the reproduction is tuned with an environmental homing as it can be specific temperature or salinity gradients. This is the case of the Atlantic tuna, which migrates to diverse spawning grounds in the Mediterranean (among which the Balearic Sea is foremost, Reglero et al. 2013) looking for specific conditions that are provided by intermediate waters resulting from the mixing of newly inflowing surface and older resident Atlantic water (Alemany et al. 2010; Balbin et al. 2013). In the Alboran Sea, blackspot seabream (*Pagellus bogaraveo*) is likely an example illustrating these processes. Blackspotted seabream reproductive stock is fished by Spanish and Moroccan artisanal fleets in the Strait of Gibraltar (Gil 2012; Burgos et al. 2013). The recapture of juvenile tagged outside this region indicates migration of juveniles toward the Strait of Gibraltar, the main concentration site of adult specimens in the region (Gil 2012), and suggests environmental homing behavior.

ELHS are at the mercy of hydrodynamics which has consequences on their survival or mortality depending on the course of advection, the duration of egg and larval drift, and the availability of feeding resources while flowing. Hydrography may be a connective driver of different sub-populations geographically distant forming part of a determined population resource by enhancing the exchange among individuals, thereby, influencing population dynamics and the genetic structuring of populations.

12.5.2 Pelagic Larval Duration and Dispersal

The most abundant and appreciated fish species from both sides of the Strait of Gibraltar belong to the sardine and anchovy species' complexes. They have well-defined spawning and nursery grounds on both sides of the Strait (Baldo et al. 2006). The importance of the AJ is paramount to understand the manner in which it influences the biological traits of species. Its fluctuations of intensity and direction have a consequence on the recruitment of Alboran Sea anchovy via the modulation of larval advection from spawning and nursery grounds (Ruiz et al. 2013; Catalan et al. 2013). Drifting can import ELHS from remote spawning grounds into other regions whereby new imports can be fundamental to the maintenance of stock. Such is the case of the sardine spawning grounds off the Gulf of Manfredonia in the Adriatic Sea which receives imported ELHS that contribute substantially to the maintenance of the stock (Sciascia et al. 2018).

Wherever the hydrodynamic activity is intense, as in the upwelling regions where preferred vital needs are met by small pelagic resources during their life cycle, the probability of passive migration of ELHS is unavoidable. Offshore drift to the open ocean can be detrimental for stock recruitment, as it occurs with the sardine in the Iberian upwelling system (Guisande et al. 2001) or in the Canary region (Rodriguez et al. 2006; Sanchez-Garrido et al. 2019). Only larvae that were enclosed in cyclonic eddies that functioned as larval nursery grounds for neritic fish species appeared to gather survival conditions (Rodriguez et al. 2006). Offshore drifting of anchovy larvae has also been noted in the NW Mediterranean where important coastal spawning grounds exist (Palomera et al. 2007). However, it has been still challenging to link the connectivity processes to the inter-annual variability of anchovy populations in the Mediterranean Spanish coast (Ospina-Alvarez et al. 2015). Anchovy post-larval stages with ages over 2 weeks, well beyond the post-flexion stages, are routinely found in the bluefin tuna spawning grounds of the Balearic Islands in the open ocean (Rodriguez et al. 2013), demonstrating their biological sustainability during their advection from either of their original spawning sites.

In the Alboran Sea, the egg and larval connection includes inter-basin west-east connectivity from the Gulf of Cadiz and may affect the population structure of species. For instance, larvae of mesopelagic myctophid species from the Atlantic spread over the Alboran Sea and tend to concentrate over the EAG and WAG (Rubin 1997). The distribution of sardine along the north coasts of the Alboran Sea shows bimodal size frequency distributions with larger sizes in the westernmost area, which suggests the incorporation of sardine individuals of the Atlantic (General Fisheries Commission for the Mediterranean, Fisheries Assessment Data). The surface circulation pattern of the Alboran Sea previously described would confirm that the western end of this basin is most likely to receive ELHS. The most resourceful region in the Gulf of Cadiz is the shelf surrounding the Guadalquivir estuary (see Fig. 12.1 for location) in terms of ichthyoplankton, zooplankton, and fisheries (Baldo et al. 2006), where anchovy and sardine form the greater part of the ELHS. Wind influences the environmental conditions in this area and also modulates the dispersion of anchovy ELHS, with contrasting outcomes for easterly or westerly (Catalan et al. 2006). Easterlies favor oligotrophic conditions in the anchovy spawning grounds off the Guadalquivir estuary, which results detrimental to the recruitment of anchovy in the area (Ruiz et al. 2006). Numerical simulations (Catalan et al. 2013) confirm that larvae surviving over 10 days are able to reach the nursery grounds in the Alboran Sea from those spawning grounds, and anticipated that changes in the anchovy population were dependent on the AJ dynamics. PLD thus regulates the potential distributional range as a function of the survival capabilities of the species.

The temporal extent of PLD depends on the species' habitat, as inshore benthic species have shorter PLD than species belonging to the pelagic domain (MacPherson and Raventos 2006). Consequently, the former shows less distributional range. A large fraction of the 62 species analyzed in this study showed a significant relationship of PLD with distributional range. Species belonging to the *Sparidae* family, common in coastal habitats of the Mediterranean, whose ELHS belong to pelagic realm, showed relatively higher PLD's (ranging from 16 to 58 days) than the other species considered. This result can be reliably extended to the Mediterranean anchovy and sardine, species that were not referred to in the study. Other benthopelagic species as the European hake have PLD of around 40 days, according to otolith studies (Hidalgo et al. 2009, 2019).

The chances of surviving passive drift are related to the temporal duration of the PLD, which on the other hand exhibits seasonal differences in the sense that larvae originating during spring-summer show shorter PLDs than species developing in autumn-winter (MacPherson and Raventos 2006). Consequently, the PLD conditions the spatial scale of a distribution which may comprise several subpopulations (Cowen and Sponaugle 2009), although other factors are also influential. Among them, the vital habitat (benthic versus pelagic species), or location of the spawning grounds (inshore versus offshore) and depth of the spawning (see next section) are noteworthy.

12.5.3 Depth Distribution and Vertical Migration

Depth of spawning and nychthemeral vertical migrations of ELHS influence the dispersion course depending on the life cycle habitats of the species concerned. Benthopelagic species as spotted seabream (*Pagellus bogaraveo*) or hake (*Merluccius merluccius*), both inhabiting the Alboran Sea/Strait of Gibraltar region and considered priority species by the General Fisheries Commission for the Mediterranean, occupy deeper layers during their life cycle. They can be exposed to two different hydrodynamic patterns depending on the depth concerned, namely the surface Atlantic current or the underneath Mediterranean flow, which flow in opposite directions. If the ELHS reside at depths influenced by the surface circulation, their drift is basically to the east, whereas if they are found deeper, they would be transported to the west and, eventually, to the Atlantic Ocean if they are advected a long enough way/time. In contrast, epipelagic species such as sardine or anchovy are only influenced by the surface circulation (Catalan et al. 2013; Ruiz et al. 2013) and their ELHS have no chances to drift west through the Strait of Gibraltar into the Atlantic, unless the coeval of the very unusual circumstances already mentioned are exceptionally met.

Therefore, the horizontal distribution pattern of ELHS is affected by their distribution in the water column. The above-mentioned species lack specific studies on their vertical distribution in the Alboran Sea. Nevertheless, the diel behavior of ELHS for hake and small pelagic species inhabiting other regions of the Mediterranean may serve to exemplify their vertical distribution. Studies carried out in the NW Mediterranean (Olivar et al. 2001; Sabates 2004) found maximum concentration of anchovy eggs and larvae above 20 m, whereas sardine ELHS were spread over 10–40 m depth range. Despite geographic and seasonal variability differences between both spawning ecosystems, the main features of the vertical depth distribution are very likely still representative of the Alboran Sea sardine and anchovy.

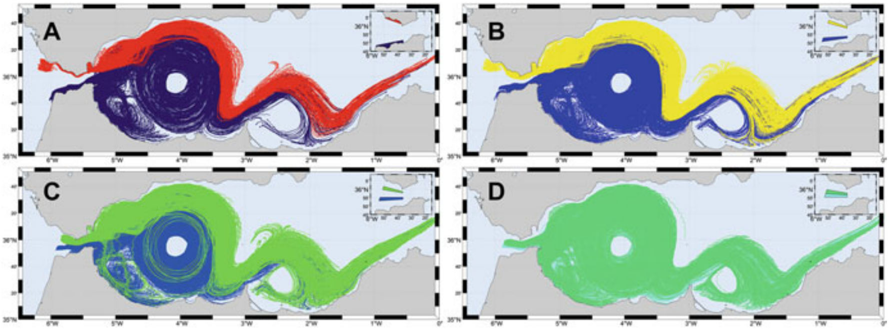

Fig. 12.8 Lagrangian trajectories of passive surface drifters calculated using the output of the numerical model in Sanchez-Garrido et al. (2013). The particles (in a number of 11,000) have been released at the surface in the western part—Atlantic—of the Strait of Gibraltar and have been adrift for 18 days, the same in all panels. For clarity reasons the zone of the initial particle release and the subsequent drifting trajectories are presented in four different maps, ranging from coastal release (panel **a**) to the release in the central part (panel **d**; see the insets in the upper-right corner of each panel)

As far as the ELHSs of these species are distributed in the upper part of the water column, the surface hydrodynamics will entrain elements of Atlantic origin into the Alboran Sea, which can have different outcomes. If the eggs and larvae are initially located in the very northern edge of the AJ (red color in Fig. 12.8a) they would get the northern Alboran shores very easily, but not the southern shore, which is only attained in the eastern exit of the basin: The AJ is a serious hydrodynamic barrier for these products. If they are located in the northern half of the AJ but not in the edge (yellow and green colors in Fig. 12.8b-c), in addition to a still very plausible ending in the northwestern Alboran Sea shore, it is also expectable ending trapped in the confines of the EAG (Fig. 12.8b and c), with uncertain fate. However, if they were at the center or southern half of the AJ (blueish colors in all panels of Fig. 12.8) the model shows that advection may provide to both the north and the south Alboran coasts with small pelagic ELHS. Thus, in the intra-basin North-South Alboran connectivity for these species, the Atlantic source cannot be overlooked.

Regarding benthopelagic species as the European hake, the vertical distribution of larvae off the Galician (NW Spain) coasts in the Atlantic ocean showed the main concentrations within the 100–200 depth range (Rodriguez et al. 2015), while in the Mediterranean hake larvae are mainly found at depths of around 90 m (Olivar et al. 2003; Sabates 2004), suggesting a contrasting scenario and implications to the surface-dispersed species. Assuming a similar vertical distribution in the Alboran Sea, larvae in the upper portion of this depth range could be subjected to entrainment by the AJ, whereas those in the lower portion may disperse through the undercurrent hydrodynamics. More interesting is the case of the spotted seabream (*Pagellus bogaraveo*) whose reproductive stock lives in the Strait of Gibraltar (Gil 2012; Burgos et al. 2013). Although little is known about the actual depth of spawning, the extraordinary amplitude of the vertical motions induced by the tidal currents in the spawning area (Sanchez-Garrido et al. 2011; Garcia-Lafuente et al. 2013) is capable to position the ELHS at almost any depth in the water column. Therefore, even though the species is benthopelagic, it cannot be ruled out the ELHS raised to surface layers and, under the influence of the AJ, be transported toward the Mediterranean. But ELHS can also remain in the lower layer and ending in the Atlantic. The very energetic hydrodynamics associated with tides makes ELHS available to be transported in either direction.

12.5.4 Spawning Phenology and Vital Rates

Vital rates at ontogenic development are greatly affected by temperature, which controls the rate of metabolic processes occurring at ELHS, thereby influencing PLD of invertebrate and vertebrate marine species (O'Connor et al. 2007). Survival of ELHSs of fish increases with ontogenic development, whereby greatest mortality rates occur at earliest stages of development. Most sensitive stages are during the egg development and lecithotrophic larval development, stages particularly vulnerable to predation. The egg development in small pelagic species is temperature dependent and lasts 3-5 days (Miranda et al. 1990; Pepin 1991; Bernal et al. 2001). In addition, growth is likewise dependent on inherited parental and maternal traits (Green and McCormick 2005; Uriarte et al. 2016). The maternal and parental influences will highly depend on the age structure of a determined spawning stock.

Considering the relevance of temperature in controlling metabolic processes, assessing the change of environmental conditions due to climatic and seasonal factors over the time span of a determined species' spawning is of utmost importance. Sardines and anchovies show partial overlapping spawning seasons (Garcia et al. this book), in which surface temperature from winter to spring can have as much as a difference of 3-4 °C, thereby influencing larval growth strategies. On average, spring larval cohorts of sardine show less production but they grow significantly faster due to a higher temperature during development (Garcia et al. this book).

Despite spawning synchronicity in a species, great environmental differences may be manifested by the local temperature regime and the production of trophic resources that originate from hydroclimatic processes. Larval growth rates of the same small pelagic species can show important differences between regions (Palomera et al. 2007). It would be the case of sardine or anchovy spawning in the bays of Malaga and Almeria (Fig. 12.1) in the Alboran Sea (Quintanilla et al. 2017). Nonetheless, the seasonality of spawning of these species has to be tuned to the phytoplankton blooms that occur in autumn and spring and trigger zooplankton production, the main trophic level which larval sardines and anchovies prey upon (Garcia et al. this book).

From yolk-sac larvae to the end of the preflexion stage, the ELHSs are exposed to predation and, possibly, to starvation depending on the available feeding resources.

Furthermore, ontogenic changes are the result of the allocation of energy toward the formation of vital organs and, in consequence, influence growth variability (Garcia et al. 2006; Garcia et al. 2003; Quintanilla 2016). In post-flexion stages, the development of fin rays provides swimming capabilities at small vertical and horizontal scales, which in turn determine survival probabilities by optimizing feeding potential.

The spawning phenology of benthopelagic species in the Alboran Sea is far less known than of epipelagic species. Nonetheless, species living in deeper layers close to the seabed where temperature is rather stable have the potentiality of year-round spawning. The NW Atlantic hake is known to spawn throughout the year with seasonal peaks in spring and autumn/winter (Recansens et al. 2008), which contrasts with the pattern observed in the Alboran Sea that is expected to occur in late winter—early spring since recruits are mainly observed in autumn (Rey and Gil de Sola 2004). The longer exposure of ~40 days PLD of this species in the Mediterranean (Hidalgo et al. 2009, 2019) implies greater risks for predation, which effect is likely buffered by their deeper depth distribution where less predation may occur.

12.6 Implications on the Populations and Ecosystems of the Alboran Sea

The transitional nature of the Alboran Sea and Gulf of Cadiz systems between Europe and Africa implies changes in ocean and ecosystem governance but also a strong commitment toward integrative co-management of the ecosystems and marine resources inhabiting these regions. Given the short distances in the Alboran Sea, populations and ecosystems might be intuitively connected due to energetic hydrodynamics in the region. However, connectivity pathways are not straight forward, as discussed in this chapter, and the likelihood of successful connectivity and its implications depend on several elements: PLD, larval behavior, timing and location of the spawning, and the capacity of each species to cross and overcome strong hydrodynamic barriers (e.g., topography and the AJ). From a perspective of the fisheries resources, there is a general acceptance of a mismatch between biological and management structures currently used in fisheries assessment (Kerr et al. 2016): spatial and demographic structures of marine populations are more complex than currently accounted for. This has, however, two complementary components: a historic question on fish stocks delineation (inter-stock) but also a more recent recognition of sub-structuring within stocks areas as a set of subunits displaying different ecological or demographic functions (intra-stock). Thus, there is a need to take into account the spatial heterogeneity of fish populations within management units beyond simple stock delineation (Berger et al. 2017). It requires the incorporation of those ecological processes that are spatially structured or, alternatively, the consideration of different population sub-units that have different demographic properties or ecological functions (metapopulations, Hidalgo et al. 2017). This is likely the case of several species in the Alboran Sea (Hidalgo et al. 2018), which are structured in three Geographic Subareas (GSAs) for management and data compilation purposes.

Long-term connectivity (low genetic differentiation) is high in general terms in the whole Alboran Sea. However, connectivity at short and middle temporal scale (demographic connectivity) is currently a major challenge in the Alboran Sea that is indeed highly species specific. Connectivity has two levels of implications in populations and ecosystems: spatial management and temporal assessment. Spatial management (e.g., no-take Marine Protected Areas, MPAs) is a key tool used in marine conservation to enhance ecosystem resilience and reduce the decline of fisheries resources. The effectiveness of an MPA (and network of MPAs) is highly dependent on careful consideration of connectivity processes in their design (Muñoz et al. 2018). In the Alboran Sea MPAs, east-west and along-shore connectivity are, in addition to mesoscale and topographic-induced processes, of higher relevance compared to potential north-south connectivity. MPAs were initially thought of as the main conservation mechanisms for coastal ecosystems, while their importance as a management measure to recover fish stocks at the continental shelf and slope is increasing (e.g., European hake, Muñoz et al. 2018). However, one of the main challenges with MPAs networks design is the general mismatch between fisheries dependency and the larval supply provided by MPAs (Andrello et al. 2017), mainly associated with local communities highly dependent on small-scale fisheries. This is likely the case in the south Alboran Sea with comparatively less protected areas compared to the north (e.g., Andrello et al. 2013). By contrast, in terms of fisheries assessment, east-west and north-south connectivity provide a deep understanding of both the spatial structure of populations beyond stock boundaries, and the influence of hydrodynamic connectivity in the recruitment success (Hidalgo et al. 2019).

The three main harvested species potentially affected by hydrodynamic connectivity in the Alboran Sea are the European hake, the sardine, and the blakspot seabream, for which ongoing research investigates cross-scale connectivity processes (Hidalgo et al. 2018). Each species represents a contrasting case study. Sardine is currently assessed by Spain and Morocco as different stocks, while hake is already assessed as a co-shared stock (General Fisheries Commission for the Mediterranean). Sardine is a pelagic species with more coastal habitat compared to hake. Their dispersion is sub-superficial and thus their potential north-south connectivity is likely affected by the AJ (Fig. 12.8). Hake displays a deeper dispersal and is less affected by the AJ, while the sluggishness of the flow in depth could decrease the likelihood of effective north-south connectivity. Black-spot seabream has a special and rather unknown life cycle. Most adults and spawners are fished in a very small region in the Strait of Gibraltar and most of the spawning is assumed to occur in the Strait, whereas larvae are thought to be mainly dispersed in the Alboran Sea. Although populations in the Mediterranean display complex spatial structures (e.g., Gargano et al. 2017; Hidalgo et al. 2019), any of these species consider still this scenario.

Future projections and perspectives in terms of connectivity are difficult to provide in the Mediterranean Sea due to uncertainties when dealing with mesoscale processes and shorter-scale features of the regional hydrodynamics, which is particularly the case in the Alboran Sea. At a global scale and given the expected northward expansion of suitable habitats of many marine species due to the temperature increase as a consequence of climate change, transboundary populations, and shared stocks are expected to augment worldwide (Pinsky et al. 2018). However, this is not likely the case in the Alboran Sea. Indeed, increasing temperature could diminish the likelihood of accomplished connectivity in the Mediterranean Sea since higher temperatures are expected to change the spatiotemporal dynamics of spawners as well as the PLD, which in turn would decrease the distance dispersed and the link among subpopulations and MPAs (Andrello et al. 2015). This later effect could be expected in the Alboran Sea. Additionally, biological characteristics of drifting larvae as growth and age, otolith isotope markers, and the population genetics must be integrated into biophysical models in order to confirm connectivity between fish populations and to cope with different spatiotemporal scales. It is particularly relevant for Atlantic-Mediterranean fish stock connectivity, a central issue in this area for which primary tools for the model construction are available from the researchers in the region (Garcia et al. this book).

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Chapter 13
Evolving from Fry Fisheries to Early Life Research on Pelagic Fish Resources

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13.1 Brief Historical Background of Fry Fisheries in Northern Alboran Sea

The northern coasts of the Alboran Sea are known to have thrived from past artisanal fisheries that exploited the early life stages of fishes. This was mainly carried out by a suite of different fishing gears dating back to the eighteenth century to the end of the twentieth century (Sañez-Reguart 1791–1795 reprint 1988; Rodríguez Santamaría 1923). These fishery studies provide detailed descriptions of the fishing gears employed by fishermen exploiting the Iberian Peninsula coasts and a general account of the targeted species and their associated catches. In the Andalusian coasts of the Alboran Sea, beach seines called *boliches* were among the most common, targeting on sardines, anchovies, and a number of other fish species, as bonitos and tunas that preyed on small pelagic shoals (Fig. 13.1).

In this historical description, the Bay of Malaga is cited as most prolific in the use of this specific fishing gears exploiting nearshore fish resources of northern Alboran (Rodríguez Santamaría 1923) (Fig. 13.1). These fishing gears continued until the twentieth century and evolved reducing its size to allow the maneuvering with a smaller number of persons. Through time, this gear was modified for the fry fishing of small pelagic species. Its modifications mainly consisted in gradually diminishing the mesh of cod ends for catching postlarval stages of sardines and anchovies,

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Fig. 13.1 Engraving of a beach seine doing the encircling maneuver to catch shoaling fishes (Sañez-Reguart 1791–1795 reprint 1988; personal copy)

oftentimes capturing shoals of postlarvae and juveniles of other species, such as *Pagellus* sp., *Boops boops*, *Mullus* spp., etc. (García et al. 1981; Reina-Hervás and Serrano 1987).

The increase of the coastal populations flanking the Alboran Sea originated from the touristic boom of the mid-1960s and 1970s led to the increase of fry fishing. This fishery typified the coastal region with numerous beach seine fishing along the coast (Fig. 13.2), especially abundant in the beaches facing the Bay of Malaga (García et al. 1981). The product of the fishery was camouflaged as "*chanquete*," the local denomination for *Aphia minuta*, a transparent gobid whose adult size was similar to the fry of sardine, anchovy, and round sardinella. The abundance of sardine in the Alboran Sea led to the first scientific reports describing their distribution in the area (Oliver 1955, 1961). An actual description of the fishing methods applied in present times providing recent data from the coastal fisheries off N Alboran coastline is reported in García et al. (2012).

With the economy rising in the 1980s, the fishery expanded because its resources were guaranteed year-round. The inshore coastline of the Alboran Sea is a haven for the growth of advanced stages of sardine, anchovy, and several other commercial fish species. Thus, the iconic image of beach seine trawling was commonplace in the shores of the Bay of Malaga (Fig. 13.2). The demand for the consumption of fry became so high that another type of artisanal fishing gear, the *birorta*, also competed for these early life resources (Fig. 13.3). This kind of fishery consisted in a small type of purse seine maneuvered by two–three persons that encircled postlarval shoals, and

Fig. 13.2 Hauling in the catch of beach seine (*boliche*) for small pelagic fry (photo from A García)

Fig. 13.3 Small purse seine (*birorta*) used for fry fishing (photo from A García)

Fig. 13.4 Cod end of beach seine and its fish fry capture (photo from A García)

unlike the beach seine (*boliche*) did not trawl over the seabed (Fig. 13.2). Such was the expansion of this type of gear during the early 1980s when as many as over a hundred small boats could be counted from the beach near the Malaga port entrance (A. García, unpublished data counts).

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Upon the integration of young scientists in the late 1970s to work in the Oceanographic Center of Malaga, it was considered necessary to provide proof for banning this obsolete fishing practice. Fry fishing was so intensive and out of regulation control measures that strong management measures were urgently implemented. Catches as shown in Fig. 13.4 are exemplary of the magnitude of the impact on small pelagic resources. As a result, during the mid-1980s, the Autonomic Government of Andalucia issued a ban on fry fishing. Nonetheless, the local culinary preferences for small fish still persist, and the lack of compliance with the regulation leads to occasional confiscations of fry catches.

The extraordinary abundance of postlarval stages of small pelagics inshore, at depths less than 20 m, propitiated research focused on early life history stages (ELHS, henceforth) of small pelagic fish species, including the modification of plankton tow procedures regarding duration and plankton gear. As in the fry fishery, ichthyoplankton sampling of postlarvae was carried out at night time when larvae surface to inflate their swim bladders, a behavioral habit that initiates schooling behavior (Santos et al. 2007). To assure greater catches with larger larvae, a squared-mouth Bongo 90 (Steve Coombs, Spartel Ltd.) was designed. To reduce larval avoidance, it is geared with a black-tinted mesh (> 1 mm) (Fig. 13.5).

The open mesh employed mostly caught postlarvae which were easily sorted on board and stored in liquid nitrogen. Short tow duration (10 min) at the surface or subsurface was considered sufficient to catch postlarvae in good condition for analyzing larval growth and condition research (García et al. 2003; García et al. 2006a, b). The plankton gear developed for sampling small pelagic larvae was later used for defining the bluefin tuna spawning habitat and to carry out larval tuna research studies in the Balearic Sea, the key spawning grounds of Atlantic bluefin

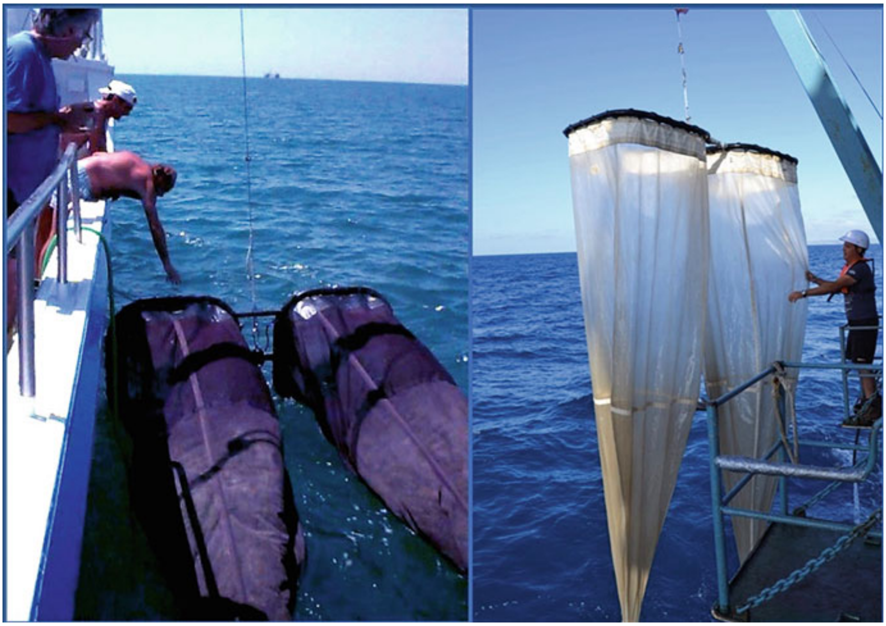


Fig. 13.5 Standard Bongo 90 net pictured in two versions: left picture, the black tint netting equipped has >1 mm mesh primarily used for nighttime hauls of small pelagic larvae; right picture, Bongo 90 equipped with 500 μm mesh (photo from A García)

tuna in the Mediterranean (García et al. 2006a, b; Alemany et al. 2010; Uriarte 2018).

The change of plankton gear and sampling at night was mainly aimed to collect larger sized larval specimens, centered on postlarval stages for its longer age history. A historical time series analysis of the Californian anchovy egg and larval abundance of the CalCOFI surveys was not able to relate neither of these variables to the recruitment success of the Californian anchovy (*Engraulis mordax*) (Bradford 1992). The study concluded that recruitment success was not related to egg and larval abundance, postulating that the abundance of postlarval stages of sizes around 15 mm would have a greater repercussion on annual recruitment.

Consequently, in the first analysis between the standard Bongo 40 tows and the Bongo 90, anchovy larval size increased to an average catch of 15 mm (Fig. 13.6) larvae in favor of the Bongo 90 gear. Furthermore, the size range of larvae being collected also increased. This net was later applied in an Atlantic bluefin tuna project (TUNIBAL) aiming to sample bluefin larvae following an ICCAT recommendation promoting research of bluefin larvae. The project showed great success in collecting large numbers of Atlantic bluefin tuna larvae since its first implementation (García et al. 2003). Similar sampling techniques were also adopted in the spawning grounds of Atlantic bluefin tuna spawning in the Gulf of Mexico, where this type of gear excelled all others in a suite of other ichthyoplankton nets (Habtes et al. 2014).

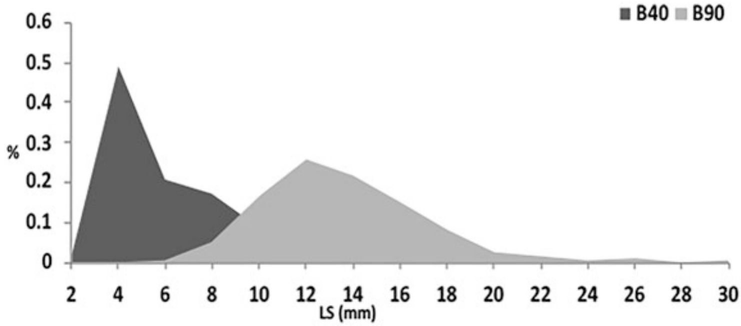


Fig. 13.6 Comparative anchovy larval catch between the B40 and B90 plankton nets

Thus, this plankton gear has become the standard type of gear for collecting small and large pelagic larvae in the field, specifically for undertaking larval growth and condition studies (Cortés 2006; García 2006) as well as ELHS trophodynamic studies based on stable isotopes analysis (Uriarte 2010; Laíz-Carrión et al. 2011). In conclusion, the sampling methods of ELHS applied in these studies stem from observing the conducts of fry fisheries.

13.2 Spawning and Nursery Scenarios of Small Pelagic

13.2.1 Coastal Hydrodynamics and Planktonic Productivity Drivers

According to the existing literature, small pelagics are particularly abundant in upwelling areas (Cole and McGlade 1988; Cury et al. 2000) where the enrichment in nutrients cascades throughout the food web, increasing planktonic production and thereby, potential larval food resources. The degree of recruitment will depend on the coupling between the timing of spawning and favorable environmental conditions for the survival of ELHS (Cury and Roy 1989; Bakun 1996; Brochier et al. 2009). The usual physical forces driving the processes that shape these conditions are winds (wind-inducing upwelling, particularly), tides, and offshore mesoscale and submesoscale (10–100 km) processes, which have a potential for conveying energy to the coastal ecosystem and make it available for mixing. All of them, referred to the northern Alboran Sea, are shortly revisited below.

From geographic and oceanographic viewpoints, the northern Alboran Sea is divided into two differentiated areas. The first one goes from Punta Europa in the eastern exit of the Strait of Gibraltar to Punta Calaburras, some 100 km to the east (Estepona area or EA, hereinafter, Fig. 13.7). The second area spreads to the east of this point and includes the productive Bay of Malaga (Malaga area, or MA). This division is motivated by the Atlantic Jet, which flows relatively close to the coast in

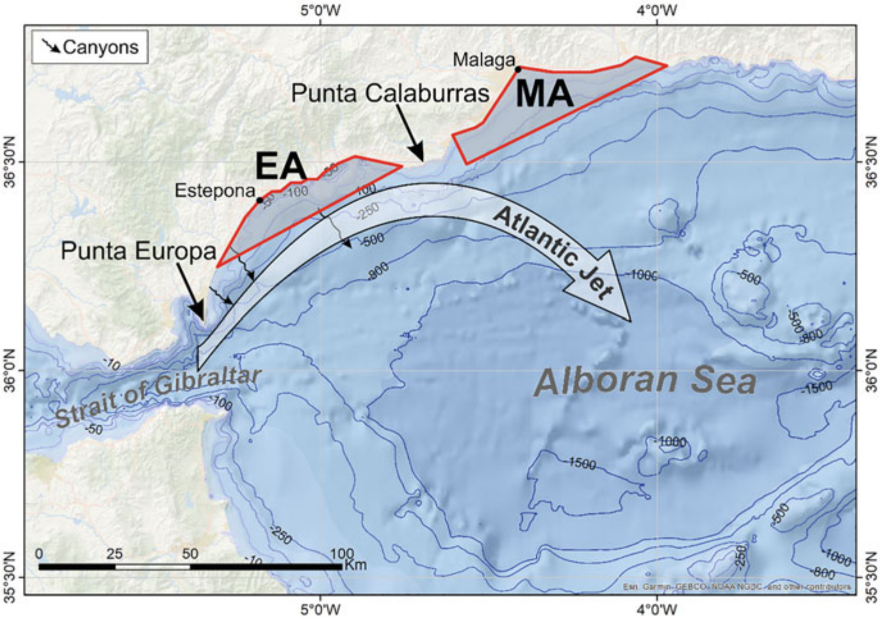


Fig. 13.7 Map of the Alboran Sea sketching the typical path of the Atlantic Jet and the two areas EA and MA mentioned in the text. Winding arrows indicate the location of submarine canyons

EA and exposes the region to its direct impact, but it detaches from the Spanish shore and starts veering to the southeast nearby Punta Calaburras, leaving the MA region partially sheltered from its influence. The jet separation from the shore as it flows past Punta Europa and Calaburras forces cyclonic circulation in both areas, which endows them with characteristics of retention zones. The retention of larvae is one of the processes that define the Bakun triad, which ultimately influences the survival of larval cohorts (Agostini and Bakun 2002; Agostini and Bakun 2002; Patti et al. 2010).

Because of the similar shoreline orientation, both areas show a similar response to wind dynamics. Westerlies induce upwelling and cool surface waters, while easterlies advect surface waters from offshore, warming the coastal environment and driving downwelling. Nine years (2003–2011) of data in the Alboran Sea (Era-Interim reanalysis, Dee et al. Dee et al. 2011) reveal the bimodality of winds, easteries, and westerlies, the former being slightly more frequent (48% versus 41%) and weaker (5.9 ms^{-1} versus 7.1 ms^{-1}) on average. In wintertime, however, westerlies are more frequent and intense (Sarhan et al. 2000). Upwelling in these regions enriches the water column and enhances primary production, which, along with their retention characteristics, meet the three conditions of the "Bakun triad" (Bakun 1996; Agostini and Bakun 2002) which define suitable environmental conditions for the spawning and nursery habitats.

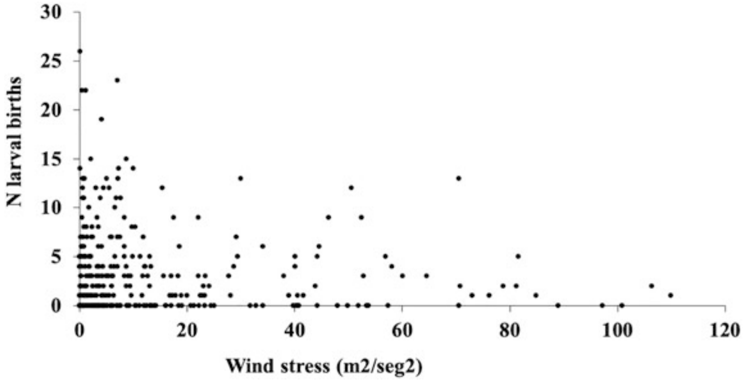


Fig. 13.8 The number of larvae born in relation to the wind stress indices observed during birthdates of all sampled sardine larvae sampled during the ECOMALAGA time series (1995, 1997–2003)

The findings from sardine larval cohorts sampled in the ECOMALAGA project (Camiñas et al. 1998) on a seasonal basis starting in 1995 and later during the period from 1997 to 2003 have shown the biological impact of wind on larval growth rates, as likewise, the effect of strong storms which may cause diminished growth rates (Maillet and Checkley 1991). The effect of coastal winds off the MA region affects sardine's spawning strategy where mature sardines prefer calm wind periods for spawning. It is in agreement with the "stable ocean" hypothesis (Lasker 1981) by which calm periods allow the formation of plankton patches, a potential food for the spawned offspring (Fig. 13.8).

Furthermore, the wind regime influences sardine larval population growth rates of different seasonal and annual sardine cohorts sampled in 1995 and during the period 1997–2003 as described in Fig. 13.9 (García 2006).

Westerlies in the nursery grounds of MA and EA affect all the northern Alboran Sea coast, promoting the fertilization of the surface layers and phytoplankton blooms (Sánchez-Garrido et al. 2014). These intense events of wind-induced upwelling are frequent, and they are followed by relatively calm periods that allow for a partial stratification of the water column (Mercado et al. 2007). This sequence of events may result beneficial, favoring the growth of larvae inhabiting nursery waters (García 2006).

Tides follow winds in importance as a physical mechanism influencing the environmental conditions in the northern Alboran Sea (Sánchez-Garrido et al. 2015). Inside the Mediterranean Sea, tides are almost inexistent except for a few places. One of them is nearby the Strait of Gibraltar and, of course, the strait itself (García Lafuente et al. 2000). Even though tidal vertical oscillations are very reduced (amplitude less than few tens of cm), the associated tidal currents can become important; the closer to the strait, the greater the current, so that tidal dynamics is enhanced in EA with regard to MA. Actually, García Lafuente et al. (1999) reported tidal currents up to 50 cm/s in the submarine canyons located in EA (Fig. 13.7),

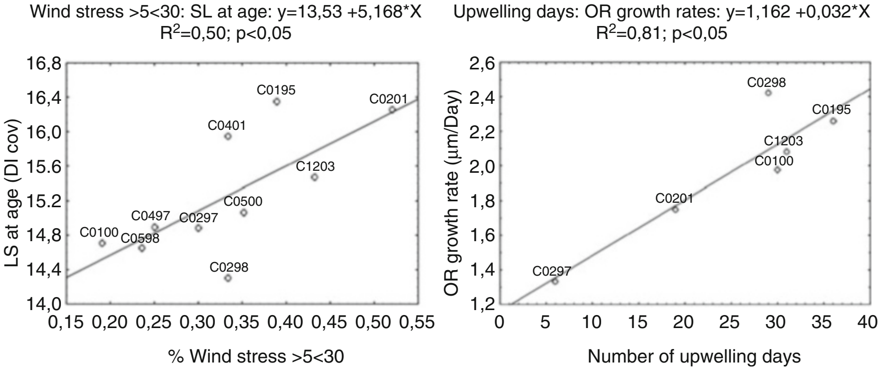


Fig. 13.9 Lineal relationship of SL at age with wind stress (ranging from >5 to < 30 and otolith radius (OR) growth rates with the percentage of wind stress and upwelling days undergone by sardine's larval life duration (C stands for cohort, then month/year) collected under the ECOMALAGA time series

whereas numerical simulations indicate values of only a few cm/s in MA. The available kinetic energy of tidal origin is therefore much greater in EA than in MA.

Significant differences between both regions also arise from the response to offshore mesoscale processes. In EA, the proximity of the jet to the shore (Fig. 13.7) causes a close dependence of the region dynamics on the fluctuations in the position of the Atlantic Jet, which are linked to the hydrodynamics of the water exchange through the Strait. Sarhan et al. (2000) showed that the north-to-south variation of the main path of the jet drives upwelling in a comparable way to the classical wind-induced upwelling, although the latter is more productive biologically due to the characteristics of the upwelled water. This mechanism is much weaker in the MA region and is concomitant with the wind regime to a large extent.

Considering the physical processes that act on both areas altogether, the EA region presents more vigorous dynamics driven by tides and by the transfer of energy from offshore mesoscale processes linked to the proximity of the Atlantic Jet. Wind-induced dynamics is similar in both regions, so that differences among them arise from the intensity of the two other mechanisms, which are noticeably more vigorous in EA. It means more available energy for mixing here and, hence, more potential for primary production, which is a positive feedback. But there is also a negative aspect related to the stability of EA as a retention area, because the accumulation of energy may eventually lead to instabilities. Sánchez-Garrido et al. (2013) showed that EA is a region prone to the release of submesoscale eddies that wander across the Alboran Sea carrying biological products with them. Even though it is essentially driven by the same mechanisms, the MA region has weaker dynamics because the energy input from offshore and the tidal energy are secondary processes, and the main driving and fertilizing mechanism here is the wind-driven upwelling. Neither instabilities like those reported in EA are observed in MA, so that the stability of this region as a retention area is considerably greater, which has obvious biological advantages for the reproduction strategy of small pelagic species and other coastal dwelling species.

13.3 Phytoplankton and Zooplankton Variability of the Alboran Sea Coast

The coastal hydrodynamics in the Alboran Sea which affects the formation of advection and upwelling processes that propitiate phytoplankton production and enriches plankton communities has been highlighted widely. In fact, the northwestern Alboran Sea represents the most productive area in the Western Mediterranean Sea in terms of chlorophyll-a (Chl-a), primary production and phytoplankton abundance (Rodríguez et al. 1998; García-Gorriz and Carr 2001; Ruíz et al. 2001, 2013; Bosc et al. 2004; Mercado et al. 2008, 2012, 2014; Patti et al. 2010; Navarro et al. 2011). Consequent with the Alboran Sea's high phytoplankton production, zooplankton biomass and production estimates of the Alboran Sea (García and Camiñas 1985; Sampaio et al. 2005; Yebra et al. 2017) have ranked among highest in the western Mediterranean (Champalbert 1996; Siokou-Frangou et al. 2010). A quarterly monitoring project carried out in MA since 1992, ECOMALAGA, describes the temperature/salinity time series (Fig. 13.10), as well as the mesozooplankton abundance and chlorophyll concentration (Fig. 13.11). The data were obtained from quarterly samplings performed principally in January–February (winter), March–April (spring) July–August (summer), and October–November (autumn). These data indicate that the annual maximum in temperature and minimum in salinity is normally obtained in summer-autumn. However, the occurrence of annual cycles departing significantly from these typical cycles is frequent (for instance, see the periods 1994–1995 and the years 1999 and 2003; Mercado et al. 2007, 2012).

The TS time series depicts strong seasonal differences in which temperature between winter and spring/summer periods differs by 6°C. Likewise, the salinity profiles provide a picture of upwelling events observed, such as that of 1993, 1999, and 2012. Such hydrographic seasonal variability shows its influence in the mesozooplankton and chlorophyll *a* variability (Fig. 13.11). The upwelling events that occurred during 1993 and 1999 showed peaks of mesozooplankton abundance and chlorophyll *a* values, while that of 2012 was mainly reflected by the peaks of chlorophyll *a* concentration. Nevertheless, the gap observed in 2013 was covered by another monthly sampling project of MA (REMALA) that also showed strong upwelling events in the winter of 2013 and summer of 2014 (see Fig. 13.10).

These data show the complex time variability patterns that feature the plankton community in the Alboran Sea. Thus, conspicuous peaks in the abundance of mesozooplankton are often registered (years 1993, 1998–1999), which are normally attributable to copepods, but it does not apply in every case. It is also notable that peaks of zooplankton often were not related to periods of elevated phytoplankton biomass (Fig. 13.11).

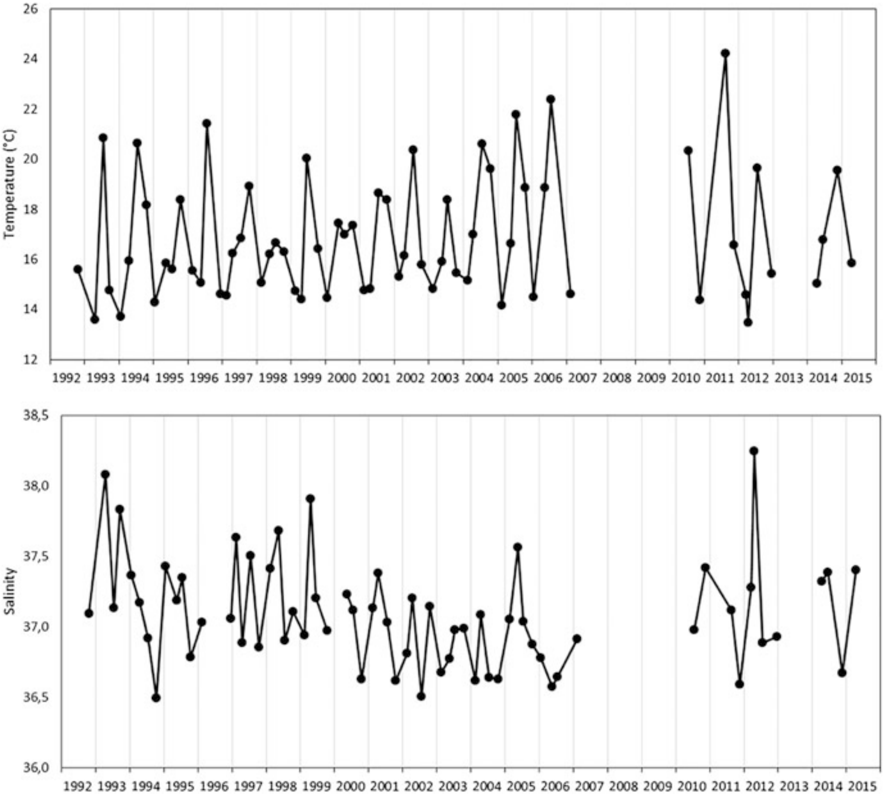


Fig. 13.10 Time series of temperature and salinity in the 20 m upper layer of a station located in the shelf of MA

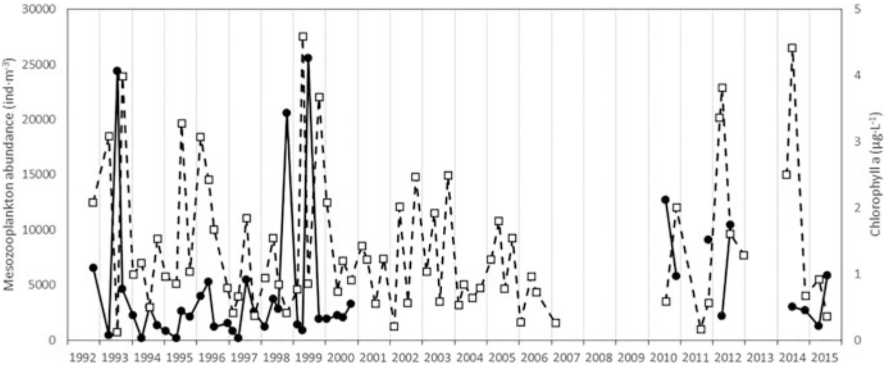


Fig. 13.11 Time series of mesozooplankton abundance (closed circles, continuous line) and concentration of chlorophyll a (open squares, dashed line) obtained in a coastal station in MA (https://www.st.nmfs.noaa.gov/copepod/time-series/es-50301/) from quarterly samplings carried out in 1992–2001 and 2010–2015 (data of chlorophyll for 2002–2007 are also shown)

This high productivity is primarily linked to the enrichment of the euphotic layer with inorganic nutrients (mainly nitrate), which supports communities of phytoplankton usually dominated by diatoms (Rodríguez et al. 1998; Arin et al. 2002; Reul et al. 2005; Mercado et al. 2005, 2007, 2011). However, the analysis of the interannual variability in the taxonomic composition reveals complex patterns (Balle 1963; Margalef 1969; Delgado 1990; Rubín et al. 1999; Mercado et al. 2005). Thus, the early works of Rodríguez et al. (1982) and Delgado (1990) reported a community dominated by small flagellates and diatoms which can be considered typical of upwelling areas. However, Mercado et al. (2005) described two well-differenced communities: one was dominated by small flagellates and diatoms (diatom-dominated community), while the other community was characterized by the dominance of coccolithophorids and dinoflagellates (non-siliceous algal-dominated communities). The analysis of time series for the period 1992–2002 revealed that both communities were temporally segregated, with diatom-dominated community prevailing from 1994 to 1997 and non-siliceous algal-dominated communities doing it from 2000 to 2002. The diatom-dominated community was mainly composed of chain-forming pennate diatoms belonging to the genus *Pseudo-nitzschia* and the centric diatoms *Thalassiosira*, *Rhizosolénia*, *Leptocylindrus*, and *Skeletonema*. The dinoflagellates belonging to the species *Scrippsiella trochoidea*, *Protoperidinium depressum*, and *Prorocentrum minimum* also appeared frequently. The second community was characterized by the coccolithophorids *Calcidiscus* and *Gephyrocapsa* and the dinoflagellates *Prorocentrum compressum*, *Ceratium extensum*, and *Ceratium furca* which were dominant during 2000–2002 (in special *Gephyrocapsa* sp.).

Irrespective of these interannual patterns, the abundance of diatoms is usually greater in spring, coinciding with greater nutrient availability. In contrast, the abundance of dinoflagellates does not follow a clear seasonal pattern. The analysis of the zooplankton abundance data also reveals a seasonal cycle characterized by maxima in summer (1964 ind m^{-3}) and minima in spring (467 ind m^{-3}, Sampaio et al. 2005). Copepods are the predominant group throughout the year, doubling their abundance in summer. However, at this time, cladocerans represent up to 40% of the relative abundance. Gelatinous plankton in general represents less than 5% of the community (Rodríguez et al. 1982; Sampaio et al. 2005). Interestingly, this seasonal cycle in zooplankton contrasts with the seasonal variations obtained for other locations in the western Mediterranean Sea, where lower biomasses of zooplankton are usually found in summer whereas higher values are obtained from April to June (Sabates et al. 1989; Fernandez de Puelles 1990; Champalbert 1996).

The joint analysis of the phytoplankton and zooplankton data series for the Alboran Sea carried out by Mercado et al. (2008) revealed that zooplankton exerts a strong top-down control on phytoplankton at the seasonal scale. However, the aforementioned interannual changes in phytoplankton composition reflected in changes in the zooplankton composition as the abundance of copepods and brachiopods decreased in 1992–1999 (possibly due to the interannual shifts in the phytoplankton communities). Furthermore, strong spring blooms of phytoplankton are normally followed by noticeable peaks of zooplankton in summer. In fact, zooplankton biomass and abundance in the NW Alboran coastal area were found to be highly correlated to chlorophyll *a* in summer (Yebra et al. 2017), indicating that taxonomic composition and abundance of the phytoplankton are the driving forces which in turn strongly influence the fate of zooplankton production (Poulet et al. 1995; Laabir et al. 1995). This planktonic production variability would in turn shape the ichthyoplankton recruitment success in the region since both abundance and quality of the potential prey for larvae vary significantly, which is probably reflected in the growth status of small pelagic larvae as is commented below.

13.4 Seasonal Characterization of the Alboran Sea Ichthyoplankton

The relative contribution of small pelagic larval catches by the fry fishery depicts the reproductive seasonality of sardine and anchovy larvae (García et al. 1981; García and Rubín 1985; García et al. 1987). The seasonal cycle extends from autumn to late spring, in which sardine larvae comprise the major fraction of catches, while in spring anchovy larvae overlap with sardine attaining its peak during the summer months. During autumn/winter, both species also overlap (Rodríguez 1990; Mafalda et al. 2008) (Fig. 13.12).

The Alboran Sea constitutes a natural passage where the exchange of Atlantic and Mediterranean water masses occurs and endows the region with an exceptional

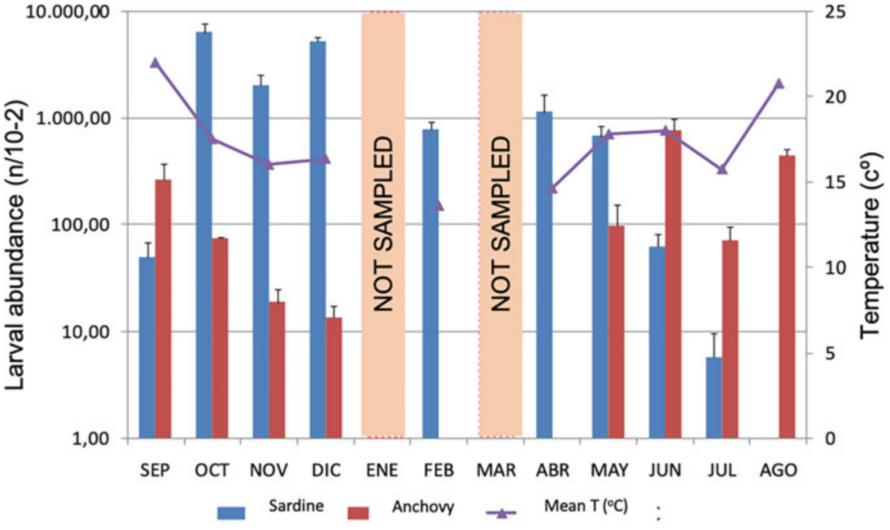


Fig. 13.12 Relative abundance of sardine and anchovy larvae in MA (N / 10 m^2), together with the average temperature at 10 m during September 2013 to August 2014 under the REMALA project (Baro et al. 2014). Note that the abundance scale is logarithmic

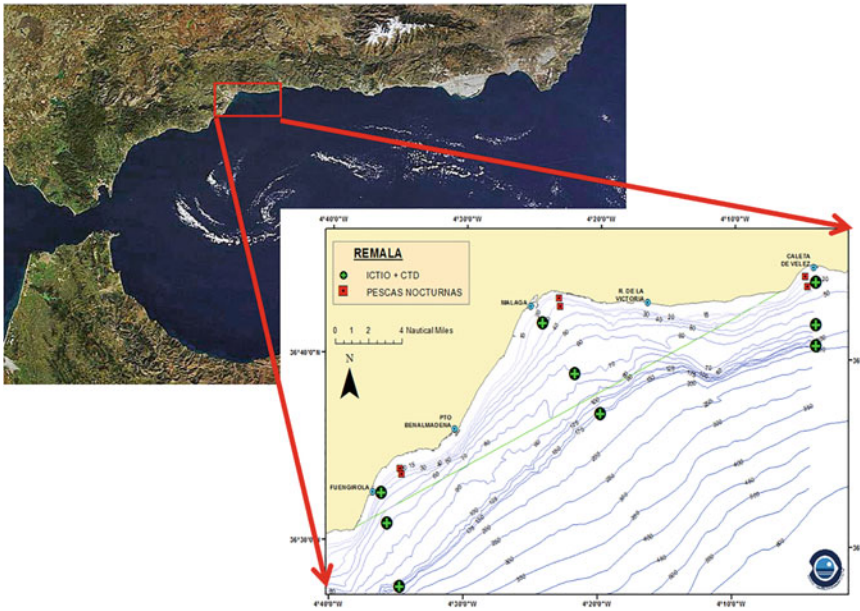


Fig. 13.13 Satellite mapping indicating study area and the ichthyoplankton and physical oceanography sampling stations in the study area during daytime (green cross) and nighttime (red square) from September 2013 to August 2014

species diversity clearly manifested in the specific composition of ichthyoplankton. An ichthyoplankton seasonal study throughout an annual cycle carried out in MA reveals the high species diversity (Marina et al. 2015; García et al. 2015). A grand total of 87 taxonomic groups were identified, in which 82 were to the species level. It is interesting to note that species of the meso- and bathypelagic domains were predominant in spite of the nine sampling stations located at shallow coastal and shelf waters (Fig. 13.13); specially noticeable is the fact that12 species representing 47.9% of the total account of larvae present during the annual cycle belonged to the Myctophidae family. Their nearshore abundance indicated an upwelling origin (Marina et al. 2015; García et al. 2015). The high species diversity is greater than that reported by Rodríguez (1990) and Mafalda et al. (2008).

The next dominant group was represented by the Clupeidae family accounting 14.38% of the total larvae collected. *Sardina pilchardus* larvae are found almost throughout the whole year (Fig. 13.14). Sardine starts spawning in September and develops its peak season during winter when temperature is lower and upwelling is more frequent and intense. Nevertheless, their larvae may still be found until late spring and early summer (Fig. 13.14).

With respect to anchovy (*Engraulis encrasicolus*), it shows the preference for warmer temperatures compared to sardine (García and Palomera 1996; Palomera et al. 2007). The Alboran Sea anchovy starts spawning in May and develops its full spawning capacity during summer and continues during autumn (Fig. 13.14).

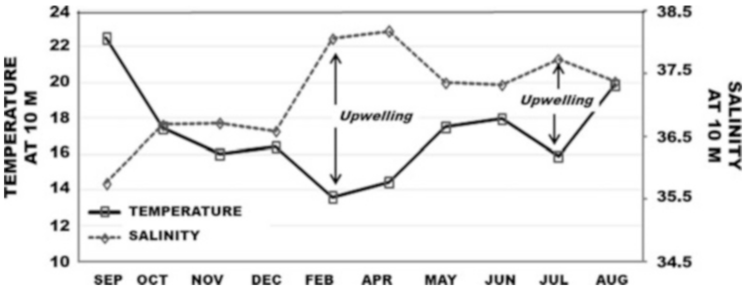


Fig. 13.14 Average monthly temperature and salinity throughout the anchovy and sardine sampling period carried out during the REMALA project (September 2013–August 2014)

Although much less abundant than the aforementioned groups, commercially important species were represented by hake (*Merluccius merluccius*), blue whiting (*Micromesistius poutassou*), axillary seabream (*Pagellus acarne*), spotted seabream (*Pagellus bogaraveo*), black seabream (*Spondyliosoma cantharus*), two horse mackerel species (*Trachurus trachurus* and *T. mediterraneus*), chub mackerel (*Scomber japonicus*), and the two Mediterranean species of mullets (*Mullus surmuletus* and *M. barbatus*).

The monthly mean temperature and salinity data collected during the surveys deviated from the annual average temperature and salinity historical series (Fig. 13.10) consequent with the observed upwelling events during winter and summer. Such events explain the high species diversity and the timing of spawning of sardine and anchovy (Fig. 13.14). During the initiation of the annual cycle, from September to December, we observed that the waters were predominantly of Atlantic origin defined by their characteristic salinity signatures. The interphase salinity between Atlantic and Mediterranean water masses is 37.5. From February to April, salinities were within the range of Mediterranean waters, explained by upwelling processes evidenced by the lower-temperature regime observed in the MA during the sampled period. From May to August, during the anchovy spawning season, salinities drop to interphase values between Atlantic and Mediterranean waters, and the temperatures rise.

It is important to remark thermic preference for warmer waters of anchovy (Palomera et al. 2007) as shown by the decrease in the abundance of anchovy larvae during July, consequential with the temperature drop resulting from the summer upwelling event (Fig. 13.12).

13.5 Ecophysiology of ELHS of Small Pelagics

13.5.1 Scientific Scope of Early Life History Research

Recruitment of small pelagic species such as sardine and anchovy is characterized by strong interannual fluctuations (Giráldez and Abad 1991) that are attributed to the survival success during the early life stages. Several factors affect fish larval mortality rates during the ELHS, although the most important ones are mortality caused by enhanced predation and/or starvation (Hewitt et al. 1985; McGurk 1986; Bailey and Houde 1989).

The survival of ELHS is therefore crucial for stock recruitment where small changes in growth rates can have important repercussions on larval mortality (Houde 1987, 2008). Mortality rates during early life are influenced by starvation and predation, generally in that sequence because starvation leads to poorer nutritional status of larvae making them more vulnerable to predation (Bailey and Houde 1989; Folkvord and Hunter 1986). Also, slower growth rates turn fish larvae extend temporally the ontogenic development at particular sensitive stages, thereby increasing predation pressure (Buckley 1984; Folkvord and Hunter 1986).

Therefore, somatic larval growth rates are critical in determining the time that larvae spend in the size classes more susceptible to be preyed upon. The research conducted on growth and condition studies at ELHS of small pelagics has shown that growth rates are influenced mainly by the surrounding temperature regime and the amount and quality of trophic resources (Ramírez et al. 2001; García et al. 2003; Mercado et al. 2007), although maternal effects can have a consequential influence on growth variability (García et al. 2003; Uriarte et al. 2016).

Temperature is a key factor controlling fish growth. Temperature affects metabolic rates of ELHS by increasing or decreasing the catabolism and anabolism of proteins and therefore the accretion of muscular tissue and the development organs during the development of ELHS. Several studies have reported enhanced larval growth at higher temperatures both in the field- and in laboratory-reared larvae (Blaxter 1991; Folkvord et al. 2004). On the other hand, nutritional condition indices are also affected by temperature. Thus, the existing studies on this subject (e.g., Goolish et al. 1984; Ferguson and Danzmann 1990) have shown that larval fish RNA/DNA tends to decrease with increasing seawater temperature. According to Goolish et al. (1984), the underlying reason for a decline in RNA/DNA in fish inhabiting increased seawater temperature would be due to the existence of a metabolic mechanism that compensates for lower RNA activity at lower temperatures, producing an increase in RNA concentration.

Alternatively, food availability (i.e., suitable prey density) and larval success in capturing their prey affect directly to the intake rates of proteins, carbohydrates, lipids, and other nutrients by fish larvae. Laboratory and mesocosm experiments have shown that food availability directly affects somatic larval growth, with well-fed larvae growing at faster rates than larvae under poor food availability. Food availability not only affects growth, but it also affects the biochemical composition of larval tissue. A poor nutritional condition, or even starvation caused by competition for food resources or by low prey density, not only has a direct effect on protein synthesis and tissue accretion rates, but it also turns larvae more sensitive to predators as their swimming capacity is reduced, thus prone to predators (Purcell 1985; Purcell and Grover 1990).

The findings reported by earlier research studies on larval growth (based on otolith microstructure) and nutritional condition (mainly based on RNA/DNA) clearly demonstrated the joint use of otolith microstructure and biochemical analysis as new tools for assessing the effect of the processes affecting larval survival and better understand the underlying causes of interannual fluctuations in the recruitment success of small pelagic species (Buckley 1984; Campana and Neilson 1985; Moksness and Wespestad 1989; Clemmessen 1994). Some of these studies and others demonstrated that enhanced growth at early life stages shows significant relationships with larval survival rates for many fish species around the world (Hovenkamp 1992; Takasuka et al. 2003; García et al. 2003; Meekan et al. 2006).

The implementation of these research tools was applied in the field, beginning with the NW Mediterranean anchovy which represents the greatest resource of this species in the Spanish Mediterranean (García et al. 1998). The experience gathered in these ELHS research proved in later years that the early life stages of sardines and anchovies confirm the growth-mortality hypothesis (Anderson 1988) by which growth is intricately related to larval mortality (Houde 1987, 2008).

In small pelagic larvae, enhanced growth is attained with higher RNA/DNA influenced by the amount of trophic resources between regions in western Mediterranean coasts (García et al. 1998, 2003; Quintanilla et al. 2015).

Thus, differences in somatic growth, otolith growth, and larval nutritional condition of anchovy larvae, from different spawning areas of the NW Mediterranean, suggested important effect of seawater temperature on larval condition as estimated from RNA/DNA. Those effects were confirmed by Ramírez et al. (2004) who studied the effect of temperature and microzooplankton biomass on biochemical nutrition indices of anchovy larvae in the NW Mediterranean Sea where temperature and microzooplankton accounted for $>70\%$ of the variability in RNA, DNA, and protein. However, the ratios of RNA/DNA and protein/DNA were only related to temperature. On average, both ratios in anchovy larvae decreased with temperature, probably reflecting the effect of temperature on larval metabolism, supporting the findings of previous studies conducted with other species (e.g., Goolish et al. 1984; Ferguson and Danzmann 1990).

Accurate estimates of growth rates and nutritional condition of larvae were needed to understand and predict fluctuations in recruitment. The ECOMALAGA quarterly sampling program supported the small pelagic larval sampling which is a methodological framework in establishing precision and accuracy under an EU-funded project (PARS, FAIR961371) grouping teams from different EU countries.

The research conducted involved different interlaboratory test studies, including samples of Alboran Sea sardine larvae, to analyze the precision and accuracy of otolith readings and the use of the RNA/DNA as tools for determining larval growth and nutritional condition. Among the main outcomes of the project was the publication of a practical manual of the tools used for recruitment studies of small pelagic fish species (Belchier et al. 2004) where different protocols regarding otolith microstructure analysis and nutritional condition were tested through intercalibration procedures and applied accordingly.

García et al. (2006a, b) observed differentiated larval growth patterns between the sardine stocks of the NW Mediterranean and the northern Alboran Sea. Larval daily growth rate, otolith growth rate, as well as RNA, DNA, and protein content at a given age were comparatively higher in larvae collected in the NW Mediterranean coast (Ebro Delta). From the somatic point of view, the NW Mediterranean sardine grew faster in body size in comparison to the Alboran Sea larvae which tended to distribute body mass increase by means of increasing body weight, suggesting in the latter that growth tends to build up body reserves possibly due to their dependence on intermittent pulses of productivity caused by wind-induced upwelling.

The NW Mediterranean sardine is exposed to differentiated environmental drivers prompting productivity, principally the Ebro river outflow that induces hydrographic frontal structures and the upwelling resulting from the Northern Current flow along the Catalonian coastline (Palomera et al. 2007). Therefore, these differences in growth rates and biochemical indices were attributed to a higher microzooplankton abundance in the NW Mediterranean, particularly in areas close to the Ebro Delta. According to previous studies, the higher abundance of microzooplankton in the closest areas to the Ebro Delta could also explain to some extent the differences in nutritional condition and growth rates found in anchovy larvae from different spawning sites located in the NW Mediterranean (García et al. 1998), although in the south of the Ebro river outlet, microzooplankton biomass has been reported to be much lower (García et al. 2006a, b). A previous study of Palomera and Lleonart (1989) larval mortality revealed differences between the northern and southern spawning sites in agreement with the former study of García et al. (1998) whereby greater growth rates were observed in the northern spawning site, within the surroundings of the highly productive Gulf of Lions.

It is interesting to also highlight the existence of differences in the biochemical composition of sardine larvae between different areas of the Alboran Sea. García et al. (2006a, b) reported that sardine larvae from the Almeria Bay presented higher carbohydrate content than sardine collected in the Malaga Bay. These differences in carbohydrate content could not be explained by differences in microzooplankton abundance or composition. Quite to the contrary, microzooplankton from the Almeria Bay presented higher protein content which was not reflected in different larval protein content. Based on these results, García et al. (2006a, b) suggested that larvae in the Almeria Bay could feed on other preys with higher carbohydrate content. It has been reported that sardine larvae feed actively on copepods eggs, nauplii, and copepodites, these accounting for 78–89% of the gut content (Conway et al. 1994; Yebra et al. 2019). However, there are also studies reporting passive feeding of clupeid fish larvae, including sardine, on phytoplankton (Lasker 1978; Walsh et al. 1980; Rasoanarivo et al. 1991).

Carbohydrate content of phytoplankton ranges from 14.1 to 55.8%, while protein content seems to be more stable ranging from 50.7 to 34.1%, (Ríos et al. 1998). In the case of zooplankton, the main constituents are proteins followed by lipids and carbohydrates (Jo et al. 2018; Jagadeesan et al. 2010). The inclusion of phytoplankton in the diet of sardine larvae from the Almeria Bay would explain their high carbohydrate content (García et al. 2006a, b; Mercado et al. 2007). From such findings, we can be likewise infer that the quality of feeding resources may be as important as the abundance of trophic resources.

The effect of quality feeding resources versus quantity was demonstrated in the larvae of the Mediterranean bluefin tuna in which three annual larval cohorts from 2003 to 2005 were analyzed from both the growth and condition standpoint. The greatest larval growth of bluefin tuna larvae was attained in 2003, under extreme temperature changes and extremely low production caused by the historical Mediterranean heat wave (García et al. 2013).

13.5.2 Larval Growth and Larval Condition Research Studies

Ramírez et al. (2001) revealed that the growth strategy of the ELHS of the winter-spawned sardine larvae in the northwestern Alboran Sea is characterized by a decrease of length increment growth rates with increasing larval ages, while growth in somatic mass gain tends to increase with age. This sardine larval growth strategy was corroborated by other studies conducted with northern Alboran Sea sardine larvae (Ramírez et al. 2004). However, studies conducted with sardine larvae in post-flexion stages (García et al. 2006a, b; size range from about 16 to 28 mm) found that size at age followed a linear pattern rather than a power pattern and thereby, the resulting growth rates for those size classes are constant (around 0.32 mm/day). The results of all these studies indicate that there is an inflection in sardine somatic growth rates, both in length and weight, which could be due to ontogenic changes of larvae during its development and by the changes in larval food items. Thus, Conway et al. (1994) based on the analysis of the gut content reported an increase in copepodites in the diet of sardine larvae larger than 15 mm collected in the north Iberian continental shelf.

Otolith growth also provides important information to understand the variability in recruitment. Thus, for the northern Alboran Sea sardine, Ramírez et al. (2001) reported that otolith larval growth was faster for older age groups in comparison with younger larvae. These differences could be attributed to growth-dependent mortality during the earlier stages of sardine larval development (Ramírez et al. 2001). Likewise, growth-dependent mortality could explain the observed increase in nutritional condition with larval length (Ramírez et al. 2001), since well-fed larvae would also have more survival rates than poor feed or starved larvae.

The studies conducted in the Alboran Sea have also allowed further insights on how larval growth, otolith growth, and nutritional condition are related. Under ideal conditions, a close relationship between larval somatic growth and nutritional condition is expected. Thus, previous studies with other species related recent somatic fish larval growth with RNA/DNA (Buckley 1984; Hovenkamp and Whitte 1991; Westerman and Holt 1994). However, the studies conducted with field-caught sardine larvae suggest that RNA/DNA is not a good indicator of somatic growth in length or age. Thus, Ramírez et al. (2001) found that the RNA/DNA and protein/DNA ratios were weakly related to somatic larval growth in mass as well as to recent otolith growth. On the other hand, previous studies have used the width of the last three-six otolith daily microincrements as a proxy of recent larval growth in some species, showing strong correlations with RNA/DNA ratios in other fish species (Clemmessen and Doan 1996). However, the studies conducted in the North Alboran Sea with sardine larvae show that the RNA/DNA ratios in larvae is generally highly variable. This may be due to a more rapid response of RNA to exogenous factors, such as temperature (Goolish et al. 1984), while changes related with somatic and otolith growth rates have a slower response to external factors (Ramírez et al. 2004).

On the other hand, the studies conducted with sardine larvae collected in the northwestern Alboran Sea revealed that RNA, DNA, protein, and carbohydrate content of larvae is highly dependent on larval age, length, and weight (Ramírez et al. 2001; Ramírez et al. 2004; Cortés 2006). Although both length and weight at a given age are indicators of somatic growth, according to the research on sardine larvae in the Alboran Sea, weight accounts for a higher percent of variability in biochemical parameters than larval length (García et al. 2005). This higher dependence on weight can be explained by the fact that these biochemical parameters are intrinsically related to cell metabolism and tissue accretion.

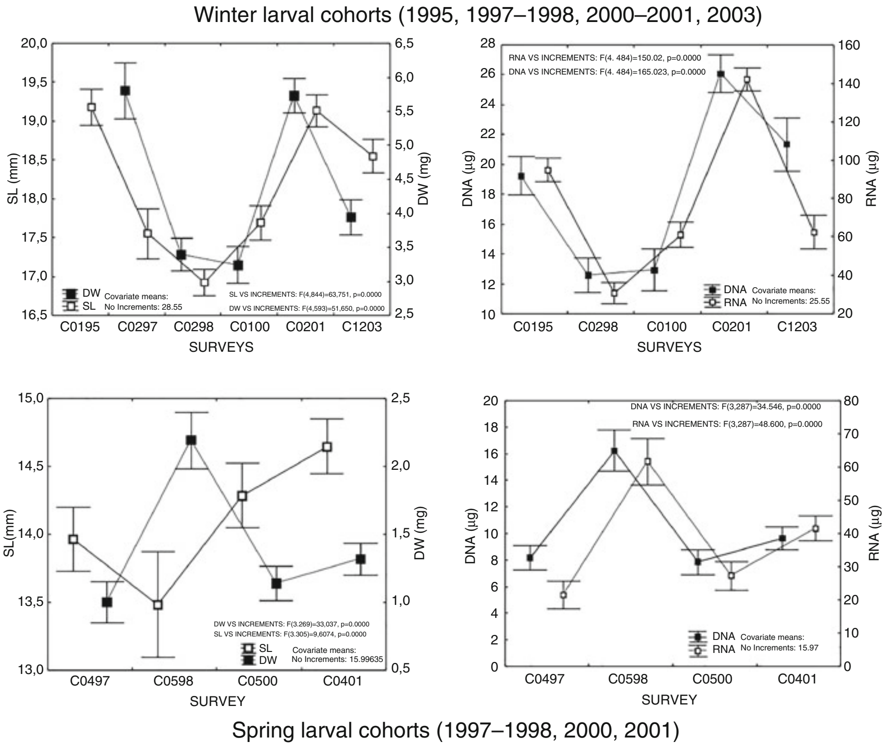
Although larval growth is highly influenced by the surrounding hydrobiological conditions predominating in their nursery sites, the influence of maternal qualities cannot be overlooked (Høie et al. 1999; Green and McCormick 2005; Uriarte et al. 2016). Recent results have shown that pre-flexion larvae of bluefin reared under controlled laboratory conditions showed maternal transmission of the stable isotopes of carbon and nitrogen (Uriarte et al. 2016) enabling future prospects of analyzing the trophodynamics of spawning females.

13.5.3 Seasonal and Interannual Variability of Larval Growth and Condition Research

The temporal variability of larval growth and condition (RNA/DNA) research of larval stages of sardines and anchovies was enabled by the ECOMALAGA sampling time series. The temporal and seasonal variability of larval sardine (García 2006; Cortés 2006) and an interannual comparison of anchovy larvae (García et al. 2003) allowed investigating the environmental and climatic drivers that influence ELHS development.

ANCOVA using daily increments (DI) as covariant showed highest sizes at age (SL) and dry weight (DW) at age between comparably equal larval size classes of sardine larval cohorts, which is consequential to having greater daily growth rates. Maximum growth corresponded to maximum DNA and RNA content during the winters of 1995 and 2001 (Fig. 13.15). During spring, the sardine larval cohorts of 1998 and 2001 showed highest growth rates.

Motivated by the faster is better hypothesis whereby faster-growing individuals are prone to have higher survival rates (Houde 1987; Anderson 1988; Meekan et al.


Winter larval cohorts (1995, 1997–1998, 2000–2001, 2003)

Spring larval cohorts (1997–1998, 2000, 2001)

Fig. 13.15 ANCOVA analysis using estimated age (DI) with somatic variables of size and dry weight (SL and DW) (left column) and nucleic acid content with age (RNA, DNA) (right column) (ECOMALAGA time series)

2006), a field-based experiment was set to verify the consequences of enhanced larval growth in the survival of the Alboran Sea sardine and anchovy.

A field test experiment verified this hypothesis on mortality of sardine larvae. A surviving cohort of sardine larvae from its original population was analyzed by backtracking growth curves and compared with the original cohort sampled 2 weeks earlier in the same nursery site (García et al. 2007). Sardine juveniles sampled and aged on a monthly basis followed postlarval growing cohorts to their juvenile stages also indicated that surviving juveniles showed enhanced growth rates (Alemany et al. 2006).

In conclusion, larval survival of both species is clearly linked to faster growth rates and better nutritional conditions. Nevertheless, the Alboran Sea sardine can show two differentiated growth strategies, favoring growth in length or alternatively in somatic mass (García 2006). The highest larval growth occurred during the winters of 1995 and 2001. Since the Alboran Sea sardine is a protracted spawner (early autumn, September to late spring, May), significantly different seasonal growth patterns occur from winter- to spring-spawned larvae. In general, greater

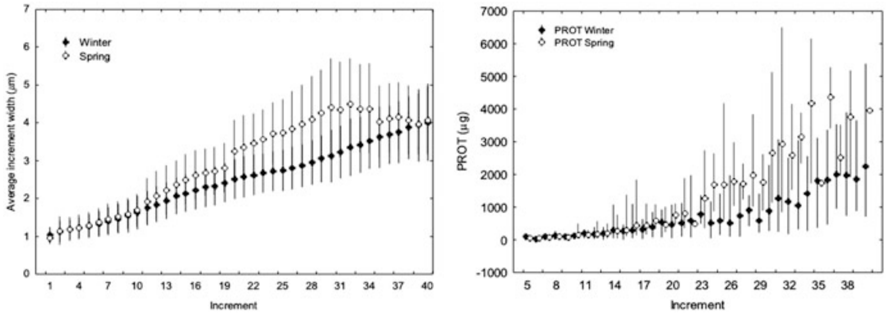


Fig. 13.16 Average increment widths observed by microstructure analysis of larval sardine otoliths (left) and protein content with estimated increments. (García 2006; Cortés 2006) (ECOMALAGA time series)

growth occurs during spring when temperatures increase (Ramírez et al. 2004; Mercado et al. 2007).

The overall larval sardine population collected from the ECOMALAGA surveys show differentiated growth patterns as shown by the accretion of daily increments considered a good proxy of growth. It corresponds to a greater protein buildup of somatic mass (Fig. 13.16). In year-by-year cases, this general picture can vary greatly because winter corresponds to greater nutrient resources, thereby enhancing growth in body mass under a low-temperature regime. On the other hand, spring shows greater hydroclimatic and nutrient variability which undoubtedly affects growth variability.

At the sardine nursery site of Malaga, wind stress showed significant linear relationships with somatic growth variables of sardine larvae monitored from 1995 to 2003 (García et al. 2006a, b) (Fig. 13.9). Alemany et al. (2006) indicated that larval survival and larval and juvenile growth rates showed a positive correlation with westerlies that induce upwelling events (Sarhan et al. 2000), in the coastal shelf and calm sea weather conditions in the inshore nursery grounds.

In general, the spring larval cohorts showed faster somatic growth rates, both in length and weight, than those born during the winter season (García et al. 2005; García 2006) due to more favorable environmental conditions with higher temperatures and higher planktonic biomass coupled to spring blooms (García et al. 2005; Ramírez et al. 2005; Mercado et al. 2007). Faster somatic growth observed in the spring-spawned sardine larvae is coupled with faster otolith growth in comparison with larvae winter-spawned larvae. Consequently, spring-spawned sardine larvae have larger otoliths with wider daily increment widths than winter-spawned sardine larvae (García et al. 2005; García 2006).

In general, spring-spawned sardine larvae presented better nutritional conditions than winter-spawned larvae showing significantly higher RNA, DNA, protein, and carbohydrate content at age (García et al. 2005; Cortés 2006; Mercado et al. 2007). However, no significant differences were observed with respect to RNA/DNA between both seasonal periods suggesting the resilience of this species to changing seasonal conditions. In this case, differences in sea temperature act as a physiological driver that modulates the estimated RNA/DNA ratios. A decoupling between larval growth and biochemical indices can be observed consequent of a delayed response of larval growth to sudden changes in environmental conditions (Ramírez et al. 2004).

The variability of seasonal growth patterns in small pelagic larvae, is modulated by the temperature and feeding resources which may undergo abrupt changes. Strong changes of trophic resources for larvae can originate from changes in the phytoplankton composition as observed by Mercado et al. (2007), where a phytoplankton diatom-based community shifted towards a coccolithophorid type of community in 2001. Highest larval growth of anchovy and sardine cohorts corresponded to this year-class (García 2006; García et al. 2003). Moreover, changes in phytoplankton community may have contributed to having higher carbohydrate content in sardine larvae sampled in winter 2000 and 2001 (García et al. 2005; Cortés 2006; García 2006; Mercado et al. 2007).

With respect to the Alboran Sea anchovy, its peak spawning occurs during summer (July–August) (Rodríguez 1990). An unexpected high anchovy recruitment occurred during 2001 (Abad and Giráldez 1990). Growth data on anchovy of the 2000 and 2001 year-class were compared which yielded a field-based study on the influence of growth on annual recruitment (García et al. 2003). The 2001 anchovy larval cohort showed a 20% increase in daily growth rates in comparison to the previous year (García et al. 2003). The birth date distribution of both cohorts showed that during 2001 these were born at an earlier period (late spring) which possibly coupled with the spring bloom because zooplankton biomass was unexpectedly high in 2001 in comparison to the previous year. Furthermore, Mercado et al. (2005, 2007) revealed important interannual changes in the predominance of the different phytoplankton groups in the Alboran Sea) shifting from a diatom-based community to a coccolithophorid- and dinoflagellate-based phytoplankton grouping.

Nevertheless, it is reasonable to think that a single event like the strong 2001 anchovy recruitment must have been triggered by changes or driving forces of biological and hydro-physical nature that occurred in the Alboran Sea. Ruíz et al. (2013) observed a relationship between the variability of the path and intensity of Atlantic Jet with the anchovy recruitment. A high kinetic energy of the current favors the production in northern Alboran, but negatively impacting anchovy recruitment, possibly inducing a greater degree of larval advection and dispersion. The year 2001 constituted an outlier of the time series of data from 1988 to 2010. The climatic and hydrographic forces of the Atlantic current are also responsible for maintaining the temporal persistence of the anchovy and sardine nursery grounds (Macías et al. 2011).

13.6 New Approaches Towards ELHS Trophodynamics

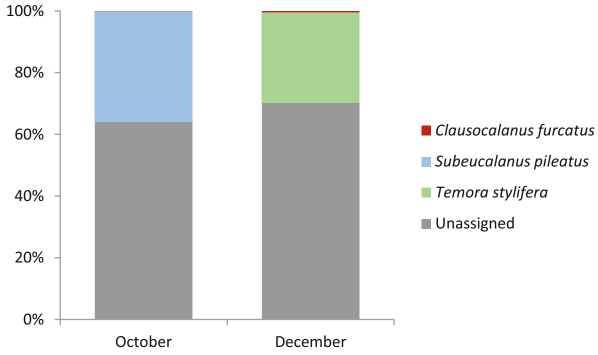
The joint analysis of growth at ELHS together with other analytical tools has led way to the development of new digital imaging tools for growth otolith microstructure analysis (Nava et al. 2018). This digital imaging tool is open to otolith experts and is continuously being updated with new applications, as otolith asymmetry. It has been shown that larval trophodynamics are strongly relevant for enhancing daily growth (Pepin et al. 2015). Studies of the trophic transfer of C and N from phytoplankton to zooplankton and ichthyoplankton by determining the isotopic composition (^{13}C and ^{15}N) of different size fractions revealed that sardine and anchovy larvae modify their diet depending on the quality or the type of food available, namely, the phytoplankton and/or zooplankton groups present (Uriarte 2010; Laíz-Carrión et al. 2011; Quintanilla et al. 2015; Quintanilla 2016). Further findings show that the stable isotope of nitrogen (δ^{15}N) showed a linear relationship between faster- and slower-growing individuals with the average values of δ^{15}N by daily age class. This link was further corroborated on the species *Auxis rochei* from the Balearic Sea. Two cohorts of this species originating from two hydrographically different water masses showed differentiated growth patterns in which enhanced growth was linked to greater δ^{15}N values (Laíz-Carrión et al. 2013).

With respect to anchovy, a comparison between the NW Mediterranean anchovy and Alboran Sea anchovy stable isotope analysis linking larval growth study showed that the NW Mediterranean anchovy population showed specialized prey selectivity associated with a low productive ecosystem in contrast to the Alboran Sea population, which showed a more generalist feeding behavior associated with an ecosystem of higher food resources. The differences between ecosystems were shown by the significant differences in the δ^{13}C values indicating differences in the carbon sources of each larval habitat (Uriarte 2010). Higher growth rates recorded greater δ^{15}N values, thereby a higher trophic position which indicates a greater feeding specialization in larvae originating in less productive regions (Uriarte 2010; Quintanilla et al. 2015). From the population viewpoint, differences in the amino acid composition of anchovy egg and larvae further corroborated stock differentiation (Riveiro et al. 2003).

A similar study comparison was carried out in the Alboran Sea sardine which has nursery grounds in widely distinct environmental characteristics, the bays of Almeria and Malaga, being the former distinguished by its lower productivity consequent with the less influence of the Atlantic current (Quintanilla et al. 2020). While δ^{15}N values were conditioned by the seasonal plankton community structure particular to each nursery area, trophic levels are influenced by larval trophodynamics. In this case, higher somatic and otolith biometric growth was related to higher trophic levels due to the higher enrichment of larvae from their potential feeding resources.

Recently, these trophic relationships have been further investigated through the molecular characterization of the diet of *Sardina pilchardus* larvae in the Bay of Malaga. The development and application of new molecular tools have allowed detecting the presence of certain groups of phytoplankton and zooplankton in the gut of ichthyoplanktonic larvae. For example, specific primers and a multiplex PCR assay have been designed to target copepod species and phytoplankton groups identified as potential preys (Hernández de Rojas et al. unpubl.), allowing us to determine their contribution, at least qualitatively, to the diet of *S. pilchardus* larvae in the nursery area (Yebra et al. 2019). Also, recent developments in high-throughput sequencing techniques have allowed the metabarcoding of the entire

Fig. 13.17 Variability in the relative abundance of prey (OTUs detected by metabarcoding of mtCOI gene) in guts of *Sardina pilchardus* larvae collected in Bay of Malaga during autumn 2013. A shift in the main prey species (calanoid copepods) was observed through the spawning season



prey field in the gut of these larvae and its variability through the spawning season (Fig. 13.17), using the mtCOI gene as a marker. Preliminary results indicate that larval sardines have opportunistic feeding habits, rather than species-specific selectivity (Yebra et al. 2018).

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Chapter 14
Description of Artisanal Fisheries in Northern Alboran Sea

Jorge Baro Domínguez, Teresa García Jiménez, and José M. Serna Quintero

14.1 Introduction

In the Mediterranean and the Black Sea, where the fishing fleet is composed of about 90,000 vessels in total, the small-scale segment (defined as embarkations below 12 m in length overall) represents more than 80 percent of the entire fleet (Srour et al. 2015). Mediterranean small-scale fishery is a very variable activity. Catches are highly multispecific and fishing intensities and strategies show very rapid fluctuations in space and time. An important variation of the number of active fishermen by area sometimes in very short periods of time is also a characteristic of the fishery (Farrugio and Le Corre 1993).

Small-scale fisheries are the most traditional in the Alboran Sea; they are widely spread on both shores and are the most numerous operating in the area (Alarcon 2001; Camiñas 1990; Robles et al. 2010). These fisheries are deeply rooted in the region and represent an important element of coastal communities. They have many positive qualities: they are implied in low-impact fishing activities, provide local sea products of high quality and have very significantly contributed to both the local economies and the cultural heritage of coastal communities.

The concept of artisanal fishery has been defined in many ways. In the Mediterranean the term "artisanal fisheries" is also usually associated with that of small-scale fisheries, both being used interchangeably and referring to a multifaceted segment of capture fisheries very commonly practiced along the coastal areas (Srour et al. 2015). The FAO Fisheries Glossary defines artisanal fisheries as "traditional fisheries involving fishing households (as opposed to commercial companies), using relatively small amount of capital and energy, relatively small fishing vessels (if any), making short fishing trips, close to shore, mainly for local consumption. In practice

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the definition varies between countries, from example from gleaning or a one-man canoe in poor developing countries to more than 20m trawlers, seiners or long-liners in developed ones (e.g. in Europe)." General Fisheries Commission for the Mediterranean (GFCM) glossary mentions that "small scale fisheries can be broadly characterized as a dynamic and evolving sector employing labor intensive harvesting, processing and distribution technologies to exploit marine and inland water fishery resources. The activities of this sub-sector, conducted full-time or part-time, or just seasonally, are often targeted on supplying fish and fishery products to local and domestic markets, and for subsistence consumption." From a practical point of view in this chapter, we are going to use both concepts in an indistinct way defining small-scale or artisanal fishery by exclusion of what is not included in them. In fact, we consider artisanal or small-scale fisheries as all the fisheries in the Alboran Sea, excluding those implemented using trawl nets, purse seine, tuna rods, trolling lines, and pelagic longlines fisheries.

In the Alboran Sea, artisanal fisheries have traditionally played an important role both in social and in economic aspects, they have been the origin of all kinds of exploitation of marine resources, with the current fisheries inheriting the long artisanal tradition that has been transformed by adapting to technological innovations.

14.2 Description of Artisanal Fisheries in Northern Alboran Sea

The Alboran Sea represents a transitional ecoregion between the Atlantic Ocean and the Mediterranean Sea, connecting both oceanic domains through the Strait of Gibraltar (Spalding et al. 2007) with particular oceanographic characteristics such as the Atlantic influence or the upwelling zones (Parrilla and Kinder 1987; Sarhan et al. 2000) and physiographic features as the very narrow continental shelf (Hernández-Molina et al. 1994; Lobo et al. 2006, 2014). Artisanal fishery in the northern Alboran Sea contains many common elements with those of other areas of the Spanish coast or other countries of the Mediterranean environment, so the types of vessels, the fishing gears, and the exploited species are similar to those of neighboring areas. However, the specificities of the oceanographic and physiographic characteristics give the fishery components that differentiate it from those of other areas (Camiñas 1990).

Despite the peculiarities of the area, it does not seem that it has contributed throughout the history to innovations in fishing. In fact and with some exceptions, the majority of fishing gear and boats traditionally used on our coasts came from other areas and were only modified to adapt them to their own needs. Given the environmental heterogeneity of the seabed, in the last decades more than 40 different fishing gears have been developed, exploiting in a very selective way the different existing ecosystems. An important issue is the great adaptability of fishing gears over time to the different administrative, technical, or market situations and how these adaptations, unfortunately, lead to the loss of traditions, fishing tools, and a part of the fishing sailor language of the Andalusian cultural heritage that, inevitably, have disappeared today.

14.3 Fishing Fleet

Regarding the fleet, four types of vessels were common in the region, according to its local name: "jábegas," "botes," "chalanas" or "pateras," and "motoras" (Camiñas et al. 2004).

The "jábega" (Fig. 14.1a) is, along with the sardinal boat, the oldest type of vessel and is currently not used for fishing purposes, although it has been par excellence the traditional artisanal vessel, at least on the coast of Malaga. In short, it is a boat that lacks a deck, with a length between 7 and 9 m and a beam of 2–2.5 m, being armed with 7–9 oars. The prow is prolonged in a peak called "botalón" in which the head of

Fig. 14.1 Types of artisanal vessels in the Alboran sea: "jabega" (**a**); chalanas" or "pateras" (**b**); motorboats: "motoras" (**c**)

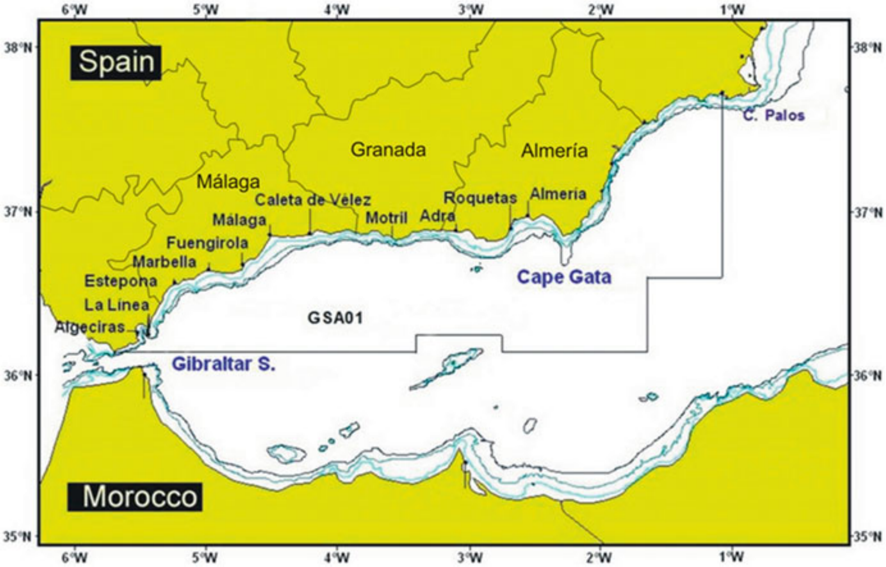

Fig. 14.2 Location of the fishing ports of the artisanal fleet

a snake was usually sculpted. It has no engine and its use was limited to fishing with the beach seines called "jábega" or "media jábega."

The "chalanas" and "pateras" (Fig. 14.1b) are vessels with a hull without chines with a gradually curved section and a flat or rounded stern. They do not have generally cover although some have small spaces to bow and to stern closed with bulkheads, to keep diverse fishing tools. They have a length between 5 and 7 m and a beam between 2 and 2.5 m. They are made of wood or fiberglass.

With the name of "motoras" (motorboats) (Fig. 14.1c) are known all boats that have an inboard engine, deck, ship's hold, and in many cases a cabin that serves as a cockpit. They have between 6 and 8 m in length and 2–3 m in width. Its gross tonnage always exceeds two tons and the power of the engine sometimes reaches 90 HP. These types of boats are the best technically equipped and can have multipurpose use.

The operative fishing fleet registered in 2018 under the modality of artisanal gears on the Spanish coasts of the Alboran Sea amounts to 318 vessels distributed in a total of 11 ports (Fig. 14.2). The coast of the province of Malaga is where the largest number of artisanal vessels is concentrated (52.0%) followed by the provinces of Cadiz and Almeria (20.4% and 19.5% respectively), being located in the province of Granada the lowest number of boats (5.2%).

At present artisanal fleet is composed of vessels of small size, with an average gross tonnage of 3.2 t, an average length of 8.2 m, and an engine power of 36.3 HP (Fig. 14.3a). The ports of Estepona, La Linea de la Concepcion, Caleta de Velez, and

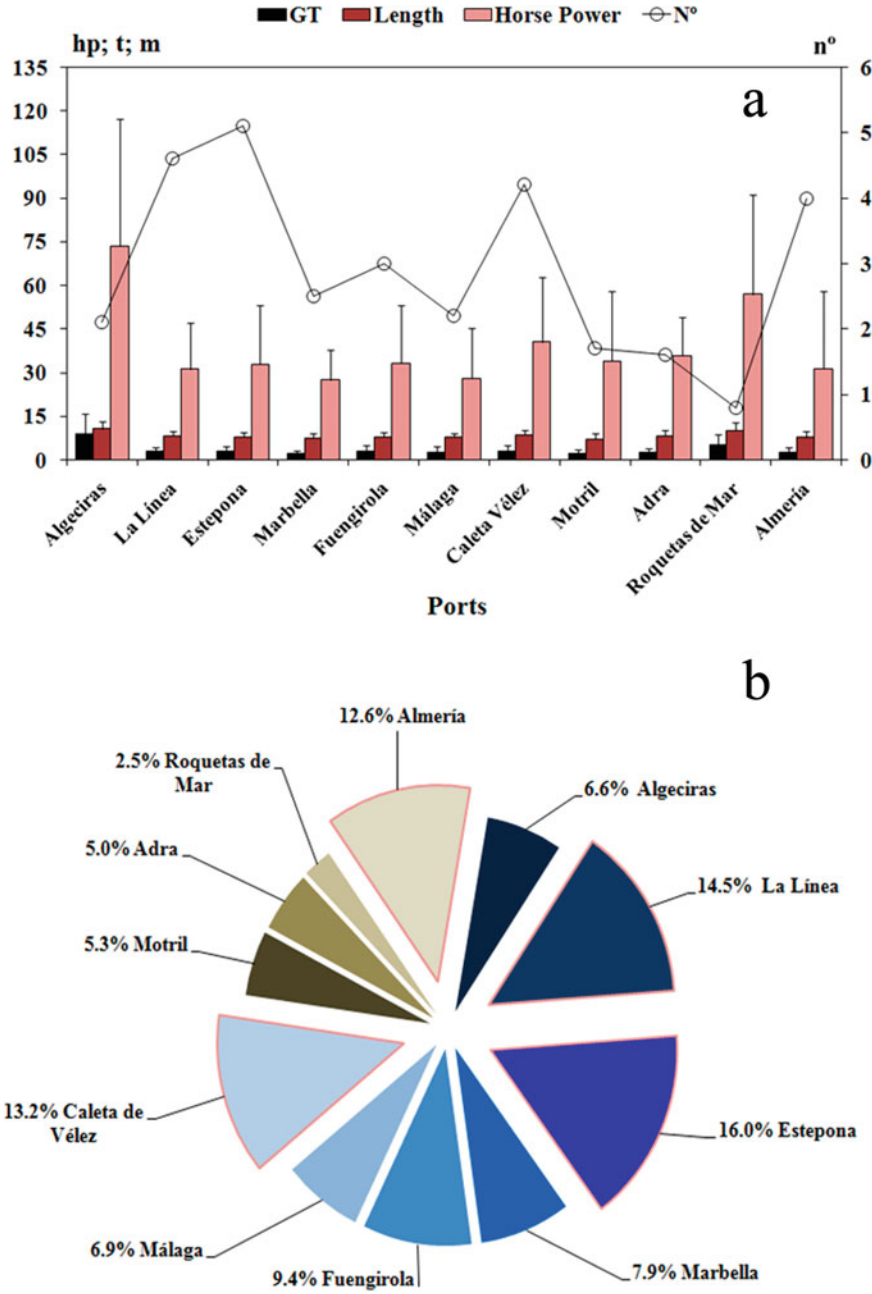

Fig. 14.3 Artisanal fleet of Alboran Sea: (**a**) number of vessel and main average technical characteristics (gross tonnes, length, and engine power) by ports and (**b**) distribution of the artisanal fleet by main landing ports

Almeria account for the largest number of vessels, concentrating these four ports 56.3% of the entire Alboran Sea artisanal fleet (Fig. 14.3b).

14.4 Fishing Gears

Camiñas et al. (2004) described up to 29 varieties of artisanal fishing gears operating on the Andalusian Mediterranean coast, many of which were scarcely used at that time and have ceased to be used today. Most of these fishing gears are still used today, but some of them have disappeared or are only used in a very limited way due to their poor performance compared to others that are more efficient, such as the "sardinal" (a surface gillnet for sardine) against purse seines or because they have been prohibited by current fishing regulations, such as beach seines or towed dredges for scallops.

At present, in order to record catch and effort data by gear types, they are grouped into the following categories: mechanized dredges, pots and traps, bottom gillnets, trammel nets, hand lines, "voracera," as a special type of hand line, and bottom longlines (Fernández Cortés and Zurita Manrubia 2003).

The mechanized dredges are used exclusively to fish bivalve mollusks (Baro et al. 1992). They are not actively towed by the main engine of the ship, but they are pulled by a powered winch while the boat is anchored (Fig. 14.4). Council Regulation (EC) No. 1967/2006 concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea, describes the mechanized dredge as: "gears consist of a net bag or metal basket mounted on a rigid frame or rod of variable size and shape whose lower part may carry a scraper blade that can be either rounded, sharp or toothed, and may or may not be equipped with skids and diving boards." Depending on the species to be captured and the fishing area, there are different types of mechanized dredges (Fig. 14.5). The number of dredges used per boat varies between a minimum of 2 and a maximum of 6, depending on the target species, being the most usual to use 3 or 4.

The fishing activity of mechanized dredges is regulated by a regional Management Plan in which safe biological reference points are established for a sustainable exploitation for the main target species: *Donax trunculus*, *Callista chione*, *Acanthocardia tuberculata*, and *Chamelea gallina.* This management plan also regulates the days and times authorized for the exercise of the fishing activity, the fishing grounds, the closed seasons, and the authorized minimum landing sizes by species.

Traps and pots (Fig. 14.6) are stationary fishing gears that retain their prey that enter voluntarily or because they are attracted by the use of baits. Pots do not use baits and simulate to be a refuge or an adequate place to spawn to certain species. Traditionally they have been made of clay, although they are progressively being replaced by plastic ones. Pots are exclusively used to catch the common octopus (*Octopus vulgaris*). Regarding traps, which always use baits, there is great diversity according to the shape, size, and material used for their manufacture, which depends

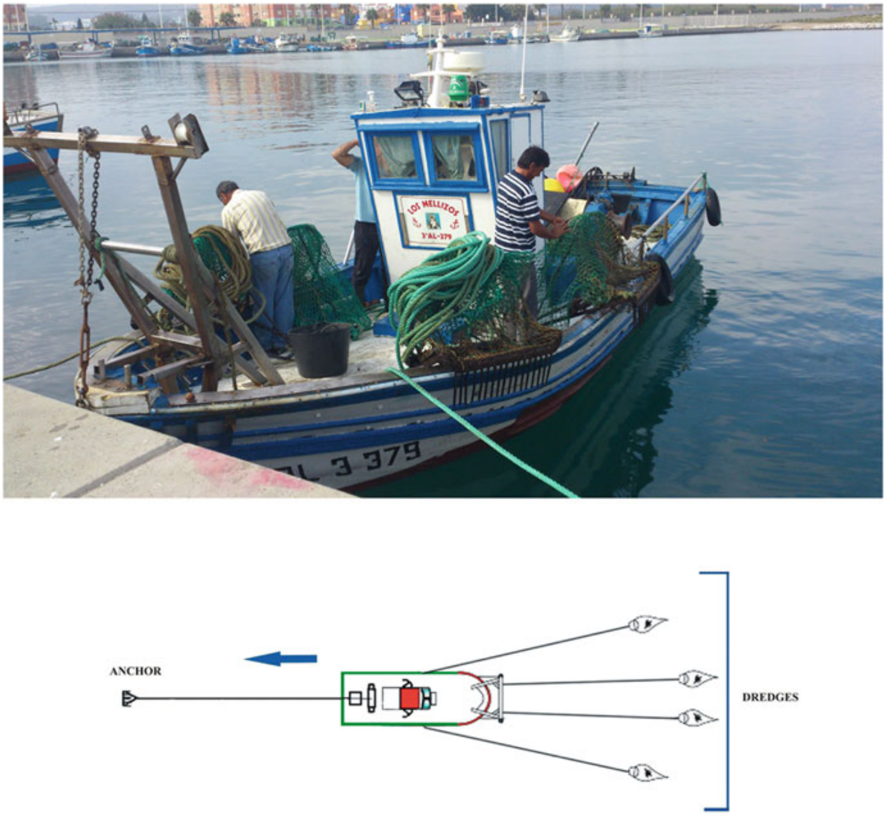

Fig. 14.4 Typical mechanized dredge vessel and scheme of the fishing technique

both on the custom in each area and on the target species. Unlike pots, traps are used to capture a variety of fish, crustaceans, or cephalopods.

Set gillnets and entangling nets are gears formed by one or more netting walls mounted between two ropes, the upper line (headrope) is provided with floats and the lower one (footrope) with weights (Fig. 14.7). In the area, these nets consist of single or triple netting (known as trammel nets). Sometimes different types of nets can be combined in a single fishing gear as the combined gillnets-trammel net. Gillnets are commonly known in the area as “redes de pelo” (“hairnets”), because they are made of very thin nylon. Trammel nets consist of three overlapping layers of netting, two of them outer (known as “albitanas”) with a larger mesh size than the inner net, mounted together on the same frame ropes. In gillnets, fish are retained by their gills, while in trammel nets the whole or part of the body of the fish is entangled. Both gillnet and trammel nets are set anchored on the bottom in vertical position, marking the ends of the gear by means of surface buoys that can be hauled

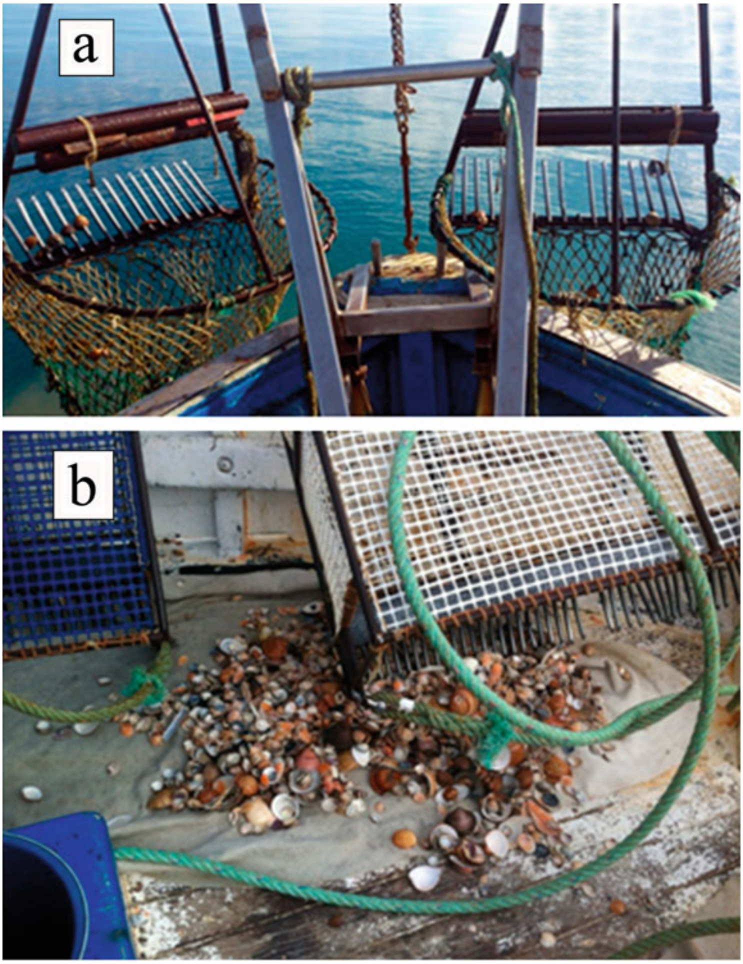

Fig. 14.5 Types of dredges by target species: (**a**) *C. chione* and *A. tuberculata*; (**b**) *D. trunculus* and *C. gallina*

by hand but the use of a net hauler is very common. Gillnets and trammel nets are used for both fish and cephalopods.

Within the category of hooks and lines, there are two basic types in the area: handlines and bottom longlines. In these fishing gears the prey is attracted by the use of baits that are placed on the hooks. Handline is a vertical line that consists of a line to which is attached a sinker and one or several baited hooks. It is used to catch fish or cephalopods (Fig. 14.8) and in the area closed to the Gibraltar Strait, mainly in the Atlantic area outside the Alboran Sea, there is an important artisanal fishery using a very specific type of handline called "voracera" targeting *Pagellus bogaraveo*. Bottom longline is a set longline consisting of a mainline, which is set parallel to

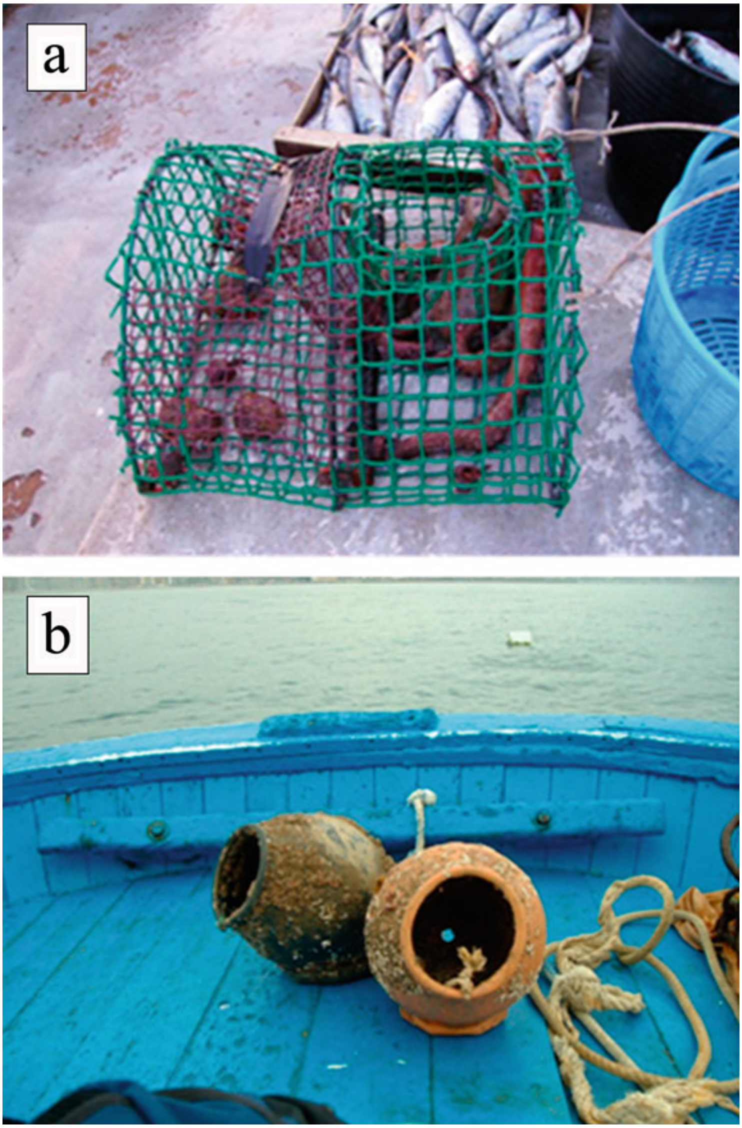

Fig. 14.6 Different type of traps: (**a**) classical baited trap and (**b**) clay pots

the bottom, from which the snoods (branchlines) hang at regular intervals and at whose ends the baited hooks are located.

Except the "voracera," the pots for common octopus and the mechanized dredges, the rest of gears capture a variety of species, so the impact on the different taxonomic groups is very different (Fig. 14.9). Nets and bottom longlines are the most used fishing gears; almost 70% of the artisanal activity is carried out with these types of

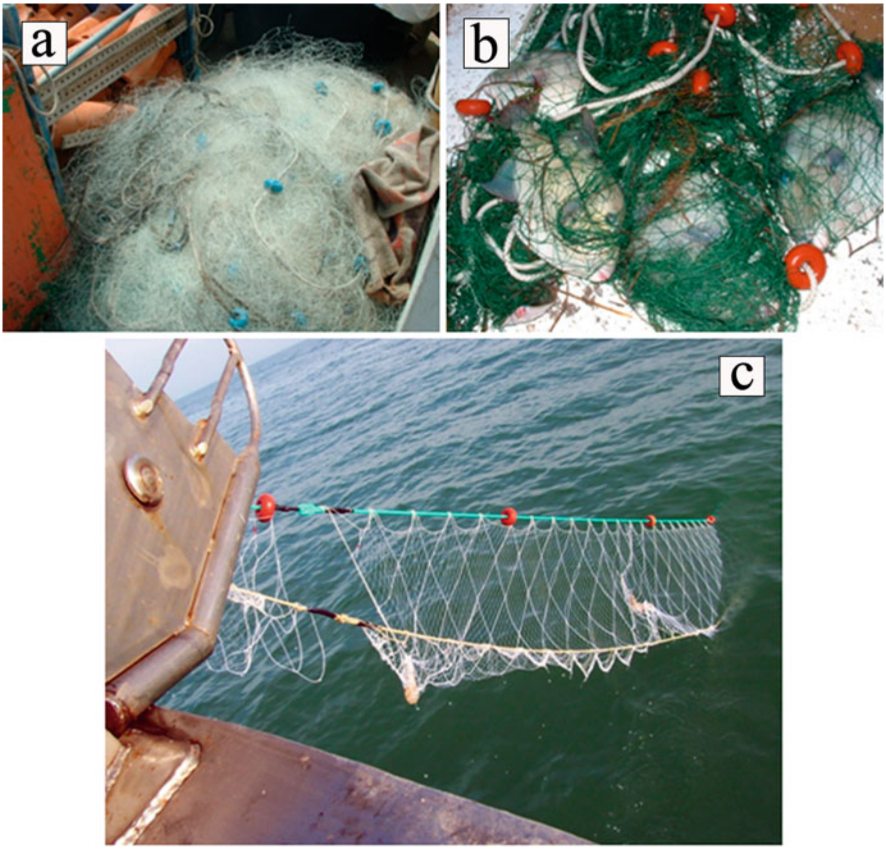

Fig. 14.7 Gillnets and entangling nets: (**a**) gillnet; (**b**, **c**) trammel net

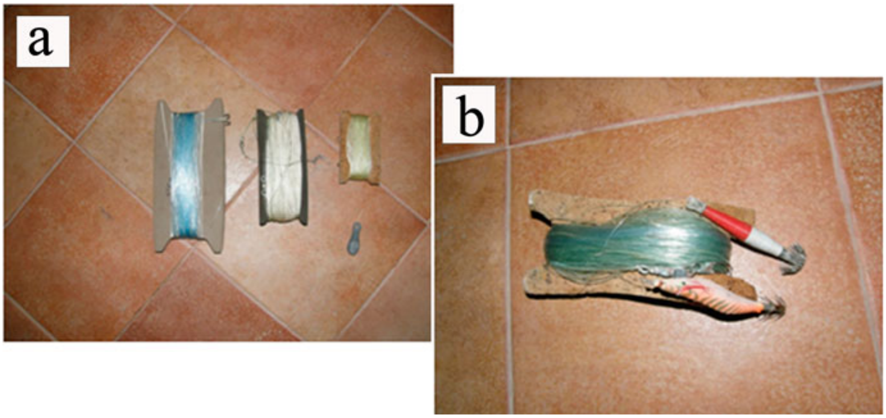

Fig. 14.8 Type of handlines: (**a**) to catch fish; (**b**): to cath cephalopods

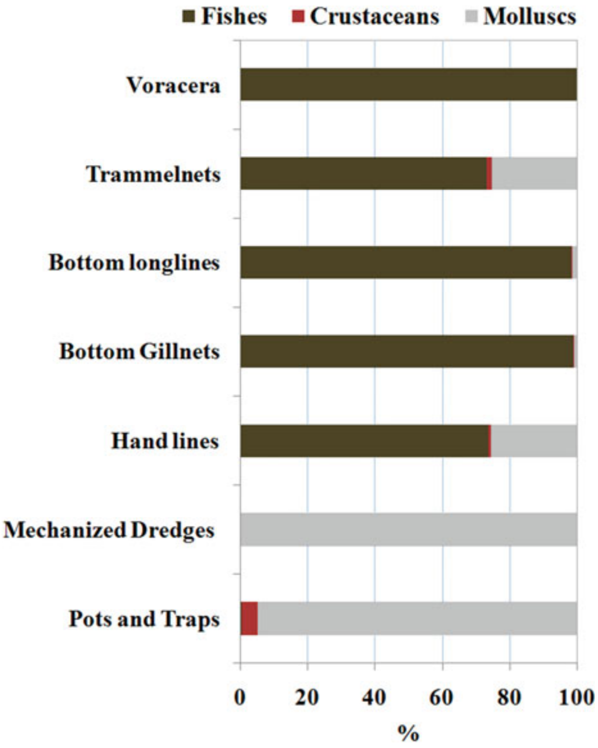

Fig. 14.9 Proportion of taxonomic groups (fish, crustaceans, and molluscs) caught by different fishing gears used by the artisanal fleet in the northern Alboran Sea

gears (period 2002–2017). Secondly, the most used are mechanized dredges (13.6%) and those with the least activity are pots and traps (12.3%).

The fishing ports with the greatest activity are those of Estepona, Caleta de Velez, Almeria, and La Linea de la Concepcion. The importance of the different gears used by the fleet varies between ports, faithfully reflecting the adaptation to the characteristics of the nearby exploited fishing grounds. In Algeciras, the artisanal fleet fish only with gillnets or lines, being remarkable the one carried out with "voracera" targeting blackspot seabream (*Pagellus bogaraveo*) or the one targeting various species of fish and cephalopods in the waters of the Strait of Gibraltar (Lozano 2011). From La Linea de la Concepcion to Caleta de Velez, the activity is widely distributed among mechanized dredges, pots and traps, gillnets, trammel nets, and bottom longlines. From Motril to the eastern end of the area, gear targeting cephalopods and fish are the most used (Fig. 14.10).

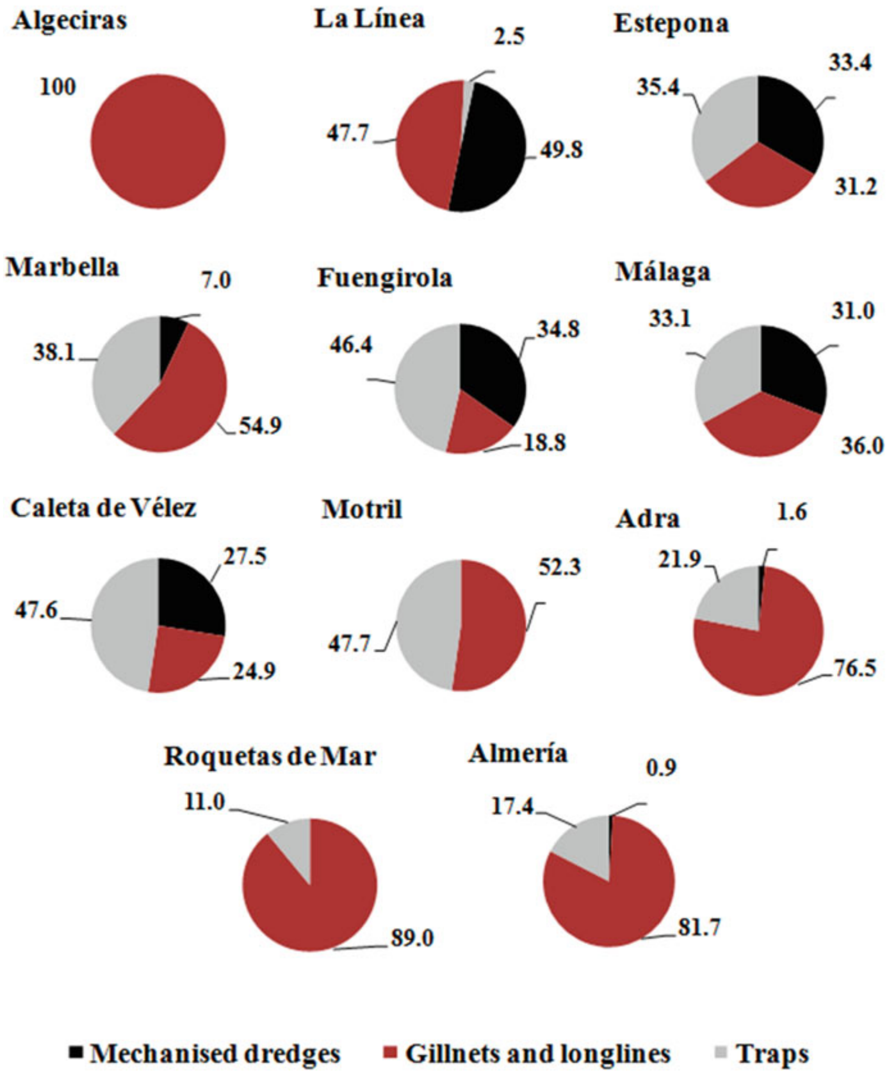

Fig. 14.10 Distribution of artisanal fisheries by fishing gear and landing port from March 2013 to March 2014. Values are given as percentage contribution of each fishery in tones (from Baro et al. 2018)

14.5 Main Fisheries: Description, Catches, and Evolution

Total landings during the period between the years 2002 and 2017 have amounted to 42,557 tones. The evolution of the catches, does not show a stability in the period considered, characterizing this evolution the discharges of certain target species and

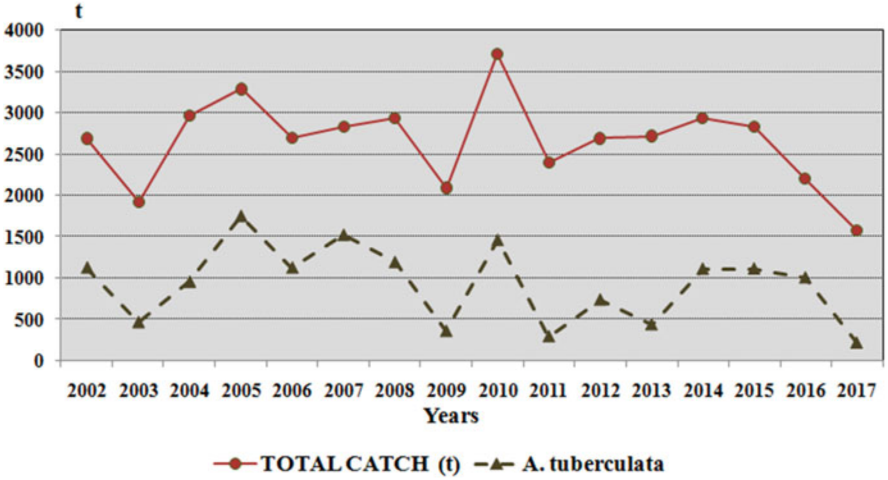

Fig. 14.11 Evolution of *Acanthocardia tuberculata* and total landings (t) of the artisanal fleet in the northern Alboran Sea in the period 2002–2017

in particular the fishing of "corruco" (*A. tuberculata*), whose exploitation is produced at the request of the canning industry, through the establishment of an agreement with the fishing fleet for a specific amount of tons and a fixed price (Fig. 14.11). This fact causes a large part of the shellfish fleet to move temporarily to the areas where the "corruco" fishing is allowed, regardless of the proximity or distance of the fishing ground to the homeports, since the revenues are insured for at least several weeks until the fixed quota is reached. The differences for years can be very large, so in 2010 the demand by the canning industry was 1462 t of "corruco," compared to 21 t in 2017. Most of the fleet that fish this species is composed of vessels that have their homeport in La Línea de la Concepcion, followed by Estepona, Fuengirola, and Caleta de Velez, which makes them the ports with the largest landings made by the artisanal fleet. The artisanal fleet captures up to 231 species (IEO data), making the greatest contribution to the total landings *Acanthocardia tuberculata*, *Octopus vulgaris*, *Auxis rochei rochei*, *Callista chione*, and *Pagellus bogaraveo*.

The catch of the mechanized dredge fishery is composed of more than 99% by bivalve molluscs. Targets species are *Acanthocardia tuberculata*, *Callista chione*, *Chamelea gallina*, and *Donax trunculus* (Fig. 14.12). During the period 2002–2017 the total catch landed amounted to 19,824 t, with an annual average catch that has fluctuated between a minimum of 1.3 t in 2013 and a maximum of 10 t in 2005. The annual landing of *A. tuberculata* is mainly responsible for the fluctuation of total catches, with no trend observed either in total catches or in those of *A. tuberculata* for the reasons above mentioned (Fig. 14.13a). The evolution of catches of the other three target species is strongly influenced by *C. chione*, showing certain stability with specific fluctuations in some years (Fig. 14.13b). *A. tuberculata* represents 76.7% of the total discharges, *C. chione* 16.17%, *D. trunculus* 2.11%, and *C. gallina*

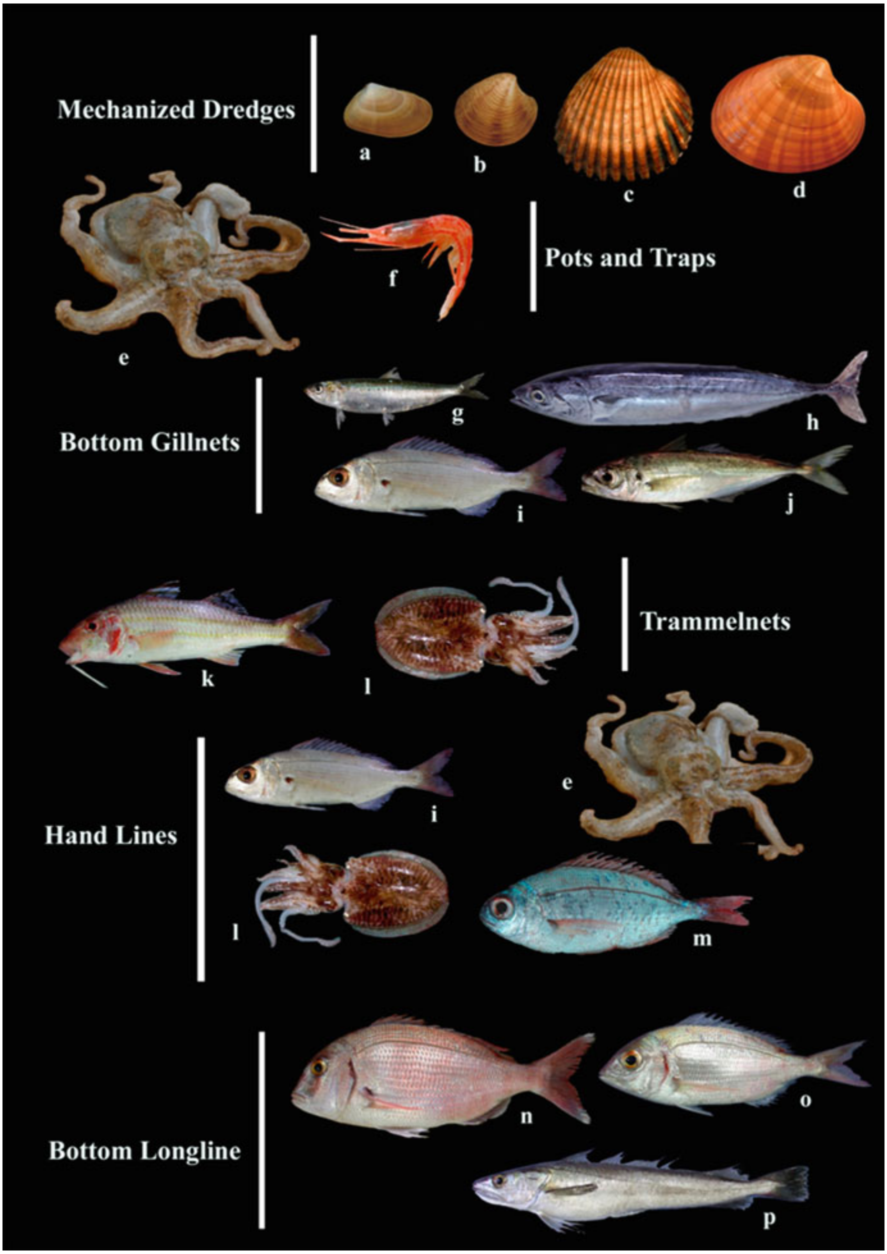

Fig. 14.12 Main species landed by gear type. Mechanized degrees (a) *Chamelea gallina*; (b) *Callista chione*; (c) *Acanthocardia tuberculata*; and (d) *Donax trunculus*). Pots and Traps (e) *Octopus vulgaris*; (f) *Plesionika edwardsii*). Bottom Gillnets (g) *Sardina pilchardus*; (h) *Auxis rochei*; (i) *Pagellus acarne*; (j) *Trachurus* spp.). Trammel nets (k) *Mullus* spp.; (l) *Sepia officinalis*). Handlines (i) *Pagellus acarne*; (l) *Sepia officinalis*; and (e) *Octopus vulgaris*). Voracera (m) *Pagellus bogaraveo*). Bottom longline (n) *Pagrus*; (o) *Pagellus erythrinus*; and (p) *Merluccius merluccius*)

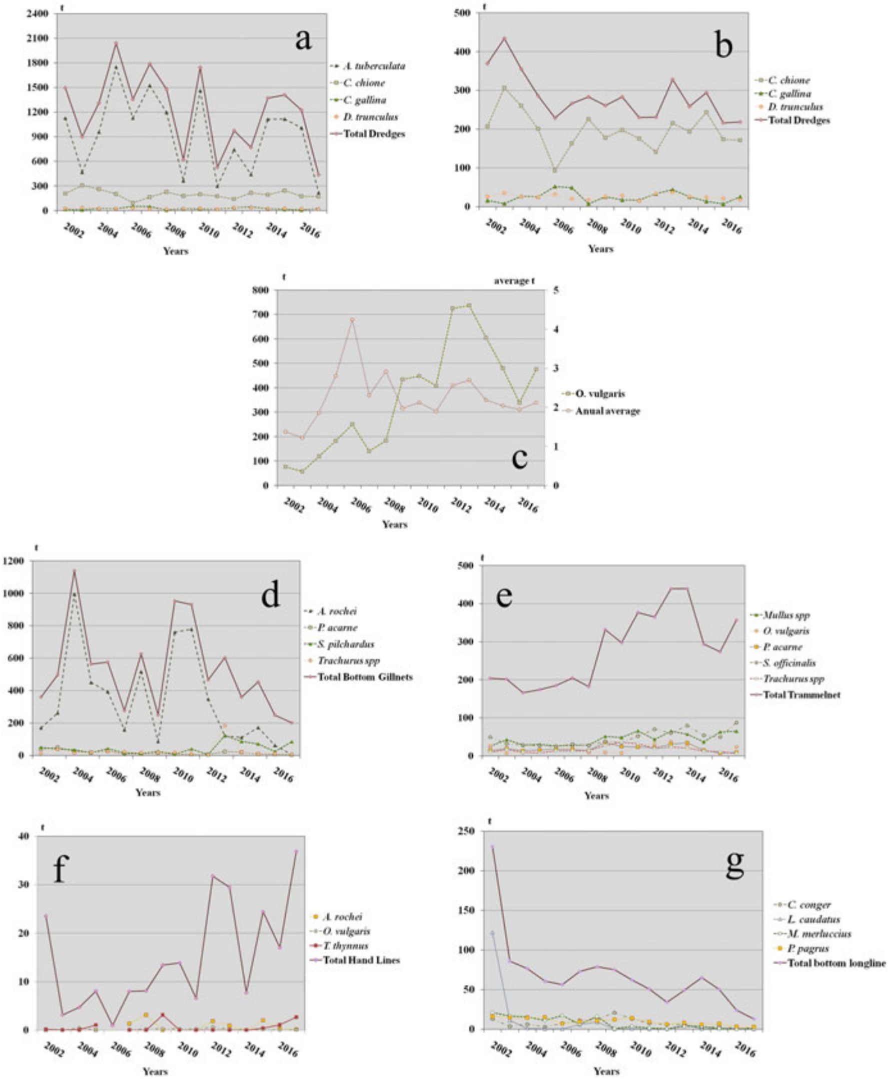

Fig. 14.13 Evolution of landings of artisanal fishery. Mechanized dredge catches: (**a**) total landing, including all species; (**b**) total landing without *A. tuberculata*. (**c**) Pots and traps. (**d**) Bottom gillnets. (**e**) Trammel nets. (**f**) Hand lines. (**g**) Bottom longlines

2.0%, the remaining 3.0% consisting of other mollusc species and even fish and crustaceans accidentally caught.

Plesionika edwarsii and *O. vulgaris* are the main species caught by traps and pots (Fig.14.12). *P. edwarsii* is the target species of vessels fishing with specifics traps, some of them fishing in very distant fishing grounds, so they are vessels that by their dimensions could not be considered strictly artisanal. Landings of *P. edwarsii* accounts for only 4.8% of the total catches of these fishing gears while pots, targeting common octopus, accounts for 95% and the remaining species representing only 0.4%. Landings of *O. vulgaris* show an increasing trend in the period 2002–2017 with a maximum peak in 2012–2013 (Fig. 14.13c). However, the average annual catch per vessel has remained stable since 2009. The fluctuations observed in the catches of *O. vulgaris* are in opposite direction to those of the mechanized dredge, due to the temporary rotation of fishing gears between pots and mechanized dredges.

Gillnets mainly catch fish (99%), and in the case of trammel nets fish and molluscs (73% and 25%, respectively). These two gears are those that capture a higher diversity of species: 188 species in the case of gillnets and 207 with trammel nets. *Sardina pilchardus*, *Trachurus* spp., *Pagellus acarne*, and *Auxis rochei* (Fig. 14.12) account for 80% of the total catches made with gillnets, although only the latter represents 63%. The evolution of the catches obtained with this fishing gear shows great fluctuations being very dependent on the capture of *Auxis rochei* (Fig. 14.13d). Trammel net catches are characterized by a great diversity of species, being *Sepia officinalis* and the two species of red mullet (*Mullus surmuletus* and *M. barbatus*), the most caught species. The catches obtained with trammel nets are not very high. In the period 2012–2017, the maximum recorded catch was 439 tonnes in the years 2013–2014, after a period of stability in catches between 2002 and 2008 (Fig. 14.13e).

The volume of catches made with hand lines is small, being quite diverse the species captured between fish and molluscs. The most commonly caught species are *Pagellus acarne*, *P. bogaraveo*, among fish, and *S. officinalis* and *O. vulgaris* among mollusks (Fig. 14.12), while the highest catches are obtained from *A. rochei*, *O. vulgaris*, and *Thunnus thynnus*, which accounts for 54% of the total landing (Fig. 14.13f).

Regarding the bottom longline, 98% of the catches are fish, with up to 127 different species being caught by this fishing gear. Among others are *M. merluccius* and several species of sparids, such as *Pagrus pagrus*, *P. erythrinus*, and *P. bogaraveo* (Fig. 14.12), the most representative (Fig. 14.13g).

14.6 Socioeconomic Aspects

The importance of the artisanal fisheries in the whole of the fishing sector in the Northern Alboran Sea is remarkable, whether we take into account the production aspects as well as the economic ones. Thus, the landings of the artisanal fleet in the Alboran ports were 1579 tons in 2017, which represent 10% of the total landed by all the fishing fleets. According to the information collected by the Council of Agriculture, Fishing and Rural Development of the Andalusia Regional Government, under the economic perspective (Junta de Andalucía 2017) the importance of this sector is even greater, since the value of sales in 2017 was more than 9.8 million €, which represent 21% of the total sold in the fish markets involved. This great difference between the percentages of the catch and its economic value, which is more than

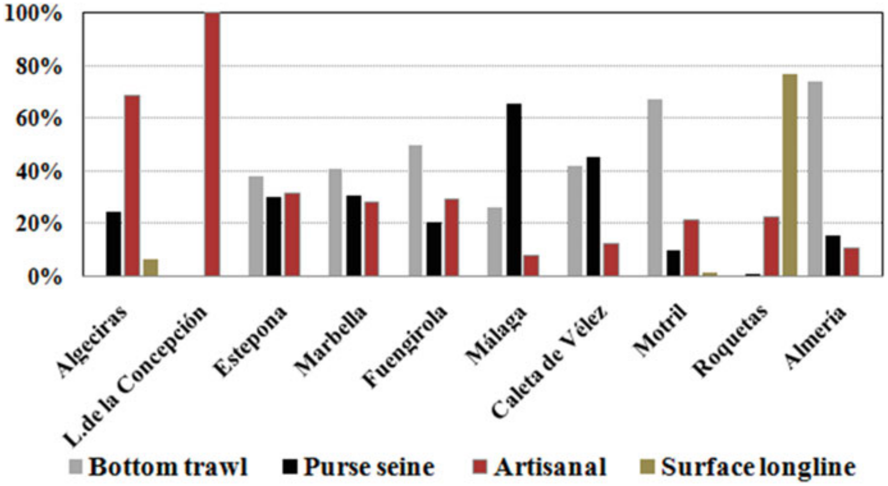

Fig. 14.14 Importance of the fishing modalities in the fish markets: participation of each modality in the total sales of the fish markets. Year 2016

double, is explained by the high value of sales achieved by the products obtained due to its high quality, and the great esteem that many of the species have in the local markets.

The economic weight of the artisanal sector is quite variable among ports, from those in which 100% of the sale comes from fishing products of the artisanal fleet, to others where the importance of this fleet is small in comparison with other semi-industrial ones, where the bottom trawl, purse seine, or surface longline are the most important fleets from the economic point of view (Fig. 14.14). Thus, in the port of Algeciras, artisanal activity is the most important, accounting for 69% of total sales, while the rest is shared between the purse seine (25%) and the surface longline (6%). In the port of La Linea de la Concepcion, there is an only economic activity linked to the artisanal sector, associated mainly to the shellfish sector that accounts for almost 90% of the landings. In Estepona, Marbella, and Fuengirola, the sales of the artisanal fleet are more or less equated to the purse seine and trawl fleets, although with slight differences between ports ranging from 28% in Marbella and 32% in Estepona. In the central and eastern area in all the existing ports from Malaga to Almeria (Malaga, Caleta de Velez, Motril, Adra, Roquetas de Mar y Almeria) the importance of the sales of the artisanal sector is the lowest compared to the rest of fleets landing in those ports, varying from 8% in Malaga to 22% in Roquetas de Mar.

In 2017, the ports which recorded the highest sales values for artisanal fishing products were Caleta de Velez and Estepona, each of which reached 13% of the total value of the sale of the artisanal catch of the Alboran Sea (Fig.14.15). This figure contrasts with the importance of landings in each of these ports, since in Estepona it is 19%, the highest in the area, while in Caleta de Velez it is only 11%. These differences between the sale value and total landings are clearly related to the value of the landed species and more specifically to the bivalves, since the port of Estepona

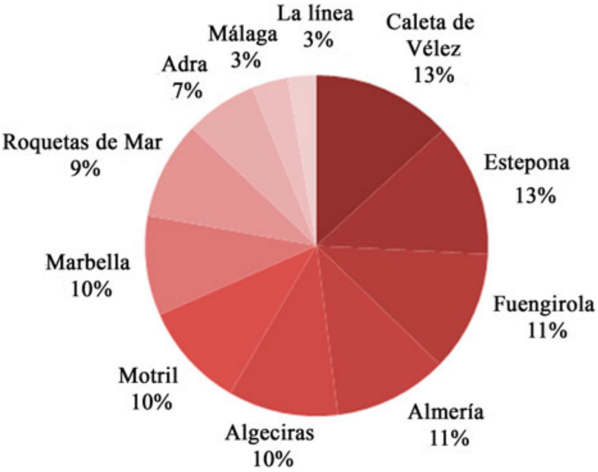

Fig. 14.15 Percentage of participation of each port on the total sales of the artisanal fleet in the Alboran Sea. Year 2017

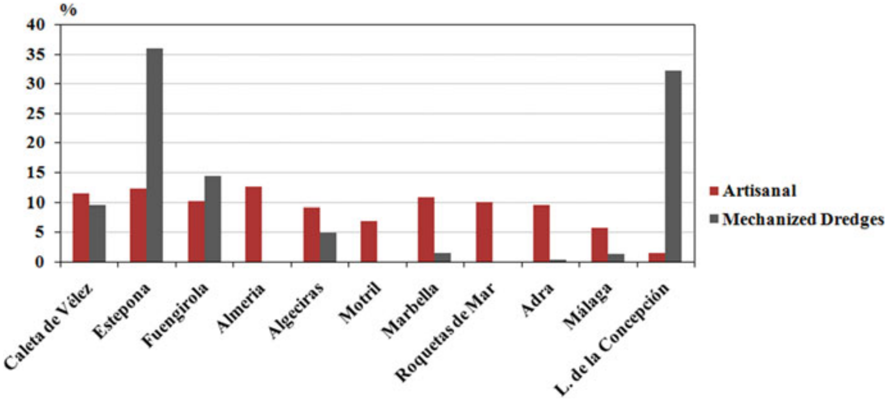

Fig. 14.16 Percentage of participation of each port on the total landings of the artisanal fleet in the Alboran Sea. Year 2017

has a landing volume four times higher than Caleta de Velez, but mainly due to the landings of the bivalve *Acanthocardia tuberculata* a species that reaches a low sale value. Next in importance are the ports of Fuengirola and Almeria with 11% of sales of the artisanal fishing sector in the area, but while there is no sale of bivalves in Almeria, in Fuengirola these species account for one-third of artisanal sales. There are also important ports such as Algeciras (10%) and Marbella (9%) where the sale of bivalves is small compared to other target species and those of Motril (10%), Roquetas de Mar (9%), and Adra (7%) where there is no landing of bivalves (Figs. 14.15 and 14.16). The ports of Malaga and La Linea de la Concepcion contribute only 3% to the Alboran artisanal sales volume.

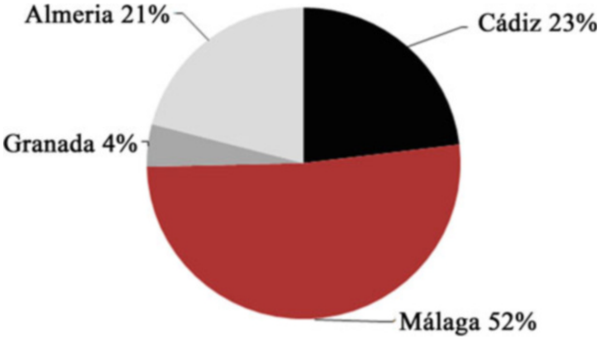

Fig. 14.17 Distribution of the number of workers by province of the artisanal sector in Alboran sea

Direct employment generated by artisanal fisheries throughout Andalusia, shows positive growth in the period 2009–2016 compared to the total number of employees in the global fleet, growing from 33.7% to 40.7% (data from the Council of Agriculture, Fishing and Rural Development of the Andalusia Regional Government). This growth is mainly due to the increase observed in the so-called “artes menores” and hydraulic dredges, the latter not used in the Alboran Sea, since in the mechanized dredge fleet, which is the most important of the coast, there is a progressive decrease going from 6.6% to 4.4%, in the indicated period. These data do not result in a net increase of workers, which is negative, however, it shows that the artisanal sector is more stable in the consolidation of employment than other fishing modalities where there is a sharper decrease.

The average number of crew members per vessel is variable but quite low given the types of boats used and it is basically conditioned by the size of the vessels and the fishing methods. The port of Algeciras with four crew members per boat is the one with the highest average, followed by Roquetas de Mar with three and the rest of the ports with only 2.

There is no detailed information on the number of workers per port in the artisanal sector of the Alboran Sea. Based on the data provided by the Andalusia Regional Government, we have estimated 658 direct jobs associated with this sector. The distribution of these workers along the coast is heterogeneous and is logically associated with the number of boats in each port. In the province of Malaga, which includes five fishing ports (Estepona, Marbella, Fuengirola, Malaga, and Caleta de Velez), there is the highest concentration of workers. The second in importance is the province of Cadiz, despite having only two ports in the area of the Alboran Sea, Algeciras, and La Linea de la Concepcion, given the importance in the latter of the artisanal fleet. In the province of Almeria, with three fishing ports (Adra, Roquetas de Mar, and Almeria), the number of workers directly employed in the artisanal vessels is very similar to that of Cadiz. The province of Granada occupies the last position and very far from the previous ones, since it only has the fishing port of Motril (Fig.14.17). The distribution of workers by gender is clearly biased toward men since the percentage of women barely reach 1%.

The main value of fishery products from artisanal fisheries is their high quality, freshness and proper conservation as the proximity of the fishing grounds to local

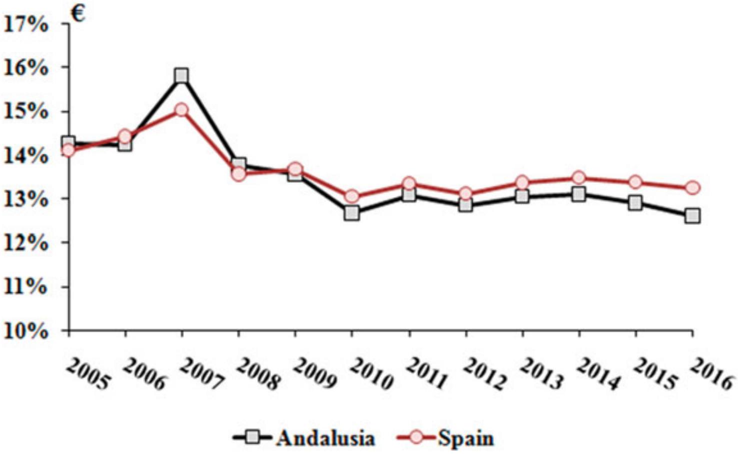

Fig. 14.18 Consumption of fish products/total consumption in food

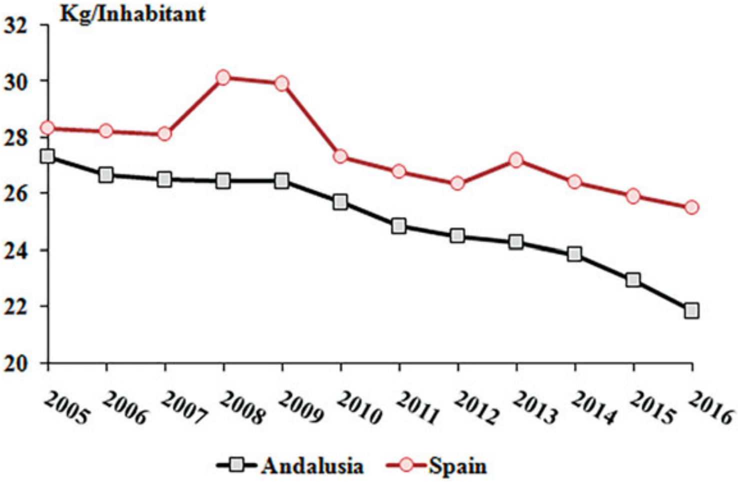

Fig. 14.19 Consumption per capita in fishery products in Spain and Andalusia

auctions allows fot their daily sale. These are species of great tradition and roots in coastal communities and therefore they are highly demanded but they are also much appreciated by the tourists that visits the Alboran coast.

According to data from the Ministry of Agriculture, Fisheries and Food, in 2016 the expenditure on fishery products in Andalusia accounted for 12.6% of the total expenditure on food. This value is slightly lower than the figure for the whole of Spain, which was for the same year of 13.2%, and has experienced a negative evolution in the period 2005–2016 (Fig. 14.18). The consumption per capita in Andalusia behaves in the same way since, for the same previous period, has decreased by 5.5 kg/inhabitant, almost doubling the decline observed in the whole of Spain that was only 2.9 kg/inhabitant (Fig. 14.19).

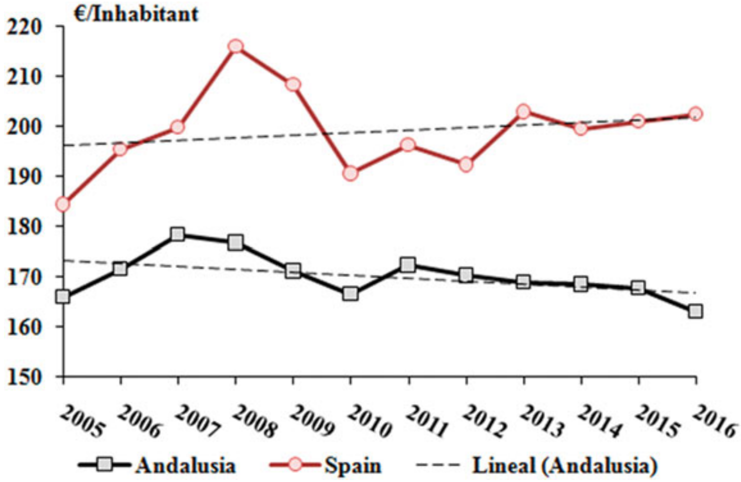

Fig. 14.20 Per capita expenditure on fish products in Andalusia

These values are reflected differently in Andalusia and Spain regarding the average expenditure per inhabitant per year (Fig. 14.20). Therefore, while in Spain, in the period 2005–2016, there is an upward trend in per capita expenditure, unlike the per capita consumption, in Andalusia this trend is downward, in line with lower consumption per inhabitant and a lower percentage of expenditure on fishery products. This disparity between Andalusia and Spain must be caused by a difference in the market price of fishery products according to their final places of sale, as well as by the lower consumption observed in Andalusia.

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Chapter 15
Description of Artisanal Fisheries in Southern Alboran Sea

Mohammed Malouli Idrissi and Mériem Benziane

15.1 Introduction

The Moroccan Mediterranean coast extends from Saïdia in the East to Tangier in the West, along a length of almost 512 km of coastline. It includes nearly 90 landing sites for fishing products, including 6 fishing ports, 5 fishing villages, and 8 landing points (Malouli Idrissi et al. 1999, INRH; Malouli Idrissi 2004, CAR/ASP).

Artisanal fishing in the Mediterranean Sea is one of the mainstay of the region's economy. It offers a significant number of jobs and provides an important amount of currency to the country, through the exportation of its products.

The rocky nature of the seabed at the Mediterranean level, the presence of diversified fishery resources of high commercial value and the migration of Bluefin tuna and swordfish across the Strait of Gibraltar, have been the vectors of the development of a particular small-scale fishery, composite, and multi-gear (Malouli Idrissi 2018, FST Tanger).

At the regional level, the artisanal fishing fleet is about 3100 units. The artisanal fishers use different kinds of fishing gears (nets, hooks, traps) and targeting a multitude of species during specific periods of the year (Malouli Idrissi et al. 2008).

The Mediterranean Sea has a great biological diversity characterized by the presence of sedentary stocks made up of a high commercial value fish species. Its strategic position in connection with the Strait of Gibraltar, allows the passage of high migratory species, in particular Bluefin tuna and swordfish. This gives the region a wealth of additional species in high international demand, such as Octopus, blackspot seabream, etc. (Malouli Idrissi 2004; CAR/ASP).

In the previous chapter (Baro et al. 2020, in this book), was described the importance of artisanal fishing in the Mediterranean Sea in general, and the Alboran Sea in particular. Moreover, Baro et al. (2020) highlighted the importance of

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socioeconomic aspects. In a similar way, in Morocco the small-scale fisheries have important socioeconomical and food security aspects (Malouli Idrissi 2007; Malouli Idrissi and Zahri 2002).

This chapter gives a brief description of artisanal fishing in Morocco starting with presenting the main ports and landings points, describing the several gears used and underlining the main fisheries and socioeconomics indicators.

15.2 Fishing Fleet in Southern Alboran Sea

The artisanal fleet consists of wooden boats having a length not exceeding 7 meters (m) and a GRT less than 3 units. These boats are usually equipped with an outboard motor, with a horse power ranging from 15 to 25 Hp. The inboard engine are very rare whose power varies between 12 and 35 Hp (Table 15.1) (Malouli Idrissi et al. 2008; Malouli Idrissi 2018) (Malouli Idrissi 2009; Malouli Idrissi and Zahri 2002).

There is another kind of artisanal boat at some fishing sites, commonly called "Chebbak." These boats are larger than the ordinary boats, with a length that can reach up to 9 m and a GRT around 5 (Malouli Idrissi et al. 2008). These boats use exclusively small sized purse seines to target small pelagic, mainly sardines. These boats are made up of wood. Their technical characteristics are quite homogeneous:

- Not bridge.
- The age can reach up to 74 years.
- They are equipped with an outboard motor with a power of 25 Hp on average.
- They are usually annexed by 2 small boats, one used to gather pelagic fish by the light of the lamps (Lamparo) and another boat for the collection and transport of fish catch to the landing places. The Chebbak activity is a very old fishing practice that dates back to the 1940s and is considered an ancestral heritage in the region.

The number of fisher's onboard (crew) per boat is variable, depending on the size of the boat but does not exceed five fishermen for the ordinary boat. However, it varies from 8 to 13 fishers with an average of 10 people for onboard engine boat "Chebbak."

Table 15.1 Technical characteristics of the SSF boats in the Moroccan Alboran Sea

Technical characteristics	Age of the boat	Power[a] (Hp)	GRT (Tx)	Length (m)	Hollow (m)	Width (m)
Minimum	4	15	0.48	3.5	0.57	1.62
Maximum	47	25	2	6.87	1.03	2.2
Mean	15	17	1.62	5.5	0.77	1.85

[a] Only "outboard" engines that are taken into account in calculations

15.2.1 Fishing Ports

Generally, the ports possess all the necessary fishing infrastructures, these include, a wharf; a dike; a fuel station; a fish market; shops supply of fishing equipment; an engine repair shop; one or two ice factories, sometimes; places for the deposit of fishing equipment are available. (Malouli Idrissi et al. 1999, INRH; Malouli Idrissi et al. 2002, FAO-COPEMED; Malouli Idrissi 2009; Malouli Idrissi and Zahri 2002).

The six fishing ports are Tangier, M'diq, Jebha, Cala Iris, Al Hoceima, and Nador (Fig. 15.1).

15.2.2 Fishing Villages

Small ports or fishing villages generally, possess some fishing infrastructures, such as a wharf, a dike, a fish market, a fuel station, fishing equipment deposits, and sometimes an ice factory (Fig. 15.2).

Fig. 15.1 Picture of Hoceima fishing port

Fig. 15.2 Picture of Cala Iris fishing village

15.2.3 Structured Landing Beaches

These sites are built within the framework of the National Land Use Planning Program of artisanal fishing. These sites are no "offshore" equipment. Generally, the existing infrastructures are a fish market, where auctions are held, administrative office, shops for the deposit of fishing equipment, and an ice factory (Fig. 15.3).

15.2.4 Open Beaches

These kinds of SSF sites are very much in demand by seaside tourism in the summer season, because of the quality of sand and bathing water they offer. This good situation is due to their distance from cities and industrial areas. These sites are devoid of any basic infrastructure and fishing. Fishers have to move to a major port to get supplies, fishing inputs, and to repair their engines (Fig. 15.4).

15.2.5 Isolated Sites, with Seaside Activities

These sites, despite their isolation, they know seaside and important touristic activities in summer. These activities generate additional income for fishers. The

Fig. 15.3 Picture of artisanal fishery site Bel Younech

Fig. 15.4 Small-scale fishery site Tamernout

Fig. 15.5 Small-scale fishery Site Oued Mersa

prices of fish are higher than those recorded during the other seasons of the year, because of the higher demand. (Fig. 15.5).

15.2.6 Isolated Sites, Without Seaside Activities

These are very isolated sites, with difficult to very difficult access by land. Generally, they are so far from cities and active areas. They have no infrastructures and provide less protection for fishermen (Fig. 15.6).

Small-scale fisheries sites are distributed along the Moroccan Mediterranean coast. In the three important ports and their regions, Al Hoceima, Nador, and Tangier, the small-scale fleet is about 50% of all boats in the Moroccan Mediterranean (Fig. 15.7).

Fig. 15.6 Small-scale site Tamguerte

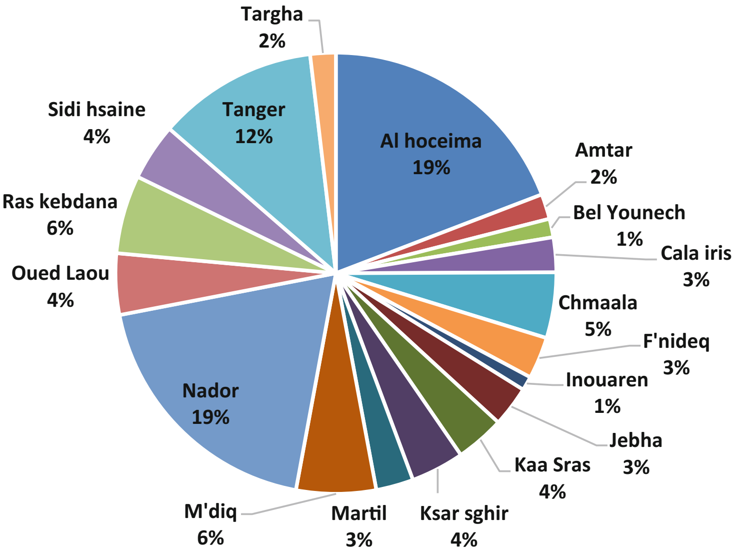

Fig. 15.7 Distribution of artisanal fleet by main landing port

15.3 Fishing Gears

The artisanal fishers use a large number of fishing gears depending on the fishing area, the target species, and the season. The number of gears used for targeting species vary from 2 to 11 per site. The gears are classified into two categories: nets and hooks gear. (Malouli Idrissi et al. 1999, 2017; Malouli Idrissi 2007).

15.3.1 Nets

The three main nets used: the trammel net, the bottom net, and the beach seine (Idrissi and Malouli idrissi 2008; Malouli Idrissi and Abid 2011).

The trammel net is used in the majority of the Small Scale Fisheries sites. They target a variety of species, especially the Sparidae. This gear is used all over the year (Fig. 15.8).

The bottom gill net is used for catching several species, the demersal and benthic species, mainly *Solea solea*, *Boops boops*, and *Pagellus acarne* (Malouli Idrissi and Zahri 2002).

The beach seine targets several species, the main ones belonging to the Sparidae family. The depth of the fishing area does not exceed 24 m. This technique is rarely

Fig. 15.8 Picture of Net

used, it requires a high number of fishers for the attraction of the seine from the sea to the coast, sometimes fishers use animals or tractors.

15.3.2 Hook Gears

The major hook gear used in the Moroccan Mediterranean Sea: longline, handline, and troll line (Table 15.2) (Idrissi and Malouli Idrissi 2008; Malouli Idrissi 2009; Malouli Idrissi and Abid 2011; Srour et al. 2003).

Table 15.2 Characteristics of hook gears used in the Moroccan Mediterranean Sea

Gear	Longline	Handline	Bluefin tuna Handline	Troll line
Local name	"Palangris"	"Chambil"	"Senara de Toun"	"Mouchtra"
Techniques	Longline set at the bottom	Handline set at the bottom	Handline on midwater	Trolled handline
Targets species	*Blackspot seabream*	*Pagrus pagrus, Pagrus caeruleostictus, Blackspot seabream, Diplodus sargus*	*Thynnus thynnus*	*Pagrus caeruleostictus, Diplodus sargus*
Accessory species	*Pagrus pagrus, Pagrus caeruleostictus, Pagellus acarne, Pagellus erythrinus, Phycis phycis*	*Cusk-eels, Pagellus acarne, Pagellus erythrinus, Phycis phycis*	*Xiphias gladius, Centrophorus uyato*	*Pagrus pagrus, Epinephelus caninus, Epinephelus marginatus, Cusk-eels*
Bait	Sardine, octopus, cuttlefish	Sardine, cuttlefish, squid, or an artificial bait	Octopus	Artificial bait, called "Mouchtra"
Number gears/boats	16	5	5	5
Form of use	The longline is rigged and picked up the same day	The handline is rigged and picked up every 10 min	The tide is 6–8 h. The handline is lifted once the fish bites on the hook	The handline is drag in the bottom
Period of use	All year	All year	June to September	April to September
Length	150–200 m per longline, 1500 hooks	150– 350 m per hand line	200–500 m	150–350 m per hand line
Number of hooks/ basket	60	1 or 2 per line	2 to 3	1
Depth	Until 300 m	Until 350 m	Until 400 m	Until 350 m

Table 15.3 Distribution of fishing gear by region (example)

Region	Gears
Tanger	Longline, handline, jigger, trammel net, bottom net, beach seine
M'diq	Longline, jigger, hand line, trammel net, surface net, bottom net, beach seine, trolling line, drag
Jebha	Longline, jigger, handline, trammel net, surface net, bottom net, beach seine
Hoceima	Longline, jigger, handline, trammel net, surface net, bottom net, beach seine
Nador	Longline, jigger, handline, trammel net, surface net, bottom net, beach seine, trolling line

15.3.3 *Other Gears*

The fishers use the dredge gear to collect shellfish. The two major targeted species are the red shell (*Acanthocardia echinata*) and the varnish (*Venus Chione*).

In conclusion, in the Moroccan Mediterranean Sea, some fishing gears are used by a high number of fishers, such as the longline and trammel nets that are found in almost all sites. Handline, bottom net, and beach seine are not necessarily used in all SSF sites.

Other gears are specifics to some SSF sites, like Bluefin handline, used only at 4 SSF sites in the region of Tangier (Table 15.3).

15.4 Fisheries

15.4.1 *Main Fisheries: Description, Catches, and Evolution*

The number of active boats in the Moroccan Mediterranean area goes from 2337 in 2013 to 3042 in 2018, which represents a 30% increase during this period. (Fig. 15.9).

Landings of small-scale fisheries have reached 4000 tons in 2018, which represent a 18% decrease with respect to 2017. The catches were relatively stable between 2013 and 2018, with a pick in 2014 (4900 tons). The value of landings has been rising since 2013 with a slight decrease in 2018 (Fig. 15.10).

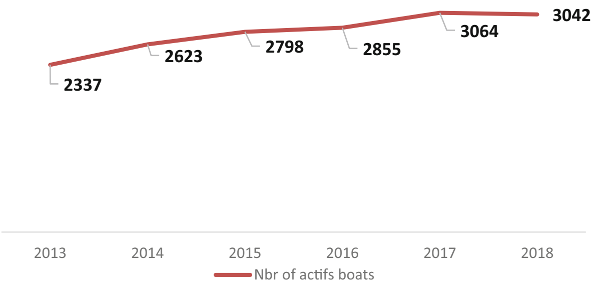

Fig. 15.9 Number of operational boats

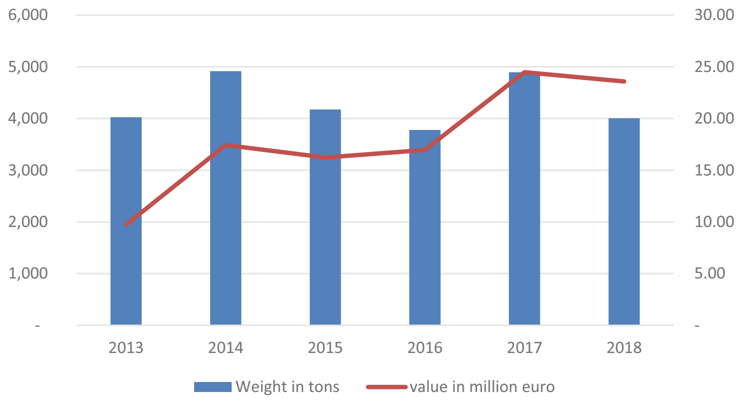

Fig. 15.10 Landings of SSF in Mediterranean coast 2013–2018

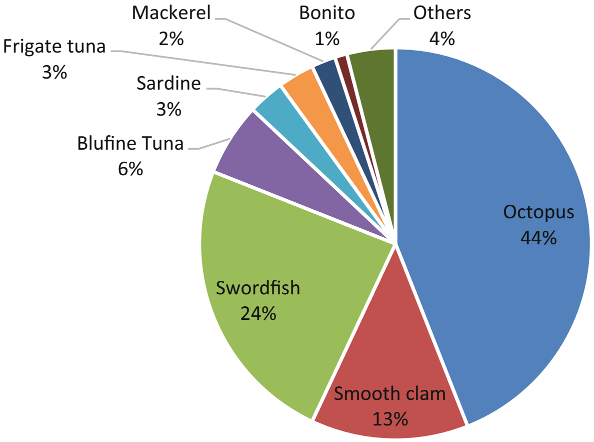

Fig. 15.11 The distribution of landed species by the artisanal fishery in the south Alboan Sea (Morocco 2018)

The main species landed in 2018 by small-scale fisheries is octopus, which represents approximately half of the landings in weight (Fig. 15.11). Swordfish comes in second position in weights (24%). Other species made up of small pelagics, and sparidae represent 4% of landings in this segment (Fig. 15.11).

The octopus is mostly caught in Al Hoceima and Nador, in the East and Center of the Mediterranean Coast, while swordfish is especially fished in the area of Tangier in the extreme west of the Mediterranean Coast (Fig. 15.12).

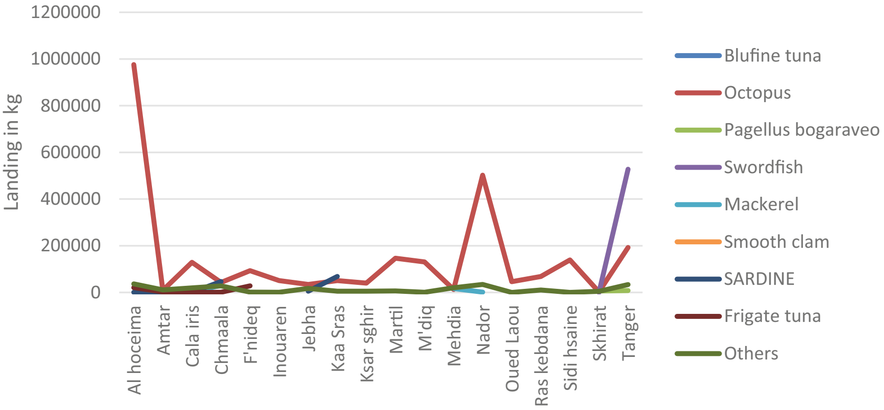

Fig. 15.12 Main species landed in main landing port (2018)

15.5 Socioeconomic Aspects

Taking into account the production aspects as well as economic ones, Small-scale fisheries is one of the very important sub-sector of the fisheries activities in the Southern Alboran Sea. The landings of the artisanal fleet in Moroccan Mediterranean ports were 5000 tons in 2017, which represent 15% of the total landed by all the fishing fleets. According to the information collected by the national office of fisheries, the importance of this sector is even greater, since the value of sales in 2017 was more than 23 million €, which represents 39% of the total sales in the fish markets. This great difference between the parts of the catch and its economic value, which is more than double, is explained by the high value of sales achieved by the products obtained due to their high quality, and the high demand for many of the species.

The economic weight of the artisanal sector is quite variable among ports. From those in which a 100% of the sale comes from fishing products of the artisanal fleet (Chmaala, Kaa Sras, Ksar Sghir, and Sidi Hsaine, for example). In other ports, the importance of artisanal fleet is not significant in comparison with other coastal ones, where the trawlers, purse seiners, and longliners are the most relevant fleets from the economic point of view (Fig. 15.13). In Tangier port, artisanal activities have a higher importance, accounting for 17% of total sales; the rest is shared between the purse seiners (49%) and the longliners (7%) (Fig. 15.13).

In 2018, the ports, which recorded the highest sales values for artisanal fleet were Tangier (31%) and Al Hoceima (25%) (Fig. 15.14). The volume landed is the same in these two ports, but the value of species landed is higher in Tangier. The Nador port is the third important one, with 13% in sales values, mainly due to sales of *Octopus vulgaris* (Fig. 15.15).

Direct employment generated by artisanal fisheries in the Moroccan Mediterranean Sea, shows a positive trend in the period 2009–2016 compared to the total number of employees in all fishing fleet, going from 33.7% to 40.7% (Fisheries

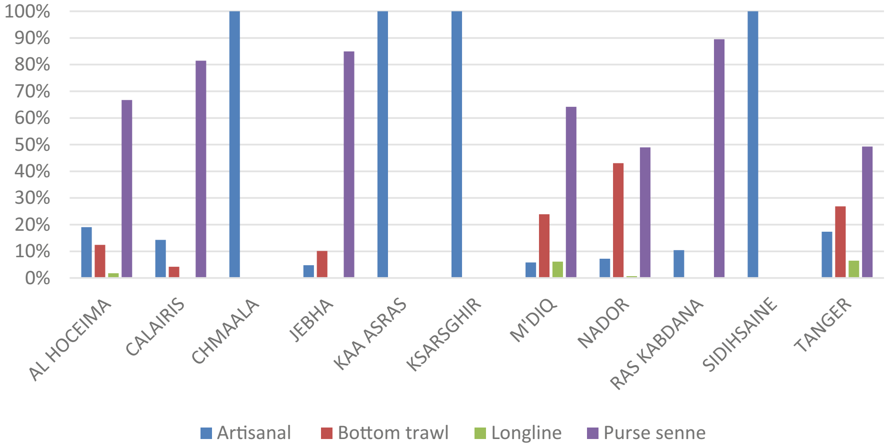

Fig. 15.13 Importance of the fish landing by segment (2018)

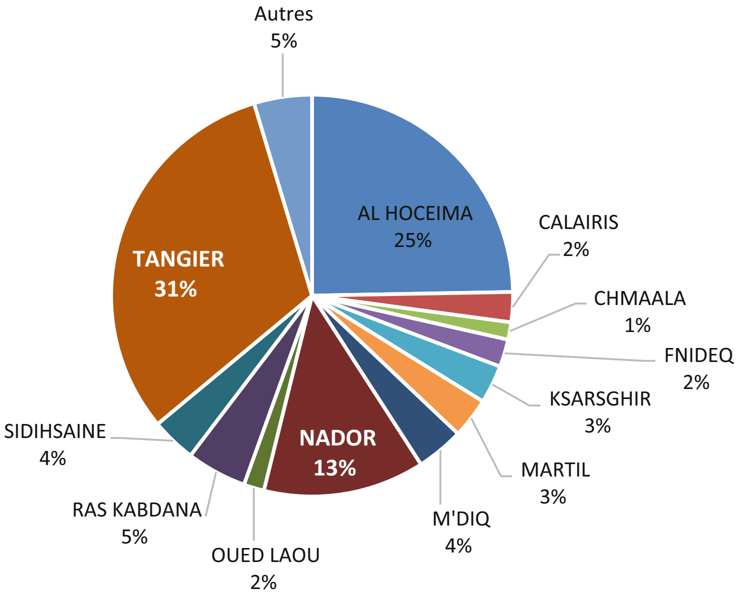

Fig. 15.14 Importance of the SSF total sales by port in South Alboran Sea (2018)

Department), but, these data do not result in an increase of workers. However, it is known that the artisanal sector is more stable in the consolidation of employment than other fishing sectors where there is a clear decrease. However, wages and income levels are lower.

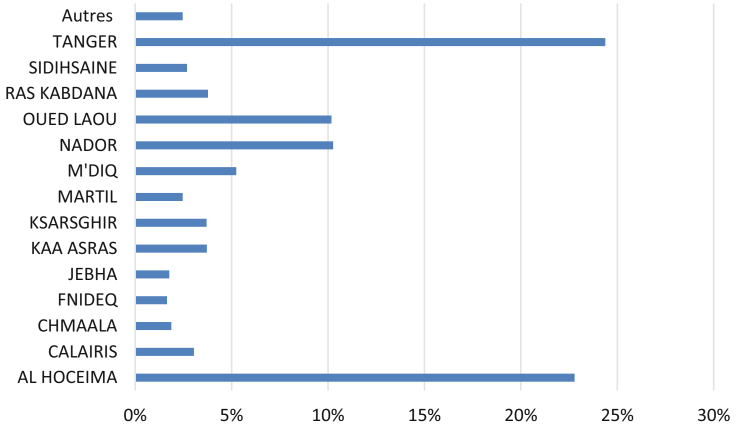

Fig. 15.15 Importance of SSF landings by port in South Alboran Sea (2018)

The average number of crewmembers per vessel is variable but remains quite lower given the size of boats used the fishing techniques used. The highest average number of crewmembers per boat (4) is recorded in the Tangier port, followed by Chmaâla and M'diq with only 2 workers per boat. The number of direct jobs in the artisanal sector from the South of Alboran Sea is about 9000, but its distribution along the coast is heterogeneous. Thus, the most important concentration of workers are found in Nador and M'diq.

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Chapter 16
Small Pelagic Resources: A Historic Perspective and Current State of the Resources

Ana Giráldez

16.1 Introduction

Fishing was one of the first activities that humans engaged in to meet their nutritional needs. At first these needs were met on an individual basis, but over time, and after the preservative properties of salt were understood, a thriving trade evolved. Some 3000 years ago, one of the most important economic activities in the Mediterranean was a trade in salted and dried fish. For example, the Phoenicians were actively engaged in trading these products.

Small pelagic fishing has been of historic importance in the Alboran Sea, with Malaga as its most important port. The origins of Malaga are almost as old as those of the salting industry. Many authors have attributed its name to the traditional manner in which fish were prepared: some philologists have suggested that the name of the city derives from the Phoenician word *malach* which means salt seasoning or salting, whereas others have suggested where the fish is dried. During the Roman period, the preserved fish industry in southern Spain was so important that there were merchants based in Rome who traded salted fish from Malaga.

In the 1940s and 1950s, Estepona, and Malaga in particular, maintained large canning industries. At that time the fleet could freely fish in the rich fishing grounds of North Africa. Throughout its history, and due to its location, Malaga has always been associated with fishing and its derivatives. However, the coast of Malaga is on a very narrow continental shelf, and thus the amount of fish that can be caught there is low. Therefore, the large commercial activity that has existed since the beginning of the twentieth century has always been based on the unloading of fish taken from the rich Moroccan fishing grounds (both Atlantic and Mediterranean). Boats fished

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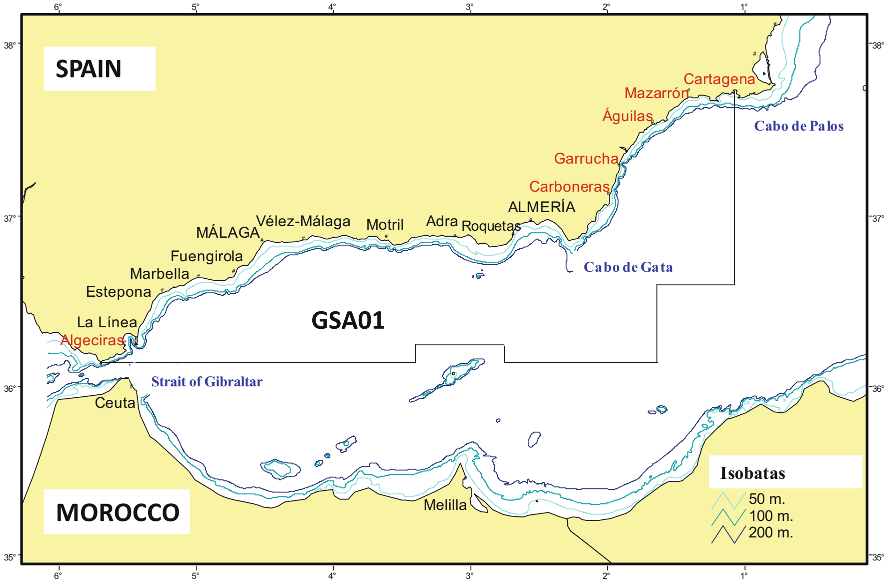


Fig. 16.1 Geographic area of the GSA01 showing the fishing ports. The ports shown in *black* correspond to the *SMR (South Mediterranean Region)*

freely in these areas until 1956, when Morocco achieved independence. Thanks to fishery agreements between Spain and Morocco, fishing has continued; however, the same agreements included a reduction in the number of licenses, and thus there has been a marked decrease in landings.

Over the years, small pelagic catches have experienced strong oscillations. The current sardine catch is very low with only 3500 tons being caught in 2017 (30% of the catch in 1992). After 7 years of very low anchovy catches, there was a slight recovery in 2002 (3200 tons); however, they remain at low levels. This situation has been partly compensated for by catches of other less important species such as horse mackerel (*Trachurus* spp.) and mackerel (*Scomber* spp.). Although Malaga has been one of the most important ports in the so-called South Mediterranean Region (SMR) (i.e., from the Strait of Gibraltar to Cabo de Gata and the ports of Ceuta and Melilla) (Fig. 16.1), currently, the most important port is Caleta de Vélez. In the 1940s, 24,000 tons of sardine and anchovy were landed annually in the SMR. The importance of this figure resides in the fact that it represents the amount of all species caught on any gear in the whole area per year at the present time.

The small pelagic fishery in the Alboran Sea has been described by De Miranda (1930, 1931) and Bellón (1950), with a special focus on the so-called Maritime Province of Malaga, and the entire area by Abad and Giráldez (1990a) and Giráldez and Abad (1991, 2000). More studies have focused on Malaga because the Spanish Institute of Oceanography has had a laboratory in the city since 1913 (Pérez-Rubín 2014).

We conducted a review of small pelagic fisheries of anchovy (*Engraulis encrasicolus*, Linnaeus 1758) and sardine (*Sardina pilchardus*, Walbaum 1792) in the SMR. This overview focuses on a long historical series of landings, the characteristics of the fleet, differential characteristics of this type of fishery by port, the fishery effort during the last decade, acoustic assessment, and the economic aspects of the fishery.

16.2 Geographical Situation and Data Employed

The Alboran Sea covers the marine area running from the Strait of Gibraltar to Cabo de Gata. The latter is connected by an invisible line to Cape Figalo (Algeria), which forms the border on the eastern edge of the area. Over time, fishery studies have slightly modified the way in which fishery statistics are grouped due to special interests concerning management, stock assessment, and logistics.

The oldest historical series of sardine and anchovy landings are grouped into the SMR, which corresponds to the old 37.1.5 division of the General Fisheries Commission for the Mediterranean of the Food and Agriculture Organization (GFCM/FAO). This grouping covers ports from Cabo de Gata to the Strait of Gibraltar and also includes the ports of Spanish cities Ceuta and Melilla in northern Africa (Fig. 16.1).

Currently, the aggregated data for the CGPM working groups is obtained from the Geographical Subarea 01 (GSA01, Fig. 16.1), which groups together the SMR and the Gulf of Vera (between Cabo de Gata and Cabo de Palos). However, this study uses the SMR for purposes of comparison with the old series.

The ports of Ceuta and Melilla used to be important landing points. However, Melilla no longer has a purse seine fleet, and in 2005 the number of landings in the port of Ceuta (last updated info) represented only 1% of the landings from the total area of the SMR.

Data on the historical series of catches (from 1945 to 2017) were obtained from the official statistics of the General Fisheries Secretariat (SGPM), Fisheries Regulatory and Market Fund (FROM), and the Spanish Institute of Oceanography (IEO).

Data on the historical fleet were obtained from the statistics of the SGPM. This series is smaller than the landings for the following reasons: until 1964, only the number of fishing gears was counted; between 1965 and 1971, purse seine fishing was not counted separately; after this period, only ships of more than 20 GT (gross tonnage) were counted; and from 1973, the statistics included the technical characteristics of the ships.

16.3 Description of the Fishing Activity

16.3.1 Target Species

The main target species of the purse seine fishing fleet in the Alboran Sea are sardine and anchovy. Less relevant species are horse mackerel *Trachurus* spp., mackerel *Scomber* spp., and gilt sardine *Sardinella aurita* (Fig. 16.2). These species sometimes comprise a large proportion of the total catch. Seasonal catches of frigate mackerel *Auxis rochei* (Risso 1810), Atlantic bonito *Sarda sarda* (Bloch 1793), and Atlantic saury *Scomberesox saurus* (Walbaum 1792) are of great importance in the most eastern ports, thus differentiating the purse seining activity according to base port**.**

Anchovy and sardine species are short-lived coastal pelagic fish (anchovy, 3–4 years maximum, and sardine, 7–8 years maximum). These species are characterized by seasonal migrations, fast growth, early maturity, and shoaling. Both species feed on plankton (Yebra et al. 2019). Anchovies spawn in the northern Alboran during spring-summer (Giráldez and Abad 1995) and sardines during autumn-winter (Abad and Giráldez 1992).

This overview of fishery activity mainly focuses on anchovy and sardine species, whose catches have strongly varied over time. Of the two species, anchovies are the most valuable in the current market; nonetheless, the fishery activity is strongly complemented by catches of sardine because it is the most abundant species.

In addition, some purse seine bycatch species have recently found a place in the market. For example, mackerel species are mainly used for tuna fattening, and gilt sardines are used for bait. These species have high yields per night of fishing. Horse mackerel is exported to Portugal when they are abundant. These secondary species represent 50% of landings and 30% of overall economic value.

Due to variable annual recruitment, the small pelagic populations experience strong fluctuations in abundance, which leads to fishing crises because of the lack of fish.

16.3.2 Methods and Fishing Gears

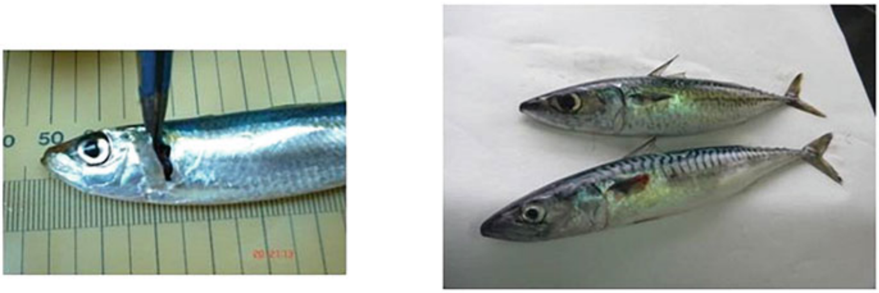
Small pelagic fish inhabit open waters and form shoals. They are fished using a purse seine boat (“Traíña” in Spanish), an auxiliary boat, and a light boat (Fig. 16.3).

Purse seine fishing gear comprises a rectangular net which is lowered vertically, thus surrounding the shoal, and ends in some triangular parts called “puños” (Abad and Giráldez 1990a). When the shoal is completely surrounded, the lower part is closed to avoid escaping and to catch the fish and then lifted back into the boat. Spanish legislation defines the technical characteristics of these fishing gears, which can be up to 450 m long by 82 m high (Fig. 16.4).

Engraulis encrasicolus. Mapama

Sardina pilchardus. Mapama

Trachurus mediterraneus



Sardinella aurita

Scomber colias
Scomber scombrus

Fig. 16.2 Main species (top) and secondary species (bottom) targeted by the purse seine fishing in the SMR. Picture source: MAPAMA

Locating Fish Using Echo Sounders Firstly, the boat searches for fish shoals using echo sounder systems. During the fishing maneuver, the auxiliary boat holds one end of the net, and the larger boat sails in a circle while dropping the net around the shoal. Once the fish are caged in the circular net, the fishermen pull a rope called the "jareta," which closes the large net, just like a bag (Fig. 16.4).

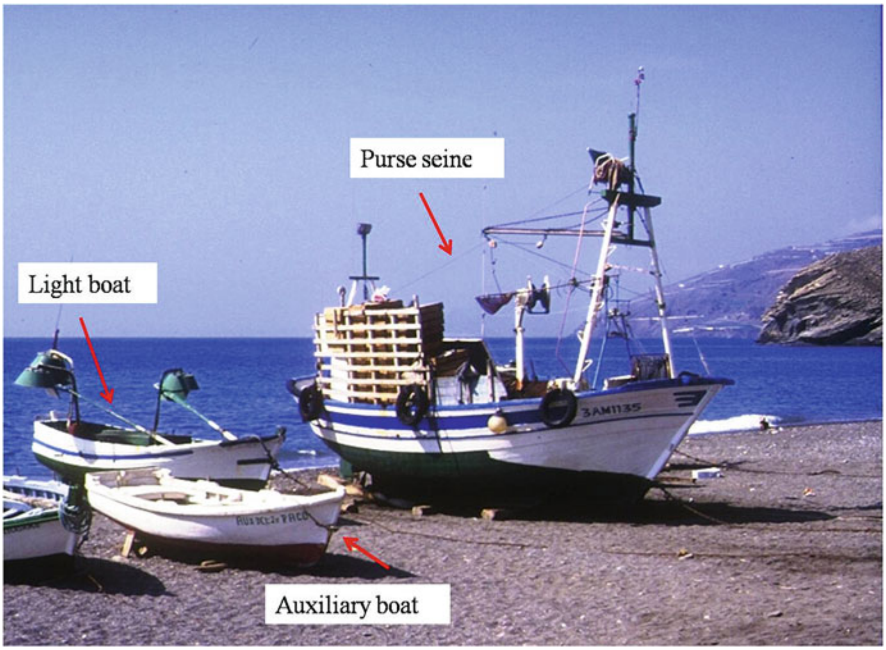


Fig. 16.3 Purse seine boat, light boat, and auxiliary boat. Albuñol beach (Granada, Spain) 1989

Fishing with Lights On dark nights, the light boat uses its lights to concentrate fish beneath it since anchovies and sardines are positively phototropic (i.e., attracted by light). Subsequently, the fish are captured following the previous method using echo sounder and loaded onto the vessel.

"Arda" Fishing On moonless nights, this method is used to catch negatively phototropic species. The purse seine skippers locate the schools using the "arda," which is phosphorescence produced by some plankton organisms when fish shoals pass by. The target species of this fishing method are small tuna species, such as *A. rochei* and *S. sarda*.

These boats set out around sunset and return at sunrise. Atypical fishing day comprises two fishing operations: the first in the late afternoon ("prima" in Spanish) and the second at sunrise ("alba" in Spanish).

Fishing Area

Currently, sardines are caught throughout the Alboran Sea, whereas anchovies are caught mainly in Malaga Bay (Fig. 16.5). In the years of abundant catches, all the fleets from all the SMR ports were concentrated in the bay. For this reason, the boats used to land in the Port of Malaga, taking advantage of the high price of anchovies in this city (Abad and Giráldez 1990a, 1997; Giráldez and Abad 1991; Giraldez et al. 1997). At present, the port of Caleta de Vélez is more important than the Port of Malaga.

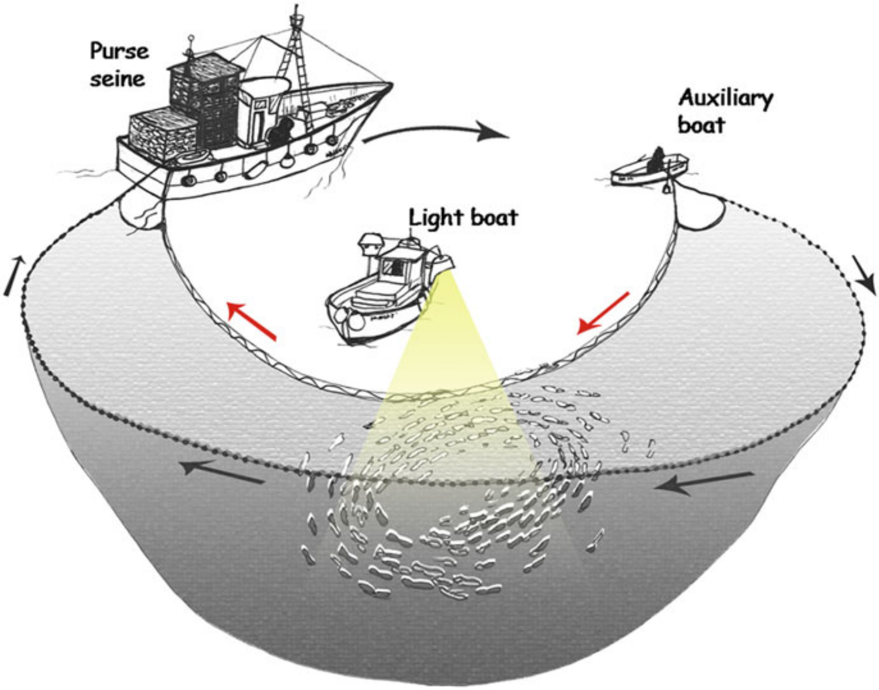


Fig. 16.4 The purse seine fishing technique (author: Ana Flores)

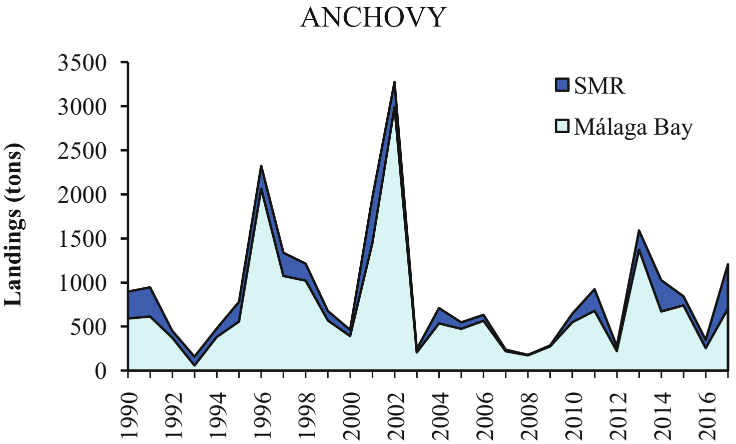


Fig. 16.5 Anchovy catches in the SMR and Malaga Bay (1990–2017)

Fishery Periods

The principal fishery periods for sardine and anchovy are summer-autumn. Summer anchovy catches correspond to spawners and autumn catches to recruits (Fig. 16.6).

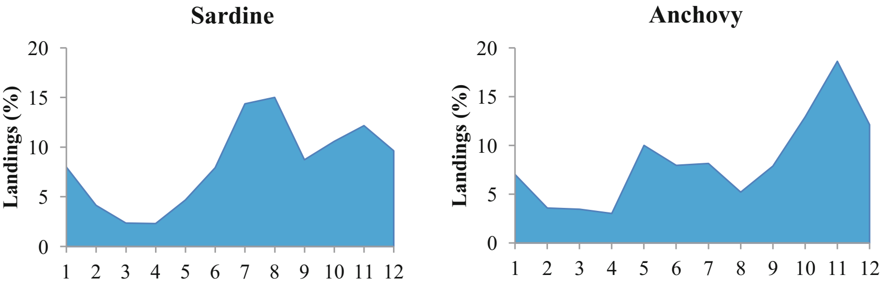


Fig. 16.6 Seasonality of sardine (left) and anchovy (right) catches in the SMR. Averages (2009–2017)

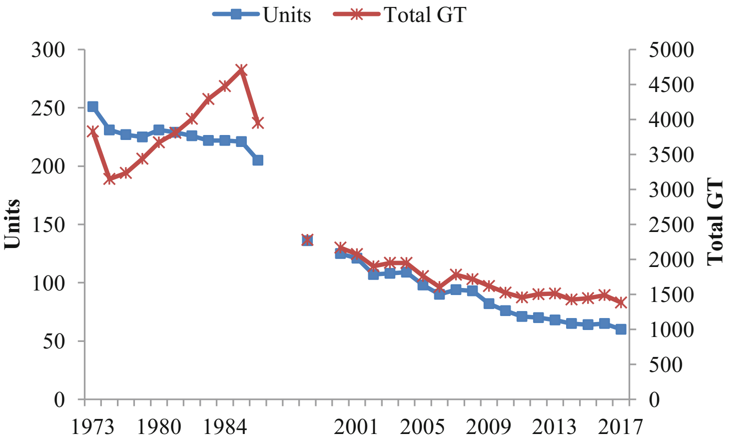


Fig. 16.7 Number of boats and overall change in GT of the SMR purse seine fleet (1973–1986, 1998, 2000–2017)

16.3.3 *Technical Characteristics and Historical Evolution of the Fleet*

The SMR purse seine fleet underwent a continuous decrease from 251 boats in 1973 to 61 in 2017 (i.e., a 76% reduction) (Fig. 16.7). This decrease accelerated from 1986 onward but has slowed down in recent years. At present, this fleet comprises small boats: 70% are less than 30 GT (i.e., average23.0 GT and158 HP). Only 9% of the fleet is less than 12 m long. Of these, only two of the boats are less than 9 m long, and these boats will continue fishing until they are decommissioned (Table 16.1).

Figure 16.8 shows the reduction in the size of the fleet after the implementation of legislation governing the minimum size of boats. However, larger boats disappeared due to the collapse of anchovy fishing grounds off North Africa, which is where the Spanish fleet used to work under fishing agreements with Morocco. Another reason for this disappearance is the fall in anchovy catches in the Gulf of León, the mouth of

Table 16.1 Purse seine fleet by SMR ports (2017)

	GT interval										Length interval	
Ports	<10	10–20	20–30	30–40	40–50	50–60	>60	TOTAL	Average GT	Average HP	6–12	12–24
Almería		5	4	1	1			11	25.3	165.2		11
Roquetas		2						2	18.2	136.5		2
Adra		1	2	3	1			7	30.3	213.1		7
Motril			1	1				2	28.1	200.5		2
Caleta de Vélez	2	3	6	3	1			15	24.5	165.7	1	14
Malaga		1			1			2	30.5	232.0		2
Fuengirola	2							2	6.7	67.5	1	1
Marbella	2	3	2				1	8	21.9	139.8	2	6
Estepona	2	2				1		5	21.1	160.8	1	4
La Línea	1							1	6.8	87.0	1	
Ceuta	2	4						6	13.1	78.3		6
Total	11	21	15	8	4	1	1	61	22.8	156.5	6	55

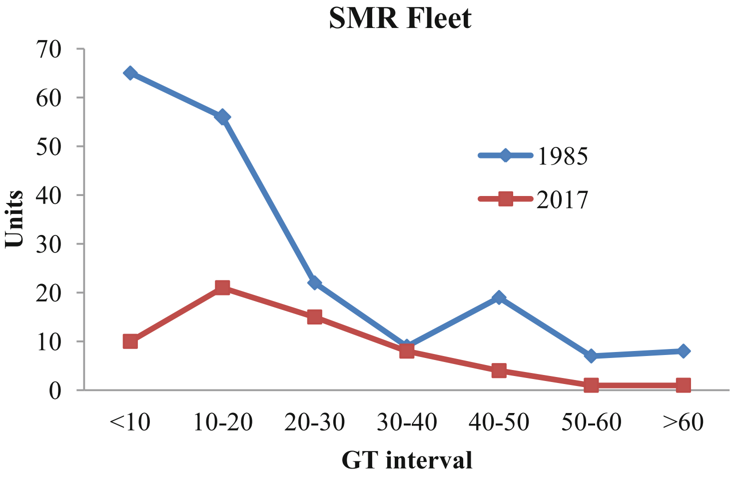


Fig. 16.8 SMR purse seine fleet by GT interval (1985 and 2017)

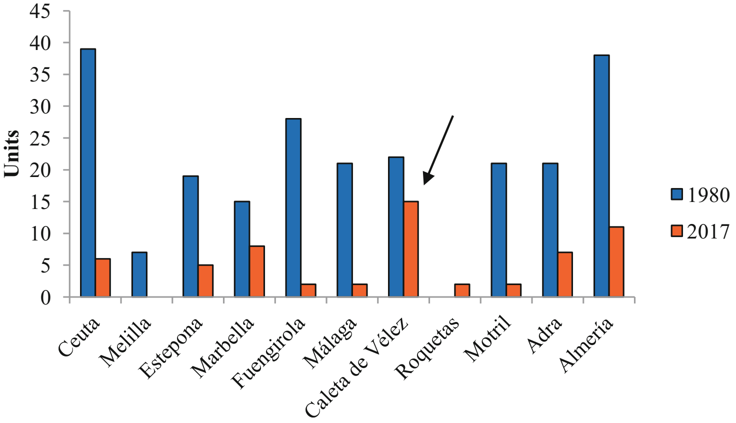


Fig. 16.9 SMR purse seine fleet by port (1980 and 2017)

the Ebro River, and off the coast of Valencia, which is where boats from Adra, Almería, and Malaga used to fish each season (Abad and Giráldez 1997). Nowadays, only the largest boats from Adra and Almería work regularly on the Spanish east coast during summer and only if anchovy species are abundant. In 2013, 22% of the fishing activity and landings in the GSA06 (Northern Spain) were conducted by purse seiners based in the GSA01.

Figure 16.9 shows the fleet by port between 1980 and 2017. Over time, all these ports have experienced a great reduction in the number of boats. In 1980, the most important fishing ports were Ceuta (North Africa) and Almería. Nowadays, Caleta de Vélez is the most important by port and is also the one that has been less affected by this decrease (Table 16.1).

16.4 Historical Series of Catches

16.4.1 Historical Series of Catches in the SMR (1945–2017)

Sardine From 1945 to 1956, a high percentage of catches occurred in North Africa. However, there was a decline in interest in these species with the coming of Moroccan Independence in 1956. Together with other decreases in ports such as Melilla, the collapse continued in North Africa until the virtual disappearance of sardine landings in 1985 (Fig. 16.10).

Until the 1960s, the most valued species were sardines. However, in 1962, the price of anchovies reached the same value on the market following the high demand for preserves, which was probably due to changes in culinary tastes. The value of anchovies was further raised by the use of new synthetic nets. This is because anchovies tend to become stuck in nets and then putrefy, which makes nonsynthetic nets rot. However, synthetic nets are resistant to this process. Subsequently, the price of anchovies surged so much that they became the main target of the Spanish fishing activity. Nowadays, sardine catches are low. Thus, their value and market price have increased to the point that their price can sometimes match that of anchovies.

Anchovy Until 1978, it was impossible to physically separate anchovy catches from the north and south of the Alboran Sea. During the 1940s and 1950s, the economic value of anchovies was low. During these periods, they were typically caught by fleets operating out of Ceuta and Melilla, as well as by some from northern Alboran ports. From the 1970s until 1984, a large fishery became established in the southern Alboran Sea. Spanish boats fished in this area thanks to an agreement between Spain and the Moroccan government. Some 28,000 tons of this species

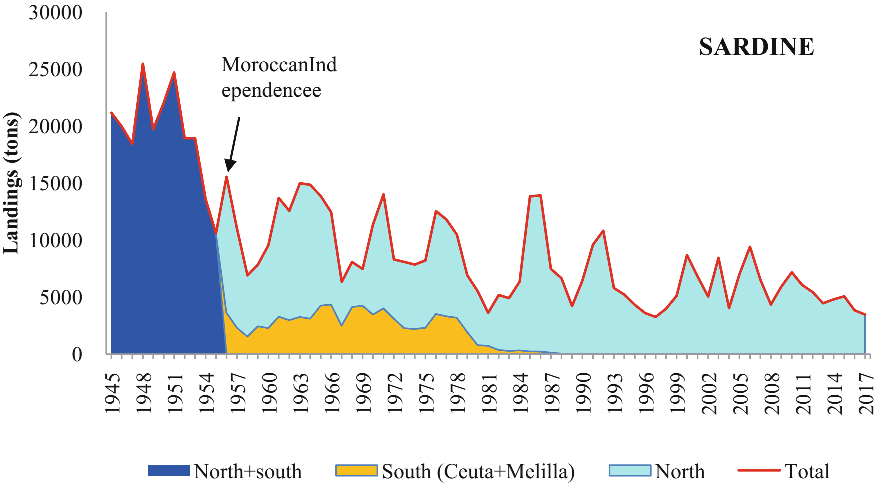


Fig. 16.10 Sardine landings in the SMR (1945–2017)

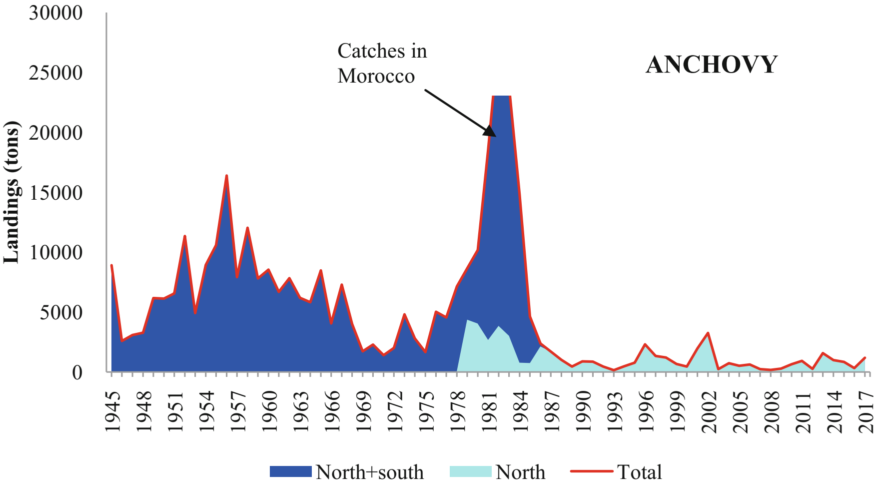


Fig. 16.11 Anchovy landings in the SMR (1945–2017)

were landed in the SMR ports in 1982 (Fig. 16.11), of which 87% came from the southern side of the Alboran Sea and 13% from the northern side (Giráldez and Abad 1991).

In 1993, landings in the northern area reached an all-time low at 157 tons. In that year, there was very low recruitment of anchovies, which was probably due to the demographic boom of boarfish *Capros aper* (Linnaeus, 1758) species in the Alboran Sea (Abad and Giráldez 1990b).

16.4.2 Most Recent Historical Series of Catches in the SMR (1985–2017)

In the last 24 years, there have been marked fluctuations in catches of the main species (sardine and anchovy) (Fig. 16.12) and secondary species (horse mackerel and mackerel) (Fig. 16.13). Of the total catches, sardines comprise between 39% and 58% and anchovies between 1% and 22%. Obviously, variability is very high. The horse mackerel series includes catches using other gears and represents 30% of the total catch.

16.4.3 Catches by Port

Between 2009 and 2017, the largest catches in the most eastern ports, such as Almería, Adra, and Motril, were *Trachurus* spp. and *Scomber* spp. (Fig. 16.14).

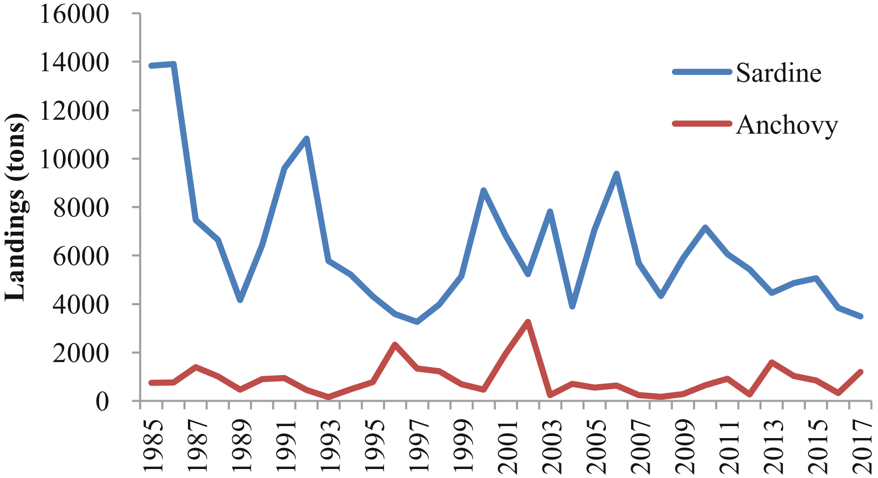


Fig. 16.12 Sardine and anchovy landings in the SMR (1985–2017)

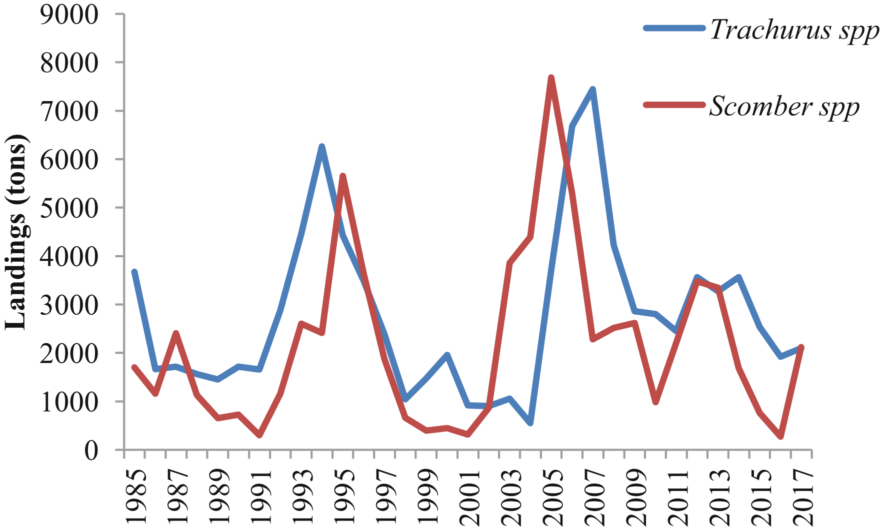


Fig. 16.13 *Trachurus* spp. and *Scomber* spp. landings in the SMR (1985–2017)

However, sardines remained the most important species. In these ports, the catch of secondary and other bycatch species comprised 79% of the total catch and 59% of the economic value. In the ports of Malaga Bay (Caleta de Vélez, Malaga, and Fuengirola), sardines comprise a higher percentage of the total catch. This area is the only one with relevant levels of anchovy catches. In most western ports (Marbella and Estepona), sardines are the most important species.

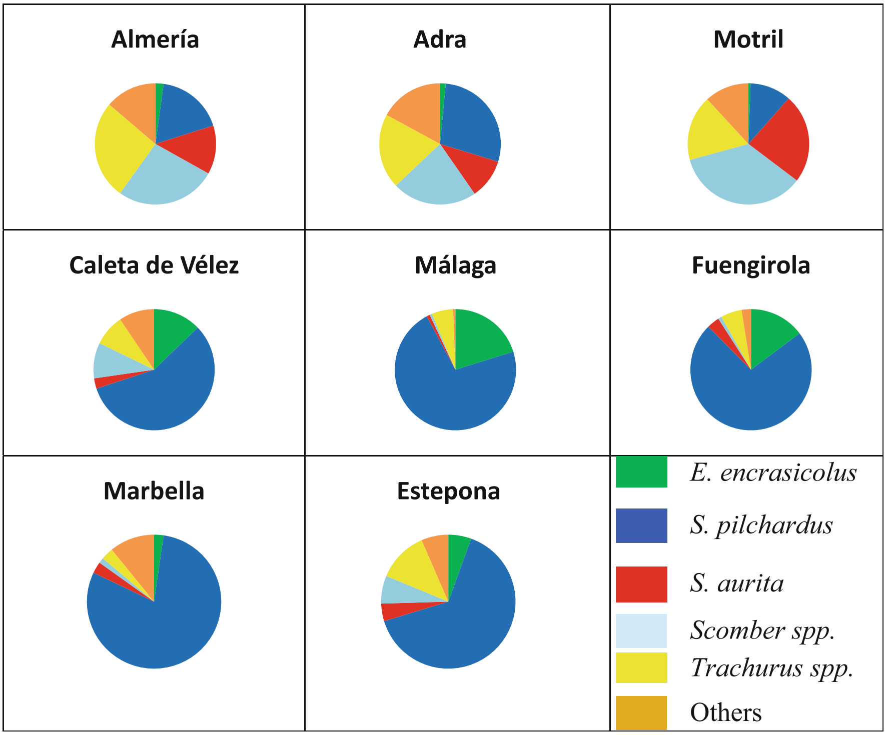


Fig. 16.14 Distribution of landings by port (2009–2017)

Data on the ports of Roquetas de Mar and La Línea have not been taken into account because, on the one hand, landings from the area of Roquetas de Mar are made in the port of Almería and, on the other hand, La Línea only has one small purse seiner.

16.4.4 Catch per Unit of Effort

Catch per unit of fishing effort (CPUE) is the total catch divided by the total amount of effort used to harvest the catch. The standardized CPUE is typically used as an abundance index. In the present case, the effort unit used is a fishing night.

The CPUE of sardine had a spike in 2010 and another in 2015–2016. It then underwent a dramatic decrease in 2017 (Fig. 16.15), when the catch was at its lowest in the entire historical series. In contrast, the catch and CPUEs of anchovy are increasing (Fig. 16.16).

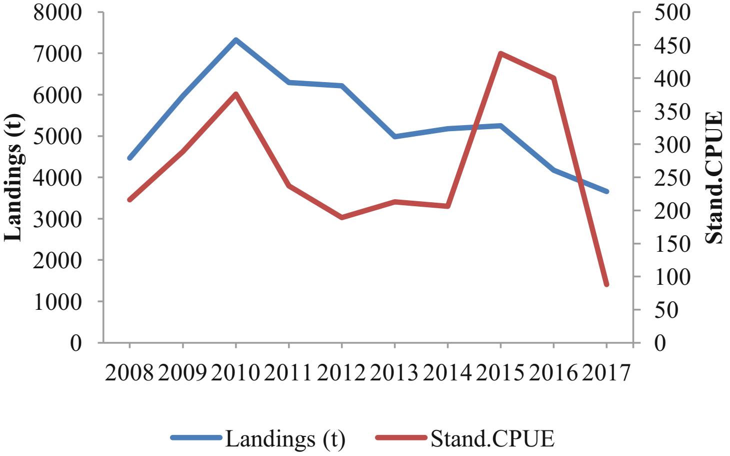


Fig. 16.15 Trends in sardine landings and standardized CPUEs in the SMR. 95% total landings GSA1 (2008–2017). Abbreviation: stand. CPUE, standardized CPUE. Modified from Serghini et al. 2018)

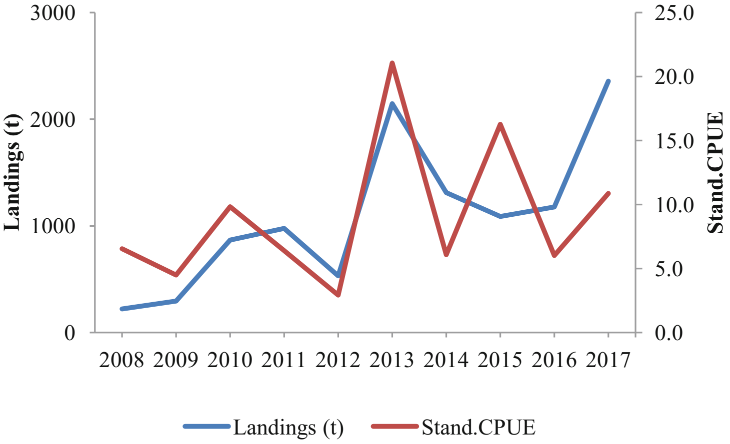


Fig. 16.16 Trends in anchovy landings and standardized CPUE in the SMR. 85% total landings GSA1 (2008–2017). Abbreviation: stand. CPUE, standardized CPUE. Modified from Serghini et al. 2018)

16.5 Independent Information on the Fisheries: Acoustic Surveys

The IEO conducts an annual acoustic assessment survey to establish the biomass of small pelagic species in the Spanish Mediterranean Sea. Until 2009, the ECOMED survey was conducted every year between November and December, which is when anchovies undergo recruitment and sardines spawn. Nevertheless, in 2009, the

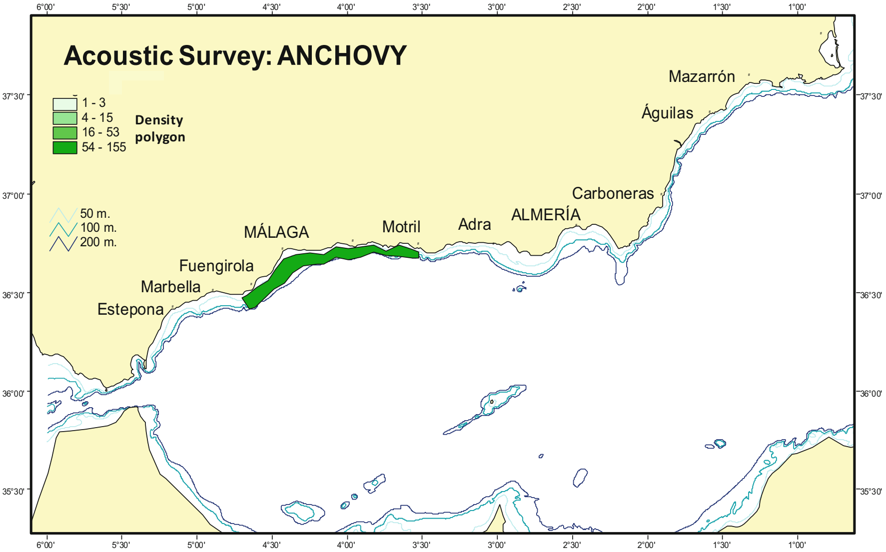


Fig. 16.17 Anchovy distribution (November–December) in the northern Alboran Sea (GSA01). IEO acoustic Survey

European Union provided funds for an acoustic assessment survey coordinated by other Mediterranean countries known as the MEDIAS survey. The need to coordinate and standardize methodologies with other European Union countries meant that the IEO had to switch their survey from autumn to summer, which is the anchovy reproductive season and the sardine resting season.

Figure 16.17 and 16.18 shows distribution densities of the two most important species in November and December.

Although anchovy abundance is highly variable between years, Fig. 16.17 provides an averaged representation, showing that the anchovy population is concentrated in Malaga Bay. The differential characteristics by port (Fig. 16.14) are a representation of the map shown in this figure.

Although sardine abundance is highly variable between years, Fig. 16.18 provides an averaged representation, showing that sardines are distributed throughout the whole northern Alboran zone with a greater abundance in the western area. The differential characteristics by port (Fig. 16.14) are a representation of the map shown in this figure.

16.6 Economic Aspects of the SMR (2002–2017)

Figure 16.19 shows the volume of landings and economic value of the species taken by the purse seine fleet in the SMR. Sardines are the most caught species. Even though the unit price of sardines is low, they are of great economic value to the

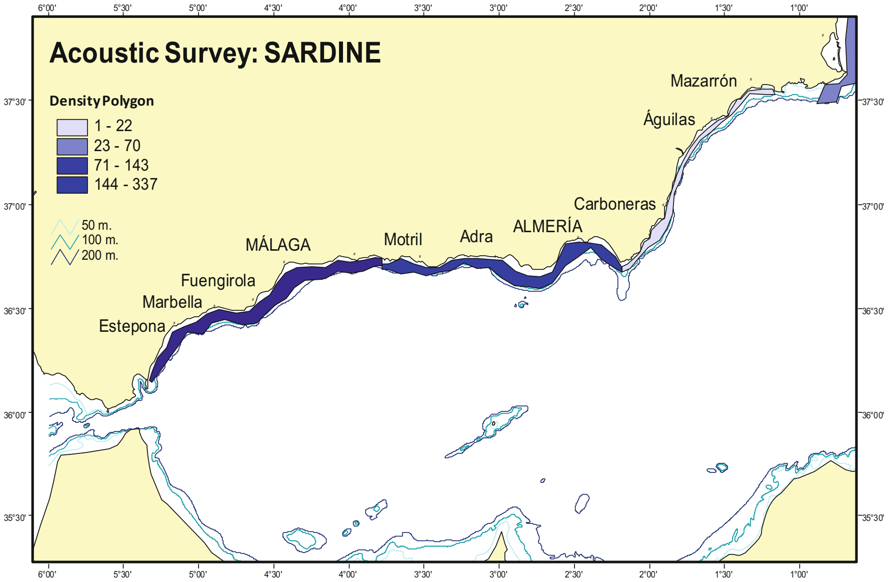


Fig. 16.18 Sardine distribution (November–December) in the northern Alboran Sea (GSA01). IEO acoustic survey

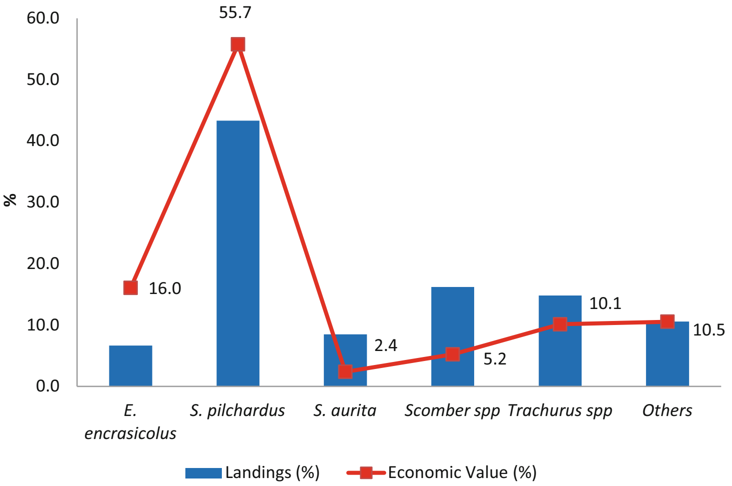


Fig. 16.19 Average catch and economic value (%) by species in the SMR (2009–2017)

fishing industry because they are the most caught species. The catch of secondary species is relevant because they represent as much as 50% of the total landing by weight and 29.1% of the economic value of the total catch.

In 2017, small pelagic landings in the SMR represented 68.9% by weight and 33.1% of the economic value.

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Chapter 17
North Atlantic Oscillation Effect on the Biology and Fisheries of Tuna Species in the Alboran Sea

José Carlos Báez, Ignacio de Loyola Fernández, and Juan Antonio Camiñas

17.1 Introduction

Tunas and tuna-like species are considered highly migrating species (HMS) (Joseph 1977; Maguire et al. 2006). The Mediterranean Sea is a spawning area for many of these HMS (Karakulak et al. 2004; Druon et al. 2011; Reglero et al. 2012). The Alboran Sea is an important hotspot for tuna species (Báez et al. 2009). Moreover, the Alboran Sea shows important productive areas where the tuna species are concentrated (Sabatés and Recasens 2000; Alemany et al. 2010), and, for this reason, the Alboran Sea has been an important fishing area for tuna species since ancient times.

According to the data available in IDAPES (2020) and ICCAT (2020), the four main target species of tunas and tuna-like species in the North Alboran Sea, in the open sea, are Atlantic bonito (*Sarda sarda*), bullet tuna (*Auxis rochei*), bluefin tuna (*Thunnus thynnus*), and little tunny (*Euthynnus alletteratus*) (Fig. 17.1). On the other hand, according to ICCAT (2020), the main four species in the South Alboran Sea of the tuna fisheries in the open sea are Atlantic bonito (*Sarda sarda*), bullet tuna (*Auxis rochei*), bluefin tuna (*Thunnus thynnus*), and plain bonito (*Orcynopsis unicolor*)

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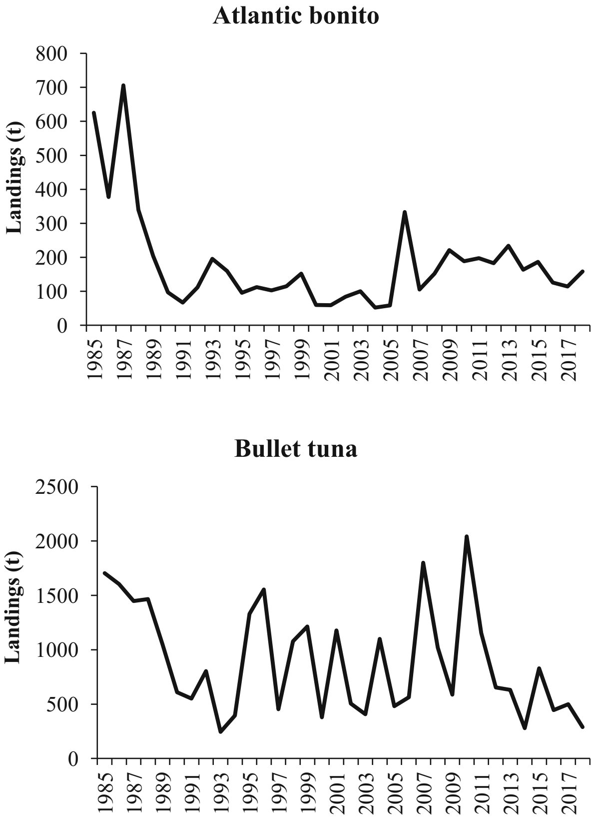


Fig. 17.1 Evolution of the landing (t) trend of the four main target species of tunas and tuna-like species in the North Alboran Sea, in the open sea, are Atlantic bonito (*Sarda sarda*), bullet tuna (*Auxis rochei*), bluefin tuna (*Thunnus thynnus*), and little tunny (*Euthynnus alletteratus*) during the period 1985–2018. Data sources in IDAPES (2020)

(Fig. 17.2). The main north/south difference is that on the south shores of Alboran, little tunny is less frequent; in fact in recent years, there is no landing of little tunny declared by Morocco, with a total of 443 t during the study period that contrasts with the 915 t declared by Spain at the north of Alborán Sea. On the other hand, plain bonito is the fourth most important species of tuna in the south with 655 t, while in the north of Alborán, there are no catches reported. Plain bonito is the target by fisheries only in the South Alboran Sea (UNEP-MAP-RAC/SPA 2014)

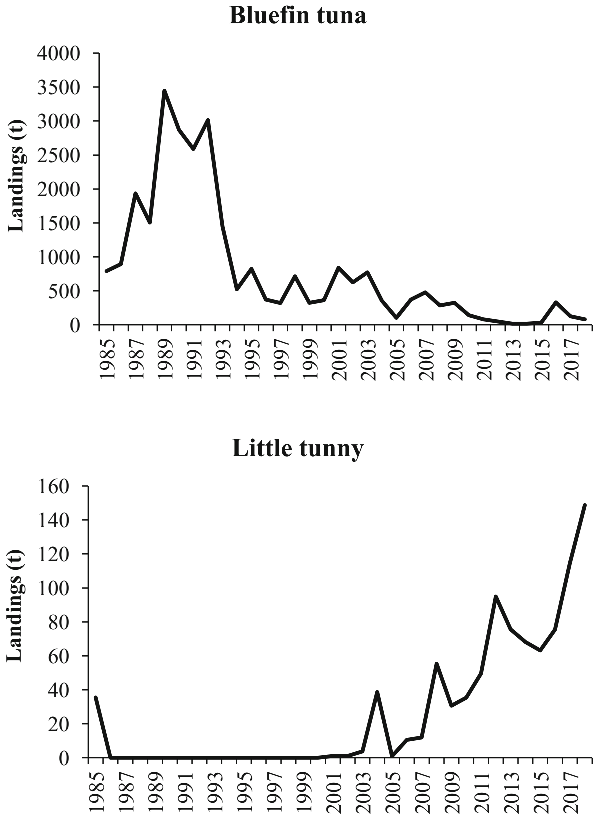


Fig. 17.1 (continued)

17.2 History of the Tuna Fisheries in the Alboran Sea in the Last Century

Bluefin tuna fishery is the most ancient fishing industry in the world (Di Natale 2012a, b, 2018). The bluefin tuna fishery in the area of the Strait of Gibraltar and the Alboran Sea is as old as the first settlers that arrived on the Andalusian coasts. The researcher, Mario Morcillo Moreno (personal communication), suggested that the Atlanterra cave (Zahara de los Atunes, Cádiz) was used since that time as an observatory to detect the arrival of schools of tunas. A solar calendar was found inside the cave showing the exact moment of the sunset on the horizon at the dates of the arrival of tunas. The cave paintings found show that this activity has been done for about 5000 years. In 1791, a Spanish officer published the Historical Dictionary of the National Fishing Arts (Sáñez-Reguart 1791-95), showing the fishing activity and the description of the different tuna traps in the Strait of Gibraltar and Alboran Sea areas, the fishing grounds both at the north and the south of the area. Likewise, the Alboran Sea has been an important fishing area, which is evidenced by

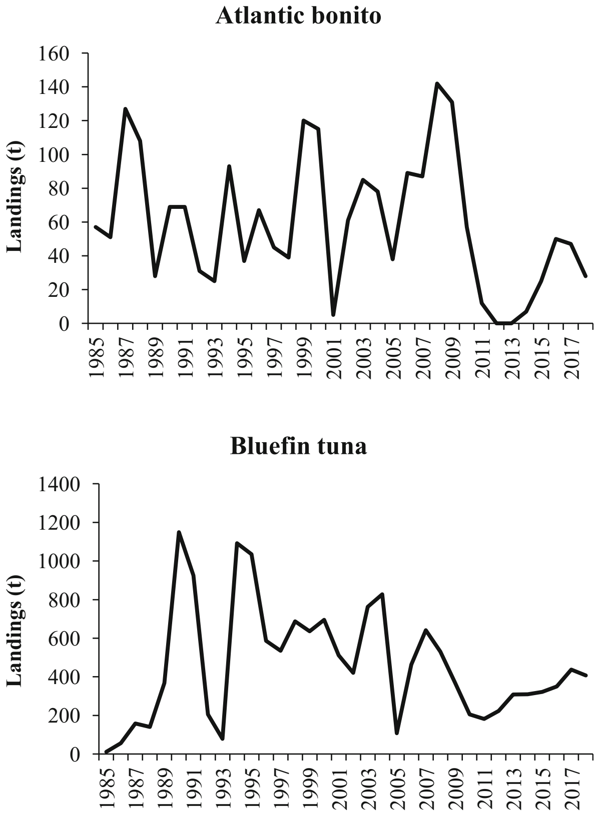
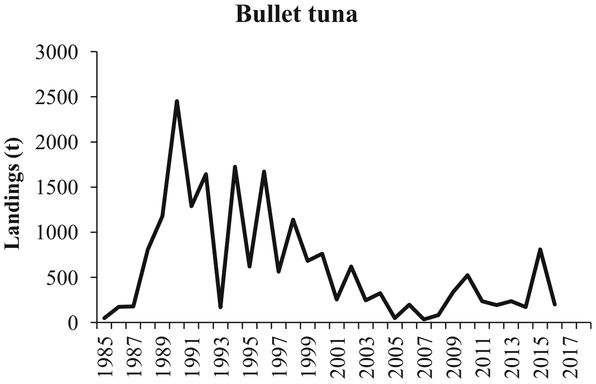


Fig. 17.2 Evolution of the landing (t) trend of the four main target species of tunas and tuna-like species in the South Alboran Sea, in the open sea, are Atlantic bonito (*Sarda sarda*), bullet tuna (*Auxis rochei*), bluefin tuna (*Thunnus thynnus*), and plain bonito (*Orcynopsis unicolor*) during the period 1985–2018. Data sources in ICCAT (2020)

complementary pottery and salting industries' archaeological findings (Muñoz 2012), for tuna species since ancient times (Rodríguez-Roda 1964; Abad 1995).

Currently, the bluefin tuna fishery consists mainly of traditional trap nets (almadrabas), bait boats, and artisanal fisheries, all fish in the continental shelf, although the South Andalusian longliners used a drifting longline targeting bluefin tuna (Camiñas 2006). In addition to the abovementioned traps, a fishing activity, using handline and live bait targeting this species, has been carried out in the Strait of Gibraltar area since 1996, in depths ranging from 500 to 800 m (UNEP-MAP-RAC/SPA 2014; FAO 2018). This handline fishing technique is conducted by the artisanal fleet of Morocco and Spain (Abid et al. 2012, 2014).

Small tunas, bullet tuna, Atlantic bonito, and little tunny are caught by tuna traps and purse seine vessels targeting clupeoids and with artisanal gillnets in the Alboran Sea (Santamaria and Deflorio 2005). In addition, there are several artisanal fisheries (fixed gillnets and small surface longlines) targeting these small tuna species.



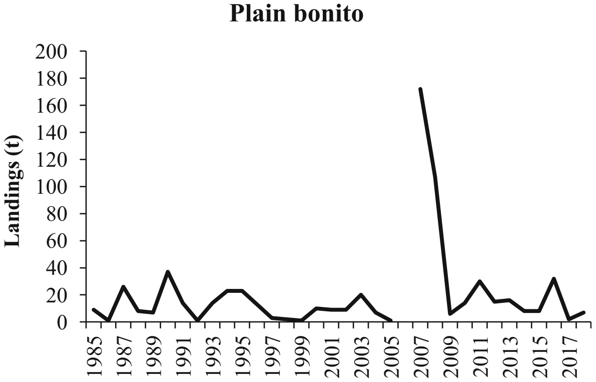


Fig. 17.2 (continued)

Gillnets are used throughout the year due to the large number of target species (Báez et al. 2009; FAO 2018). The "bonitera" is a local gillnet used seasonally, from August to November, during the migration of *Sarda sarda*.

The collapse of the northern European tuna fisheries at the beginning of the 1980s and the sharp fall of catches of the tuna fishing traps led to the end of the Consortium in 1971 (Segundo Ríos 2008; López and Ruiz 2012; Florido 2013; Cort and Abaunza 2015; Florido del Corral et al. 2018; Cort and Abaunza 2019). Although with important fluctuations in production, the traps in the Strait of Gibraltar evolved in the 1980s, thanks to the entry of the Japanese market demanding a high-quality product to the Spanish tuna fishery. The increased demand of local and national market; the establishment of quotas and the strong control of the commercialization implemented by ICCAT, national, and EU fishery administrations; the captures of bluefin tuna under commercial demand; and the use of new fishing gears, as the green stick recently implemented in the strait of Gibraltar by a Spanish company, represent the current reality of the fisheries targeting a very demanded species.

The bluefin tuna fishery and other industrial activities were discussed recently by Cort and Abaunza (2019) in the framework of the crisis of the fisheries of this species in the eastern Atlantic since the 1960s.

Fishing with driftnets targeting bluefin tuna was a former Spanish fishery carried out in the Strait of Gibraltar area that was pointed out as one of the most dangerous to the marine megafauna (Camiñas 1995a, b; Camiñas and de la Serna 1995; Silvani et al. 1999). Nevertheless, even in the twenty-first century, there is an illegal, unreported, and unregulated (IUU) fleet that uses this fishing gear in the Alboran Sea and other parts of the western Mediterranean Sea leading to a permanent conflict with the Spanish longline vessels that operate legally. The former Spanish driftnet fleet had its homeports in the cities of Algeciras, Tarifa, and La Línea de la Concepción, in the Strait of Gibraltar area. This activity started in the close Atlantic Ocean (de la Serna and Alot 1990) but in later years was extended to the Alboran Sea. It is prohibited by the Spanish law since 1990. The tuna reach team of the IEO in Malaga study this fleet, before and after its ban (1989–1993). After it was banned in Spain and until its absolute disappearance, the technology, fishing arts, and artisanal methods were transferred to fishermen of northern Morocco ports, where this driftnet fishery was later developed. The number of vessels based in the Moroccan ports, mainly in Tangiers and Nador, using this fishing gear in the area of the Strait of Gibraltar (Atlantic and Mediterranean areas) targeting swordfish reached almost 400 units. The driftnets were built of rectangular grid layers, with 400 mm mesh size, equipped with a float-line and a lead rope. The common dimensions fluctuate between 2 and 3 Km of total length, joining several units (Camiñas 2006). This fishery was seasonal, beginning in March and extending its activity until November. The choice of the fishing area relied on the availability of the target resource throughout the fishing season. From April and July, the fleet fish mainly westerly of the Strait of Gibraltar. From August to the end of the season, the driftnets were placed mainly in the Alboran Sea. The average duration of a fishing operation was 12 hours, but it could last up to 3 days depending on the abundance of the resource, leaving the gear drifting during that time period.

Another currently banned fishery is the small-scale fishery called “saltillo.” It was a seasonal fishing activity specialized in the capture of bluefin tuna of age class 0 (tunas born in the same year around Balearic islands move in the Iberian Peninsula coast, from southern Catalonia to Cape of Gata, in Andalusia, the eastern limit of the Alboran sea, where the nursery was exploited by artisanal vessels using this ancient gear), born at the end of the summer, when it only has a few hundred grams until it migrates to open waters or out of the Mediterranean Sea. The saltillo consisted of a hook attached to a short line and to a meter-long fishing rod, handled from a boat commonly used by commercial boats or sport fishermen. Fishing was usually facilitated by throwing dead bait, which favored the concentration of juvenile bluefin tuna. In 1985, approximately 420 t of bluefin tuna were captured by this system. ICCAT’s ban on catching tuna of less than 6.4 kg and an exhaustive control ended with that coastal and seasonal fishing activity.

17.3 North Atlantic Oscillation Effect on the Alboran Sea Area

The North Atlantic Oscillation reflects fluctuations in atmospheric pressure at sea level between the Icelandic Low and the High of Azores. The NAO is the most important source of variability, associated with many meteorological variations in the North Atlantic region, affecting wind speed and direction and differences in temperature and rainfall, particularly in winter (Paeth et al. 2003; Báez, Gimeno, et al. 2013; Báez, Macías, et al. 2013; Clark et al. 2017). The NAO index can be positive or negative. It is widely known that the positive phases of NAO induce higher than average westerly winds across northern midlatitudes with a dry climate in the Mediterranean region, while the negative phases of NAO induce major precipitation in southern Europe. The NAO is not the only climatic index correlated with interannual climate variability in the Northern Hemisphere (Hurrell 1995).

The NAO index defined by Sir Gilbert Thomas Walker and Bliss (1932) was the difference of surface pressure between two stations placed at a similar longitude but different latitude, with one placed at high latitudes (Akureyri, Iceland) and the other at middle latitudes (Ponta Delgada, Azores). However, instrumental data is currently avoided, and an estimate based on remote sensing is preferred. However, to improve the instrumental series, the meteorological station of the Rock of Gibraltar was proposed as the southern limit (Jones et al. 1997). This fact helps us understand the importance of the NAO in the climate and meteorological conditions of the Alboran Sea and adjacent areas. Báez et al. (2013) proved that the NAO, in combination with the Arctic Oscillation, a climate oscillation index which represents the state of atmospheric circulation over the Arctic, could affect the oceanographic conditions of the Alboran Sea, with great influence on the upwelling and sea surface temperature (SST). This is due to a combination of factors, such as the orography of the Alboran Sea. Thus, the Alboran Sea is shaped like a small funnel which gradually narrows towards the Atlantic Ocean and widens towards the Mediterranean Sea. The coast is very steep in the north of the Alboran Basin, dominated by mountain ranges such as the Sierra Nevada with high peaks (i.e., Mulhacen and Veleta peaks over 3000 m high), and the Rif in the south, similarly with high peaks (i.e., Mount Tidighin peak with 2455 m). Under favorable weather conditions, these peaks are freshwater reservoirs, being melted in spring and pouring the freshwater into the sea, thus altering the depth of the mixture layer and modifying the oceanography of the Alboran Sea.

It is widely accepted that small pelagic fish, such as anchovy and sardine, and migrating tuna, among other fish resources, respond to large-scale climate oscillations, such as the North Atlantic Oscillation (NAO). Thus, NAO could affect their abundance, recruitment, capturability, and physical condition of fish (Báez et al. 2011; Báez and Real 2011; Báez et al. 2013; Rubio et al. 2016). Nevertheless, there are multiple examples of the effect of the NAO on pelagic, coastal, and demersal ecosystems in the Alboran Sea (Báez et al. 2014; Báez 2016; Fernández et al. 2020).

Therefore, there appears to be a relevant association between the NAO and migrating tuna in the Alboran Sea.

17.4 The NAO and Tuna Fisheries in the Alboran Sea

In the case of migrating tunas in the Alboran Sea, the NAO may have a direct effect on the physical condition of the fish. Thus, Báez et al. (2013) in the case of prereproductive bluefin tuna; Muñoz-Expósito et al. (2017), in the case of bullet tuna; and Báez et al. (2019), in the case of little tunny and Atlantic bonito, have shown the existence of a relationship between an improved physical condition and positive phases of the NAO. Thus, in positive phases of the NAO, the physical condition of fish migrating to spawning grounds in the Mediterranean Sea is improved due to an increase in the prevalence of strong westerly winds, mediated by a positive AO or NAO, favoring the migration by reducing energy costs and by increasing the supply of nutrients (Báez et al. 2013; Muñoz-Expósito et al. 2017). Likewise, this physical condition improvement may lead to a higher gonadosomatic index (GSI) level in reproductive females (Báez et al. 2019).

17.5 Conclusions

NAO index plays a fundamental role in the biology of migrating tunas in the Alboran Sea, both improving the physical condition and reproductive potential. Thus, thanks to better climate conditions during pre-spawning migration, females can use more energy resources for reproduction, thereby improving the gonadosomatic index (GSI) levels. Moreover, recent studies show that a higher GSI female level increases larvae survival of some tuna species (Reglero et al. 2018; Hiraoka et al. 2019).

Currently, there are evidences of an abrupt global warming, an expected effect of climate change, and most likely leading to extreme climate oscillations. Extreme phases of short-term climate oscillations, such as the NAO, can lead to rapid and sudden weather responses including floods and droughts and extreme temperatures such as heat and cold waves (Vicente-Serrano et al. 2011). This combination of extreme phases could have adverse effects on the biology of migrating tunas, in such a way that it could affect reproductive success and therefore recruitment.

Finally, it is important to stress that climate oscillations may also have great effects on catchability and first sale price variability of fish, as recently shown by Fernández et al. (2020).

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Chapter 18
Demersal Resources

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18.1 Introduction

Fishery in the Mediterranean has been around for centuries, so the current fishery model is the result of this long history, and not only the result of a specific management policy. Several Greek and Latin authors attest to fishing activities in the Mediterranean, among which the works of Aristotle and Pliny should be highlighted. For example, Pliny dedicates the Book IX of his *Natural History* to aquatic animals and to describe the places where fishing was exercised using the concurrence of dolphins (Camiñas et al. 2004). As for the Alboran Sea, numerous salsary piles, created in Roman times to make garum, have been found around the coast (Camiñas et al. 2004). Technological progress and new techniques developed over centuries have gradually increased the fishery capacity of coastal peoples, but the expansion in the use of engine 100 years ago saw a significant increase in fishery pressure, with serious consequences for the state of the resources (Lleonart 2011).

Total landings in the Mediterranean and the Black Sea increased irregularly from about 1 million tons in 1970 to almost 2 million tons in 1982. They remained relatively stable during most of the 1980s before declining abruptly in 1989 and 1990, largely due to the collapse of pelagic fisheries in the Black Sea. In the Mediterranean, landings continued to increase until 1994, reaching 1,087,000 tons, and subsequently declined irregularly to 787,000 in 2013 (Fig. 18.1). Algeria, Greece, Italy, Spain, Tunisia, Turkey, and Ukraine are together responsible for slightly more than 80 percent of total landings in the Mediterranean and the Black Sea (FAO 2016).

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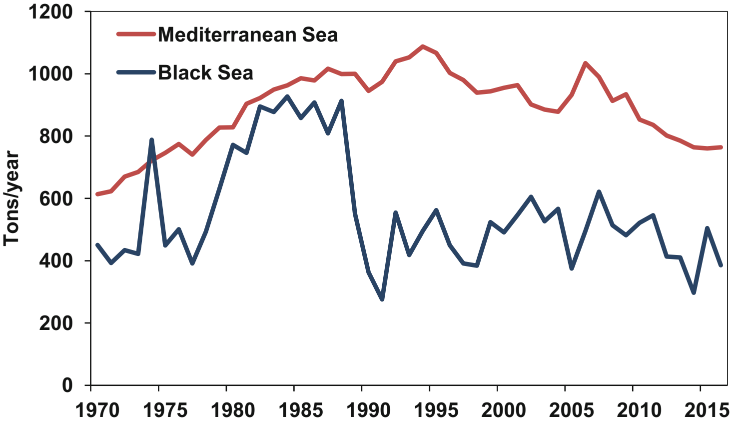

Fig. 18.1 Time series of official landings for the Mediterranean and Black Sea. Data source: FAO-GFCM (General Fisheries Commission for the Mediterranean Sea) Capture Fisheries Dataset (2019)

Despite these figures, Mediterranean fisheries only account for a small proportion of world production (some 80 million tons). However, the average prices of landings (which are mainly sold fresh) are above the average prices of world markets, and from a socioeconomic point of view, fishing activities in the Mediterranean employ a large number of people. Fishing in the Mediterranean is very diverse and varies geographically, not only because of the existence of different marine environments but also because of different socioeconomic situations. They are characterized by certain distinct features, like high diversity of the catches, high number of marketable and not marketable species, absence of large single stocks, and small-scale vessels (Damalas 2017).

Mediterranean and Black Sea waters are divided into 30 geographical subareas (GSAs), established in 2009 by the GFCM to compile data, monitor fisheries, and assess fisheries in a georeferenced manner. Therefore, from the fishery point of view, the Alboran Sea includes GSAs 01 (Northern Alboran Sea), 02 (Alboran Island), and 03 (Southern Alboran Sea). Spanish fleet operates in GSAs 01 and 02 (Fig. 18.2).

The fishing area of the Northern Alboran Sea is characterized by a very narrow shelf affected by several shelf-indenting canyons (Durán et al. 2018). Due to its oceanographic and ecological importance, with the confluence of Atlantic and Mediterranean masses, this sea supports a great marine biodiversity (García-Raso et al. 2010; Templado 2011), including a large number of commercial species. A wide variety of fishing techniques have been developed, of which bottom trawling is one of the most widely used and is responsible for the largest catches of demersal species in the area (Camiñas et al. 2004). The target species of bottom trawlers are mainly European hake, mullets, octopus, and shrimps. However, catches are composed of a large number of species (Gil de Sola 1993).

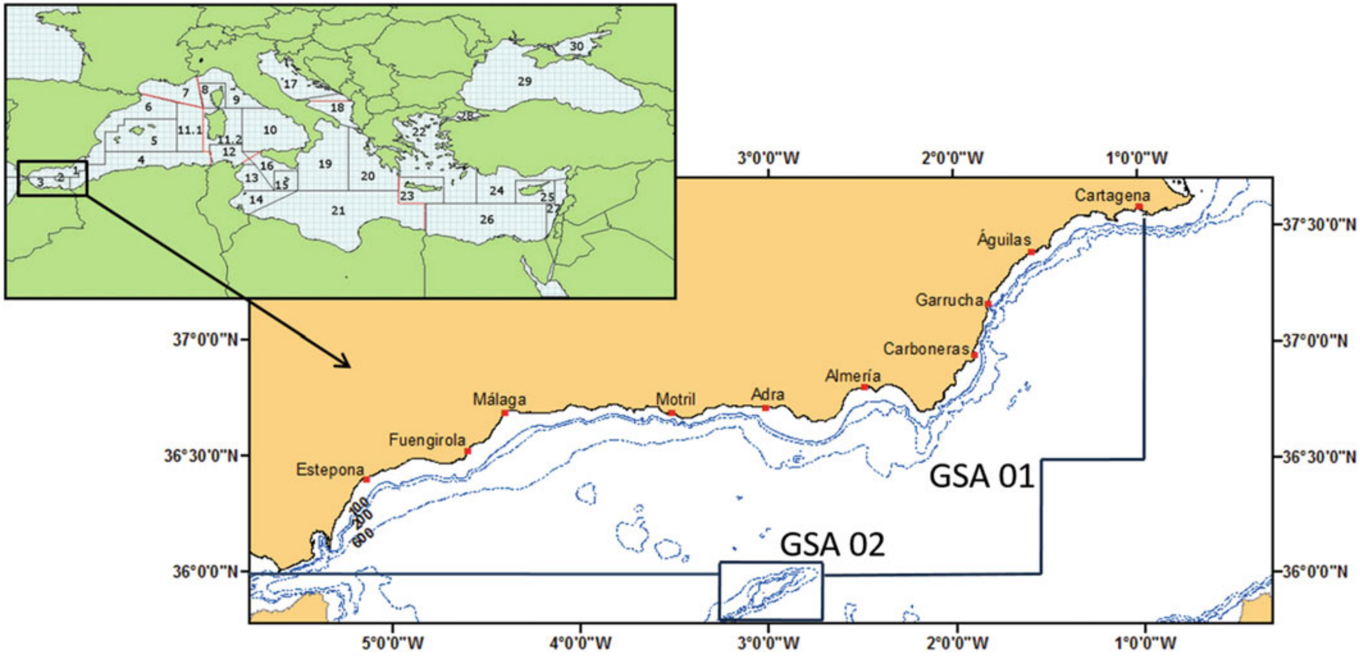

Fig. 18.2 FAO-GFCM geographical subareas in the Mediterranean Sea (green map). In detail, GSAs of the Alboran Sea where the Spanish fleet operates, with main ports

18.2 Material and Methods

The fundamental source of information scrutinized in this chapter was collected in the context of the activities of the data collection framework (DCF), carried out from 2002 to the present in the Spanish Mediterranean, both from the commercial fishery and through an experimental survey carried out in spring, from 1994, to evaluate the demersal resources (MEDITS, Mediterranean International Trawl Survey).

18.2.1 Sampling of Commercial Fishery

Sampling staff are dispersed at several locations around the coast to reduce traveling time. In general the different fisheries (otter trawls, purse seines, artisanal fleet, etc.) are widely distributed along the coast. There is a complete vessel registry and census data for landings, effort, gear, etc. as required by EU logbooks and sales notes.

The sampling design in the area is done at the metier level, for those metiers selected by the ranking system, as stated in the GFCM-DCRF Regulation (GFCM 2018a). The design has been done taking into account the representativeness of the data to collect with relation to the population (catches from the commercial fleet), considering that these data should be obtained cost-effectively, and the information obtained can be used to estimate the population characteristics of interest precisely (low variability) and accurately (unbiased). For the proposed sampling schemes, it is possible to calculate estimates of the precision of the estimators of the population parameters.

Both, for at-sea sampling and on-shore sampling, four different strata areas are considered: GSA, metier, selected ports, and time frame. For each GSA, metiers are non-probabilistic selected based on the rules of the regional RFMO (GFCM). For each combination of GSA-metier, the ports to sample have previously been selected according to previous knowledge which include their importance for each metier (both in terms of biomass landed and effort as the number of vessels) as well as their availability to carry out the sampling (both predisposition and adequate facilities). Finally, the time frame (quarter or month) is set to force the sampling to cover the entire year.

For the collection of individual information in order to estimate age, maturity, sex ratio, and weight of the main species, a number of individuals by length class every period (month, quarter, or year) will be selected.

The estimation of the biological parameters and their uncertainties will be carried out using the tool INBIO 2.0 ("Estimation of biological parameters and their uncertainties through simulation techniques"), developed in R environment by the IEO. INBIO makes it possible to fit the most usual models and to estimate the coefficient of variation for parameters by using the nonparametric bootstrap methodology.

18.2.2 MEDITS Survey

The data from the MEDITS Survey (Bertrand et al. 2002) are obtained from a total of 25 bottom trawl surveys carried out during the spring of 1994 to 2018. The covered area was between 30 and 800 m depth (in GSA 02, between 150 and 800 m). The randomized stratified sampling design defined five bathymetric strata: 30–50 m, 51–100 m, 101–200 m, 201–500 m, and 501–800 m. Haul duration varied according to depth: 30 min at depths above 200 m and 60 min below 200 m. All the surveys were carried out with the same otter bottom trawler (GOC-73) using a net with a cod mesh size of 20 mm. The mean towing speed of the vessels was 3.0 knots. The values of the vertical and horizontal opening of the gear were monitored by a SCANMAR trawl sensor device. For each sampling station, all specimens were sorted, identified, counted, and weighed on board. In this chapter, the mean abundance (num.individuals/km2) and biomass (kg/km2) of the main target species of bottom trawl fishery were calculated per year. Also, length data for these species (mean values±standard error, mode, and size range) were calculated throughout the 25 trawl surveys. Distribution maps of the species comprise data from the last year of the MEDITS survey (from 2012 to 2018).

18.3 Fishing Fleet and Main Ports

The total fishing fleet in GSA01 and GSA02 accounts for a total of 645 vessels. The fleet is composed mainly of artisanal vessels between 6 and 12 m of overall length and trawlers and purse seiners between 18 and 24 m of overall length (Table 18.1).

The number of vessels in this area has been continuously decreasing in the last decades, from more than 1045 vessels in 2004 to 645 in 2017. The biggest reductions have taken place in the set longliners, purse seiners, and bottom trawlers (Fig. 18.3).

The fleet is distributed in 14 ports along the coast. As concerns the number of vessels, the main harbors in GSA 01 are Almeria, Vélez-Malaga, Algeciras, and Estepona. In general terms, the small-scale fleet seems to decrease from the west to the east (Table 18.2).

On the other hand, bottom otter trawl is the second fleet in the number of vessels with respect to the other fishing modalities developed in the area (Table 18.2), being the biggest in tonnage and power (Table 18.1). Also it is the second fleet in landings (the first one of the demersal fisheries) and the first fleet in economic value of the landings (Fig. 18.4).

This chapter focuses on the bottom otter trawl fishery both for its importance in demersal fisheries (Sánchez et al. 2004) and for the existence of other chapters dedicated to artisanal, purse seine, and longline fisheries.

Table 18.1 Characteristics of the Spanish fishing fleet that currently operates in GSAs 01 and 02 by fishery, showing average values (± standard deviation) of capacity (gross tonnage: GT), length (overall length: LOA), and engine power (horsepower: HP)

Fisheries	Length (m)	Vessels	GT	LOA	HP
Small scale	<6	47	0.89 ± 0.28	5.29 ± 0.61	15.64 ± 8.54
	6–12	338	2.95 ± 1.83	8.23 ± 1.40	35.59 ± 20.19
	12–18	20	11.31 ± 5.87	13.20 ± 1.15	92.05 ± 41.12
	18–24	–	–	–	–
	24–40	1	91.07	24.50	350.00
	Total	**406**	**3.34 ± 5.23**	**8.18 ± 2.15**	**37.23 ± 29.79**
Otter bottom trawl	6–12	4	6.73 ± 3.25	9.39 ± 0.88	48.50 ± 30.61
	12–18	35	24.89 ± 11.17	15.63 ± 1.43	111.85 ± 45.00
	18–24	58	64.83 ± 22.39	20.85 ± 1.80	200.79 ± 107.33
	24–40	13	100.18 ± 16.51	24.65 ± 0.52	298.85 ± 96.97
	Total	**110**	**54.19** ± 31.66	**19.23** ± 3.87	**178.54** ± 108.42
Purse seine	06–12	11	6.26 ± 2.67	9.85 ± 1.32	59.82 ± 25.81
	12–18	37	22.49 ± 10.91	15.77 ± 1.64	144.27 ± 60.69
	18–24	30	51.40 ± 15.96	20.48 ± 1.86	261.60 ± 87.86
	Total	**78**	**31.32** ± 20.90	**16.75** ± 3.93	**177.49** ± 99.90
Set longline	06–12	2	6.88 ± 1.94	10.20 ± 1.55	107.03 ± 7.11
	12–18	2	10.85 ± 5.80	13.5 ± 1.41	166.00 ± 124.45
	Total	**4**	**8.87** ± 4.21	**11.85** ± 2.26	**136.51** ± 79.61
Drifting longline	06–12	3	4.02 ± 2.76	11.23 ± 1.06	75.00 ± 58.95
	12–18	23	30.53 ± 24.56	15.06 ± 1.49	111.06 ± 33.22
	18–24	17	92.07 ± 25.79	21.61 ± 1.31	221.94 ± 96.82
	24–40	4	125.79 ± 24.90	24.94 ± 0.65	370.50 ± 74.75
	Total	**47**	**59.21** ± 44.21	**18.02** ± 4.25	**167.38** ± 103.74
Total		**645**	**19.50** ± 29.69	**11.84** ± 5.66	**89.53** ± 95.55

Data source: Spanish Fleet Register of the Secretary of Fishing (December 2017)

18.4 Trawl Fishery

The gear used is bottom otter trawl nets (in the Spanish Mediterranean, fishing with pelagic trawl nets is forbidden), which present a continuous evolution and a great variety of shapes according to the localities, vessels, and target species (Gil de Sola 1993).

Trawlers (Fig. 18.5) are distributed along the coast. The number of vessels is not related to the size of the town (Table 18.2), but it seems to depend on other variables, like tradition, activity of the port, or distance to the fishing grounds. The activity of this fleet is subject to the European Union national and regional regulations. The main measures are related to the minimum working depth (50 m), duration of fishing trips per day (12 hours) and maximum of fishing days per week (5 days), spatio-temporal closures to fishing, minimum mesh size in the cod end of the net (40 mm

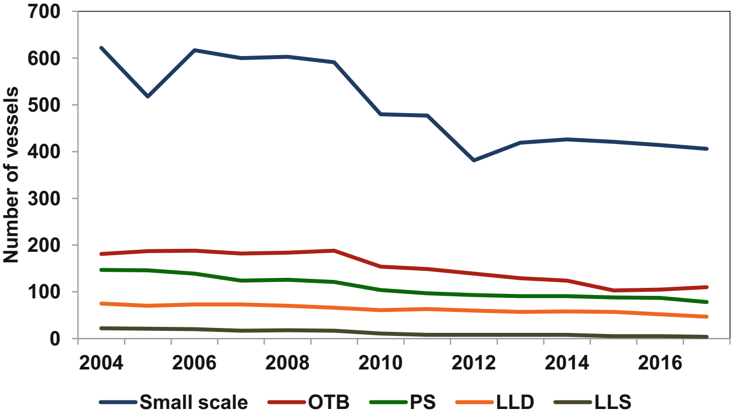

Fig. 18.3 Evolution of the number of vessels in GSA 01. *OTB* bottom otter trawl; small scale, small-scale fleet; *PS* purse seine; *LLS* set longline; *LLD* drifting longline

Table 18.2 Distribution of fleets in the main ports of GSA 01. Ports are ordered from western to eastern

Port	Trawlers	Small scale	Purse seine	Set longline	Drifting longline
Algeciras		68	1	2	2
Estepona	6	51	5		
Marbella	4	25	8		
Fuengirola	8	30	2		
Vélez-Málaga	18	42	15		
Motril	13	17	2	1	1
Adra	1	16	7		1
Roquetas de Mar		8	2		6
Almería	27	40	11		2
Carboneras	4	14	4	1	31
Garrucha	8	16			1
Águilas	9	19	3		
Mazarrón	5	14	11		
Cartagena	7	24	2		3
Total	110	406	78	4	47

Source of data: Spanish Ministry Fleet Register (January 2018). In black, ports of the Alboran Sea sensu stricto. In red, ports of the Gulf of Vera

square or 50 mm diamond meshes of 3 mm twine thickness), and maximum engine power (500 HP). Sometimes part of these measures, like the maximum engine power, is not followed by all fishermen, increasing the fishing power and causing, in the end, overfishing of resources and the ecosystems.

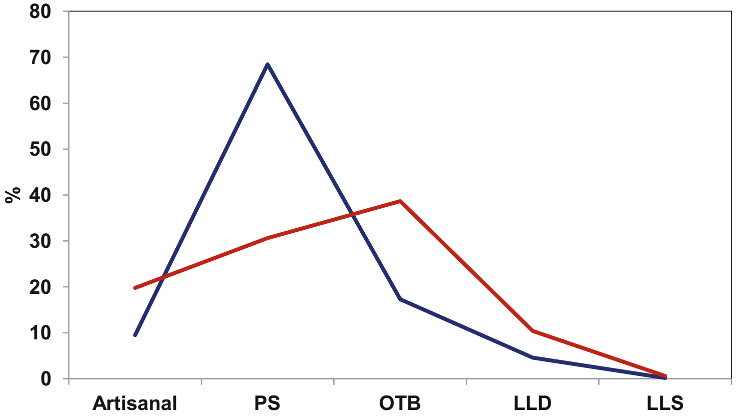

Fig. 18.4 Percentage of landings (blue) and value of landings (red) in the fleets of GSA 01. Source of data: 2017 sale notes. *OTB* bottom otter trawl; artisanal, artisanal fleet; *PS* purse seine; *LLS* set longline; *LLD* drifting longline

Fig. 18.5 Spanish bottom otter trawl operating in the Alboran waters

18.4.1 Metiers of the Bottom Trawl Fleet

One of the most commonly used terms in the description and management of fisheries is the metier (Punzón et al. 2010). A metier is a group of fishing operations targeting a similar assemblage of species, using similar gear, during the same period of the year and/or within the same area and which are characterized by a similar exploitation pattern (Commission Decision (EU) 2016/1251). In the Mediterranean, two main metier have been defined in the bottom otter trawl fishery (Commission Decision (EU) 2016/1251): bottom otter trawl targeting demersal species and bottom otter trawl targeting deepwater species. The main characteristics of the two metiers in the Alboran Sea where the Spanish fleet operates are described down below:

18.4.1.1 GSA01 (Northern Alboran Sea)

Bottom Otter Trawl Targeting Demersal Species (OTB_DEF)

European hake (*Merluccius merluccius*), deepwater rose shrimp (*Parapenaeus longirostris*), red mullet (*Mullus barbatus*), stripped red mullet (*Mullus surmuletus*), Norway lobster (*Nephrops norvegicus*), and common octopus (*Octopus vulgaris*) are the most commercially valuable species in the area and are an important component of a species assemblage that is the target of the bottom trawling fleets operating near the shore (Fig. 18.6).

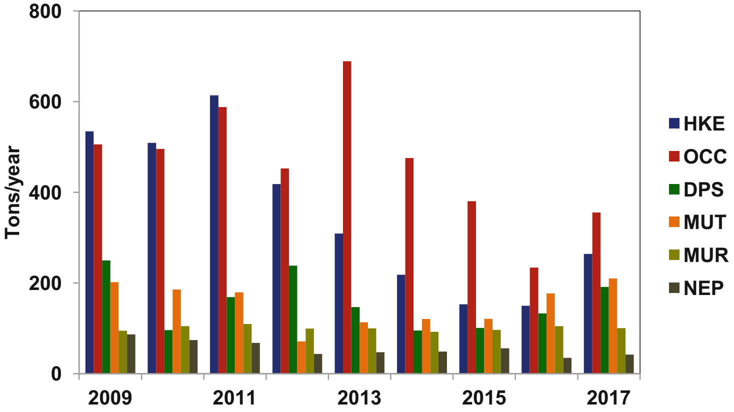

Fig. 18.6 Main species landings (tons) of trawlers targeting demersal species. GSA 01. HKE, *M. merluccius*; OCC, *O. vulgaris*; DPS, *P. longirostris*; MUT, *M. barbatus*; MUR, *M. surmuletus*; NEP, *N. norvegicus*

European hake is one of the target demersal species of the Mediterranean fishing fleets, largely exploited in GSA 01 mainly by trawlers (95% landings) on the shelf and slope and by small-scale fisheries using gillnets or set longlines on the shelf.

Bottom Otter Trawl Targeting Deepwater Species (OTB_DWS)

The blue and red shrimp (*Aristeus antennatus*) is the most important resource of slope bottom trawling in GSA 01 and is targeted by the largest vessels of the deepwater trawl fleet segment. A total of 49 vessels (average 2011–2013) had fishing activities directed towards this species in GSA 01 fishing grounds. The most important landings port in 2017 was Garrucha with 34 tons landed, followed by Almeria (22.5 t) and Aguilas (11 t). The pattern of this fishery can be considered monospecific, where the discard is practically zero for this species. The bycatch is composed of anglerfishes (*Lophius budegassa* and *L. piscatorius*) and European hake (Fig. 18.7).

18.4.1.2 GSA02 (Alboran Island)

In GSA 02, only the bottom trawl operates, mainly in the middle slope, targeting blue and red shrimp. In this GSA, fishing trips last for 4–5 days, in contrast to the rest of the western Mediterranean, where fishing trips for trawlers only last for a single day. The main base port of this fleet is Almeria, and the fishing period goes from May to October. The number of vessels operating in this area is variable because of weather conditions, and it ranges from 1 in April to 13 in August, the month with

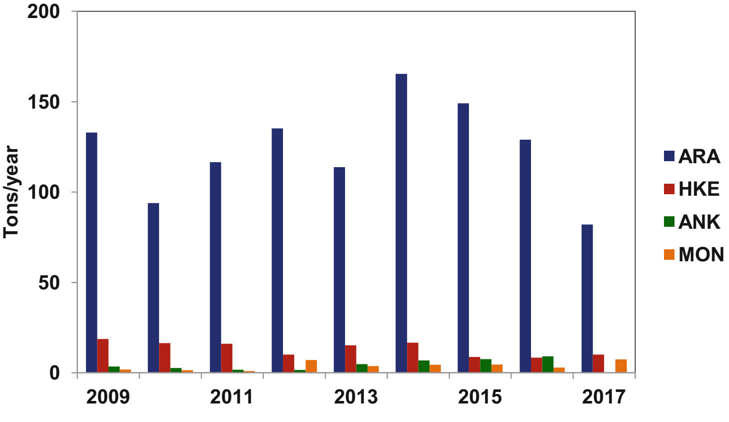

Fig. 18.7 Main species landings (tons) of trawlers targeting deepwater species. GSA 01 (ARA, *A. antennatus*; HKE, *M. merluccius*; ANK, *L. budegassa*; MON, *L. piscatorius*)

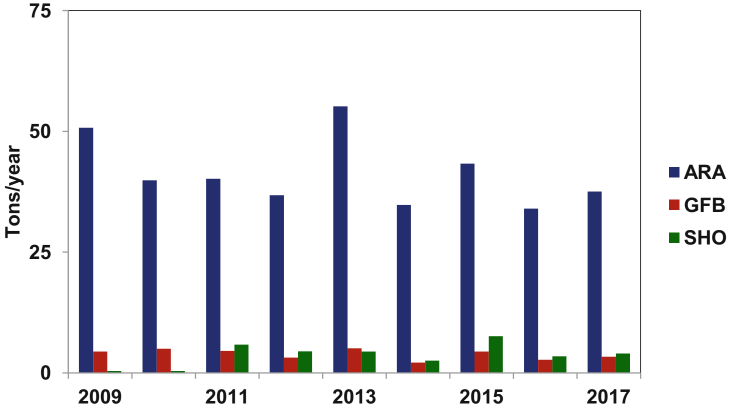

Fig. 18.8 Main species landings (tons) of trawlers targeting deepwater species. GSA 02. ARA, *A. antennatus*; GFB, *P. blennoides*; SHO, *G. melastomus*)

more fishing effort. Bycatch is composed mainly of greater forkbeard (*Phycis blennoides*) and blackmouth catshark (*Galeus melastomus*) (Fig. 18.8).

18.5 Target Species

Despite its multi-specific nature, the target species of bottom trawlers are mainly the crustaceans *Aristeus antennatus* and *Parapenaeus longirostris*; the cephalopod *Octopus vulgaris*; and the fishes *Merluccius merluccius* and *Mullus barbatus*.

18.5.1 Aristeus antennatus *("Blue and Red Shrimp")*

Aristeus antennatus (Risso, 1816) (Fig. 18.9) is an eurybathic species. It is widely distributed throughout the Mediterranean Sea, as well as in the Atlantic Ocean, from southern Portugal to the Green Cape Islands (Holthuis 1980). It is the only species of the genus *Aristeus* present in the Mediterranean Sea, where it has a wide distribution with the exception of the Adriatic and Aegean Sea where the bathymetric characteristics of them limit their presence (Holthuis 1987). It is a demersal species characteristic of the muddy bottoms of the continental slope and is characterized by a wide bathymetric distribution ranging between 80 and 3300 m (Sardà et al. 2003, 2004).

This species makes important migration, both of circadian, spatial, and seasonal character (Cartes 1993; Demestre and Martin 1993; Sardà 1993; Sardà et al. 1994, 1997; Mura and Cau 1994). In adult populations, these migrations are related to reproductive processes and habitat use. It has also been found that several

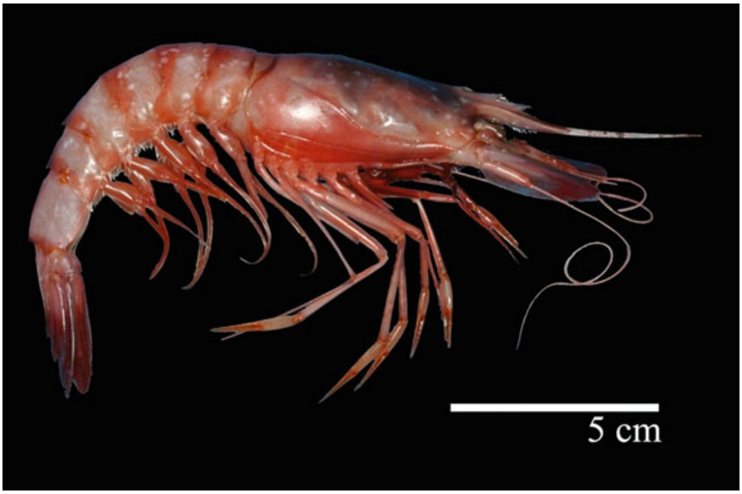

Fig. 18.9 *Aristeus antennatus* (adult female) (source IEO)

characteristics, such as the mean size of individuals, female maturity stages, and sex ratio, varied according to the spatial location (Sardà et al. 1997, 2003; Demestre 2003; Tudela et al. 2003; Cartes et al. 2018).

Sexual dimorphism is a dominant condition between species of crustaceans. The females of *A. antennatus* are larger than the males (Sardá and Demestre 1987), and the rostrum is short in adult males and long in juveniles and adult females (Sardá and Demestre 1989) (Fig. 18.10). It is estimated that they have longevity between 5 and 7 years for females and 3 and 5 years for males (Carbonell et al. 1999). The reproductive period starting at the end of the spring and lasting through the summer, with the greatest intensity in the months of June to September (Sardá and Demestre 1987; García-Rodríguez and Esteban 1999). There is variability in the size of the first maturity described in the bibliography in response to the geographic area, where the study has been conducted, fluctuating it in a range between 18.1 mm and 26.0 mm for males and 21.9 mm and 31.8 mm for females (García-Rodríguez and Esteban 1999; Carbonell et al. 1999).

It began to be exploited on the Mediterranean coasts of Spain in the decade of the 1940s of the last century. Studies on its biology and fisheries began to develop from the 1960s (Bas 1960, 1965, 1966, 1967; Massutí 1961, 1973, 1975). Studies on the biology and population dynamics are abundant on the coasts of the Spanish Mediterranean Sea, with the exception of Alboran Sea: e.g., Catalan coast (Demestre and Martin 1993; Demestre and Lleonart 1993; Sardà et al. 1994), Balearic Islands (Carbonell et al. 1999; Guijarro et al. 2008), Ibiza channel (García-Rodríguez and Esteban 1999), and Alicante gulf (García-Rodríguez 2003).

Aristeus antennatus is one of the main target species of Mediterranean deepwater trawling (Demestre and Martin 1993; Carbonell et al. 1999; Mouffok et al. 2008), and its fishing has certain characteristics which differentiate it considerably from

Fig. 18.10 Morphological rostral types of *Aristeus antennatus* (source IEO)

other Mediterranean bottom trawling fisheries. It can be considered as a monoespecific fishery (Demestre and Martin 1993); it is very lucrative, due to the high commercial value of the product, and it is performed at depths where the abundance of other commercial species is very low, since the majority of the catch is blue-red shrimp (Fig. 18.11). It does not usually contribute more than 5% of the landings by weight; it can amount to 50% of the landings by value in some ports. The fishing involves high risks as it is conducted in deep waters, and commercial trawling catches are made on the continental slope depths of 350 to 850 m (Carbonell et al. 2000), on grounds where the continental shelf and slope form submarine canyons (Sardà et al. 1994, 1997; Tudela et al. 2003). Rose shrimp abundance is higher on the slope in spring and summer (Sardà et al. 1997).

Fig. 18.11 Catches of blue-red shrimp obtained by a trawler (source IEO)

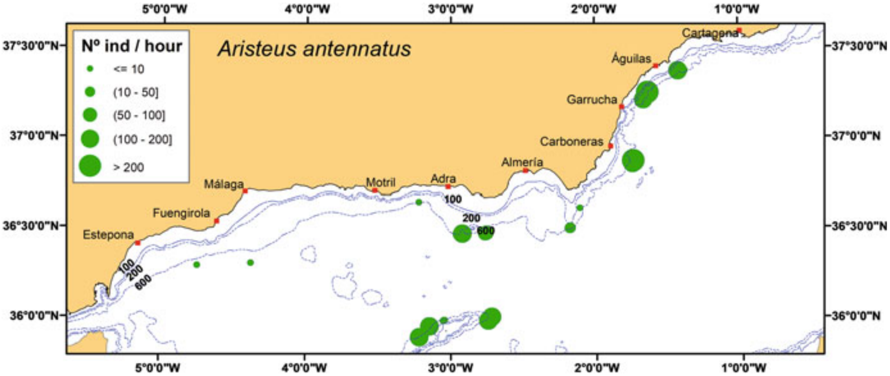

Fig. 18.12 MEDITS indices of abundance (individuals/hour) of *Aristeus antennatus* in GSA 01 and GSA 02, from 2012 to 2018

During the MEDITS surveys, the species was caught on the upper and middle slope between 414 and 786 m depth (Fig. 18.12), being more abundant at 600–800 m. For males, sizes range from 2 mm to 40 mm carapace length (CL), mean values are 25 (± 3.8 SD) mm CL, and the most common size is 25 mm CL; for

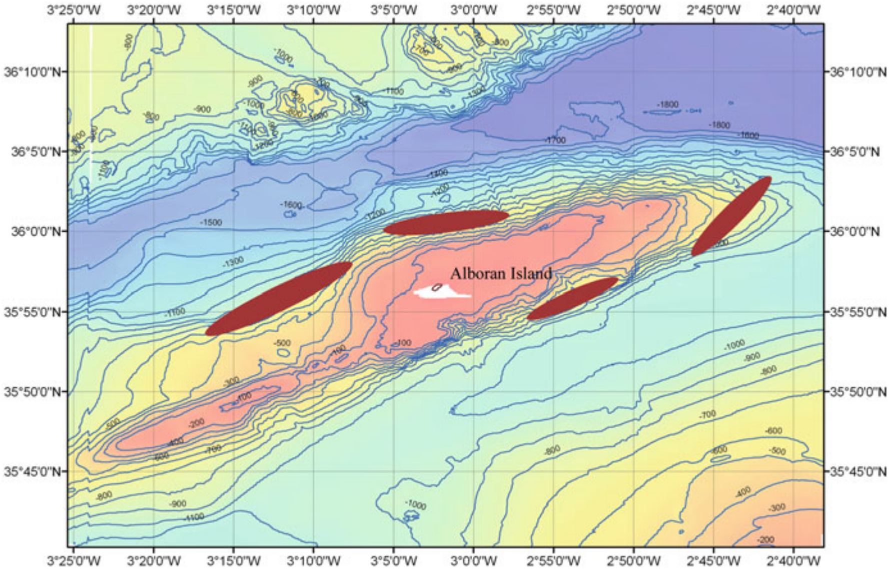

Fig. 18.13 *Aristeus antennatus* fishing grounds in the Alboran Island (GSA02)

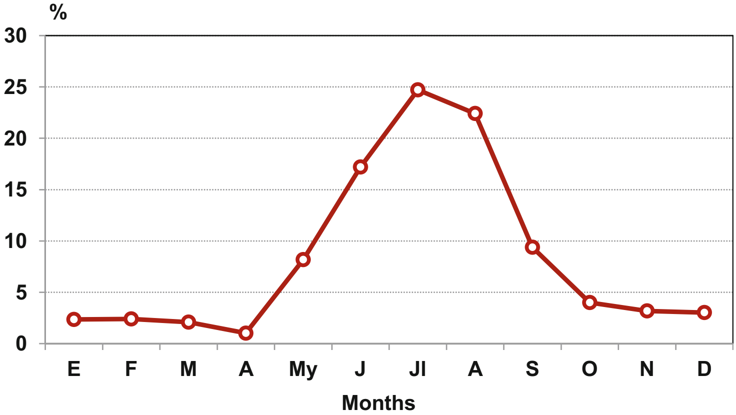

Fig. 18.14 Monthly catches of *Aristeus antennatus* in the Alboran Island (GSA02)

females, sizes range from 14 mm to 63 mm CL; mean values are 36 (± 8.2SD) mm, and the most common size is 35 mm CL.

The most important fishing grounds in the Alboran Sea are located in the vicinity of the Alboran Island (Fig. 18.13). According to Spanish regulation, trawlers can operate in the Alboran Island between 100 and 1000 m depth. The maximum duration of fishing trips is 10 days. The number of vessels authorized in the fishing grounds is currently 51, most of them >24 m length. The highest fishing activity of this fleet is carried out between May and September, and the monthly catch

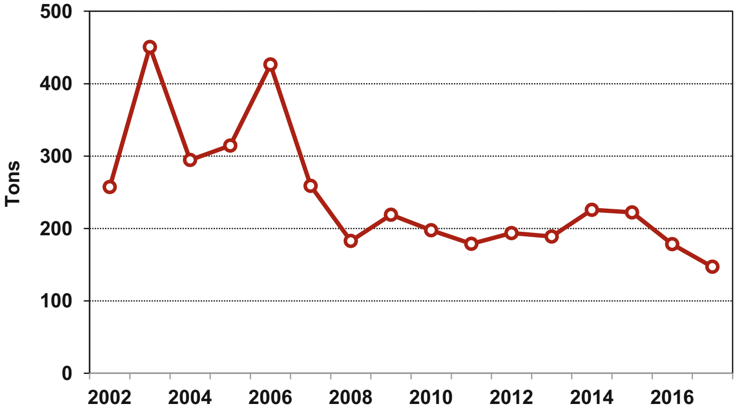

Fig. 18.15 *Aristeus antennatus* annual landings (in tons) by trawl fishery through historical series analyzed (2002–2017) in the Alboran Sea (GSA01-GSA02)

(Fig. 18.14) closely followed this pattern. A total of 35% of the landings from the fishing grounds of the island were red shrimp, while the landings coming from the fishing grounds closest to the peninsula only accounted for 5%.

The annual landings in the whole area (GSA01 and GSA02), over the period of the data series (2002–2017), have shown several oscillations, ranging between the maximum value of 451 t in 2003 and minimum value of 147 t in 2017. A large decrease in catches took place in 2007 and 2008 (Fig. 18.15). Landing sizes ranged between 14 and 66 mm CL, the mean value was 32.3 (± 8.0 SD) mm, and the most common size was 28 mm.

Following the results of the WGSAD (Working Group on Stock Assessment) GFCM carried out in 2018, the exploitation of *A. antennatus* in GSA 01 and GSA 02 shows a similar pattern. However in GSA 02, the stock status shows a low overexploitation situation, while in GSA 01, the stock status shows a high overexploitation (GFCM 2018b).

18.5.2 Parapenaeus longirostris *("Deepwater Pink Shrimp")*

Parapenaeus longirostris (Lucas, 1846) (Fig. 18.16) is one of the most important commercial crustaceans in the Mediterranean Sea, especially for the trawl fishery throughout its distribution range.

It is a demersal species found on sandy and sandy-muddy bottoms in the Mediterranean Sea as well as in the eastern and western Atlantic Ocean, from Portugal to Namibia and from Massachusetts to Venezuela, respectively (Zariquiey 1968). In the Mediterranean Sea, the species shows a wide bathymetric distribution, occurring from 20 to 750 m being more abundant at depths between 100 and 200 m (García-Rodríguez et al. 2009; Guijarro et al. 2009) and in the eastern and central

Fig. 18.16 *Parapeaneus logirostris* (source: IEO)

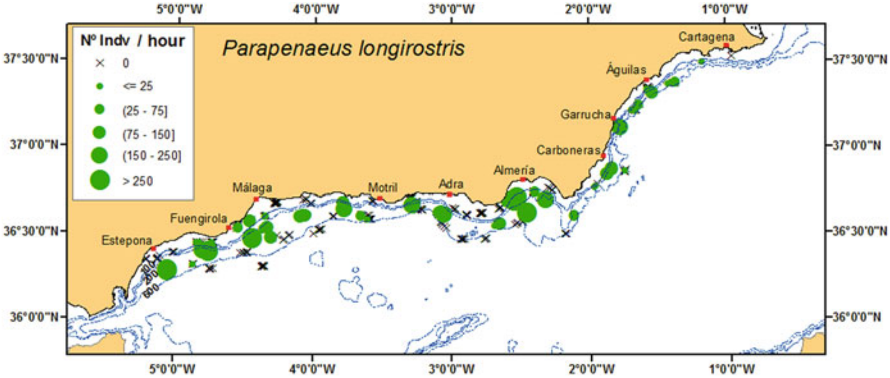

Fig. 18.17 MEDITS indices of abundance (individuals/hour) of *Parapenaeus longirostris* in GSA 01, from 2012 to 2018

basins than in the western basin. Biomass is higher between 200 and 400 m depth with a marked size-dependent distribution by depth: small individuals are found at the edge of the continental shelf while larger individuals are distributed in deeper waters (Abelló et al. 2002). In addition, some authors suggest that adults move during the spawning period to shallower waters, where the occurrence of larvae has been detected (Dos Santos 1998). In the Northern Alboran Sea, one of the most representative species on the upper continental slope (200–500 m depth) is *Plesionika heterocarpus* and *Solenocera membranacea* (Ciércoles et al. 2018).

During the MEDITS surveys carried out in GSA 01, species was caught between 50 and 700 m depth, but its abundance drops considerably below 400 m. It is distributed throughout the entire study area (Fig. 18.17). Size ranges between

3 and 41 mm CL in GSA 01; mean values are 23.8 (±5.0 SD) mm CL, common between 23 and 24 mm. Female sizes range between 5 and 41 mm CL, and mean values are 24.9 mm CL((±5.9 SD) common between 26 and 27 CL. Male sizes range between 3 and 40 CL, mean values are 22.6(±3.6 SD), and common values are 23 mm CL.

Parapenaeus longirostris is an epibenthic short-lived species characterized by higher rates of growth and mortality (Abelló et al. 2002). Continuous spawning is common both in the Mediterranean Sea and the Atlantic Ocean, with peaks of reproductive activity varying between areas without a clear trend. In the Balearic Islands, although maturing females were found all year round, two peaks were detected, one in November and a larger one in August and June (Guijarro et al. 2009). In the Gulf of Alicante, spawning can take place throughout the year too, with massive events at some points in the year, especially in spring, summer, and fall, being the most important summer (García-Rodríguez et al. 2009). According to these authors, those events can fluctuate, advancing or delaying slightly as a function of the oceanographic conditions of the year and the area studied. The size at first maturity of 25.6 mm for females in this adjacent area indicates that maturation will have to occur from the second year of life. The species shows a sexual size dimorphism, with a negative allometry of relative growth that is more pronounced in males and thus results in lower sizes of males than of females. Estimates gave higher K values for males than for females, indicating that males would reach 13.2 mm CL in the first year and females 14.8 mm CL, which would represent a maximum life expectancy of 4 and 6 years, respectively (García-Rodríguez et al. 2009).

According to the trophic guild classification from Cartes et al. (2002), *P. longirostris* is an infaunal feeder. The species displays a highly diversified diet and consumes a broad range of prey items (Cartes 1995; Kapiris 2004). In the western Mediterranean Sea, Cartes (1995) reported that *P. longirostris* had highly diversified diets based mainly on benthic organisms (polychaetes, bivalves, gastropods, and echinoderms), suprabenthic organisms (mainly gammarid amphipods), and a small proportion of pelagic organisms.

P. longirostris is one of the main crustacean species for trawl fisheries in GSA 01. It is an important component of landings in some ports and occasionally a target species of the trawl fleet targeting demersal species operates on the upper slope (GFCM 2018b). The annual landings in this area fluctuated during the all assessed series and increased in the last 3 years reaching up 201 t in 2017 with two peaks during 2009 and 2012 (Fig. 18.18). Landing sizes ranged between 10 and 49 mm with a maximum around 22–23 mm CL. The mean of landings sizes is 24.4 (±4.5 SD) mm CL.

Abundance and biomass indices from fishery-independent survey MEDITS (Fig. 18.19) do not reveal any significant trends since 1994, but interannual oscillations. For this survey the abundance and biomass indices show similar trends, peaking during 2012 and 2009. Both of them show a very sharp increment during the 2018 survey.

In the framework of the GFCM stock assessment (WGSAD) carried out in GSA 01 for *P. longirostris* during 2018, the stock status was “in overexploitation” being

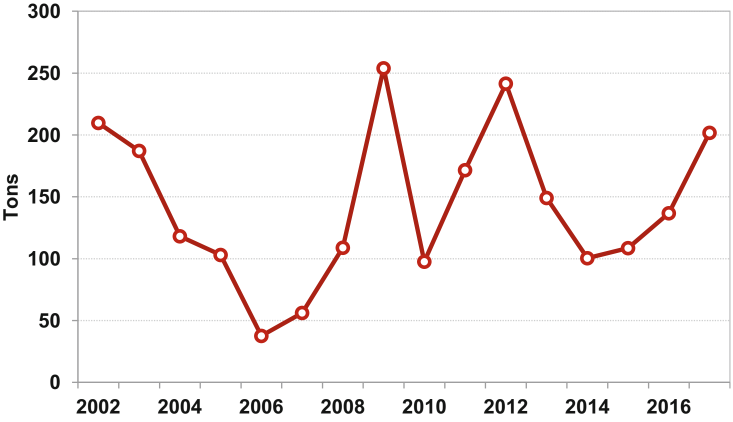

Fig. 18.18 *Parapenaeus longirostris* annual landings (in tons) by trawl fishery through historical series analyzed (2002–2017) in the Alboran Sea (GSA 01)

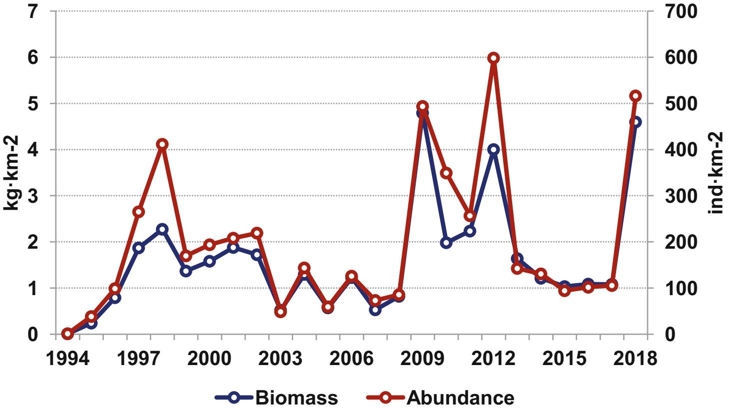

Fig. 18.19 *Parapenaeus longirostris* biomass (kg·km^{-2}) and abundance indices (individuals·km^{-2}) in GSA 01 from the MEDITS surveys through historical series analyzed (1994–2018)

the scientific advice for management of the progressive reduction of the fishing effort (GFCM 2018b).

18.5.3 Octopus vulgaris *("Common Octopus")*

Octopus vulgaris Cuvier, 1797 (Fig. 18.20) is a benthic cephalopod distributed, in a strict sense, throughout the Mediterranean Sea and central and northeast Atlantic Ocean (Norman et al. 2014).

Fig. 18.20 *Octopus vulgaris* (source: IEO)

Most of its population is confined to the continental shelf, with greatest densities shallower than 100 m depth (rare or occasionally below 200 m) habiting diverse ecological niches like rocky, gravel, sandy, and muddy bottoms (Guerra 1981; Mangold 1983; Belcari and Sartor 1999; Borges et al. 2000; Belcari et al. 2002; Norman et al. 2014). Its bathymetric distribution depends on its life cycle. *O. vulgaris* migrates from offshore to inshore waters during the breeding season for the female necessity of rocky substrate for spawning. After, the adults die, while youngers migrate to deeper water where growth and mature take place (Mangold-Wirz 1963; Guerra 1981; Quetglas et al. 1998; Garcia-Martínez et al. 2017).

In the MEDITS survey carried out in GSA 01, *O. vulgaris* was caught between 40 and 341 m depth (Fig. 18.21).

In the Mediterranean Sea, *O. vulgaris* is predatory feed predominantly on crustaceans (mainly decapods), mollusks (mainly bivalves), and fishes; it can also be cannibal, feeding occasionally other cephalopods (Guerra 1978; Quetglas et al. 1998; Norman et al. 2014; Sánchez et al. 2015). A wide range of predators prey on this species, mainly vertebrates (cetaceans, birds, teleost fishes, and elasmobranch) and other cephalopods (Hanlon and Messenger 1996; Norman et al. 2014).

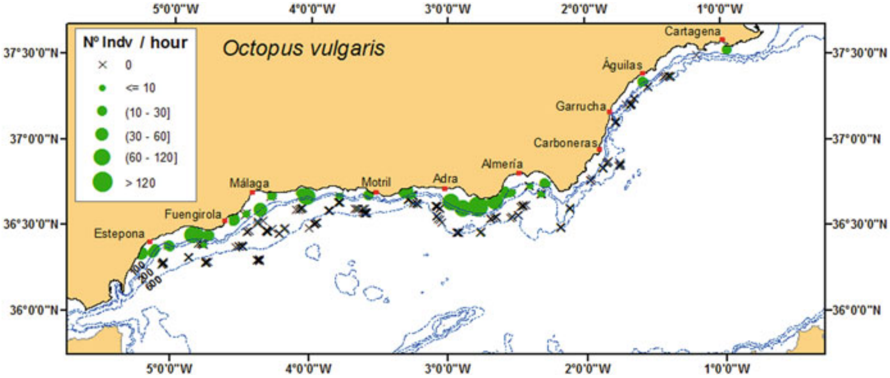

Fig. 18.21 MEDITS indices of abundance (individuals/hour) of *Octopus vulgaris* in GSA 01, from 2012 to 2018

O. vulgaris is a short lifespan species (1–2 years) with rapid growth and large individual variation in growth rates (Mangold 1983; Domain et al. 2000). Spawning takes place once in their lifetime, often seasonally, with a high fecundity and an indirect embryonic development with a planktonic phase (paralarval) (Rocha et al. 2001). The natural mortality in this species is high (especially on the paralarvae phase) and depends on environmental conditions, with highly variable recruitment success (Faure 2002; Sánchez et al. 2015).

In the Northern Alboran Sea, *O. vulgaris* is the most important marketed cephalopod, with a great commercial interest and economic value (Junta de Andalucía 2016). It is mainly fished by coastal trawlers and small-scale fleets (pots and traps). Trawl fleet operates on depths below 50 m only in soft, sandy, or muddy bottoms, while small-scale fleet operates in any type of bottoms in coastal areas and is a highly selective gear, focusing on *O. vulgaris* (Sánchez and Obarti 1993; Quetglas et al. 1998; Borges et al. 2000; Tsangridis et al. 2002; Belcari et al. 2002). The annual average landings for 2002–2017 in the Northern Alboran Sea were 1009.9 t (56.40% was caught by trawl fleet). These annual landings showed significant fluctuations, from 600 t to more than 1600 t. Similar trend occurs in the MEDITS survey (Fig. 18.22).

The cause of these fluctuations in *O. vulgaris* landings are unknown; although different assumptions are suggested, like the following: (i) the influence of environmental conditions on recruitment through influence on adult fecundity, hatching success, growth and mortality of paralarvae, and the food availability and (ii) the increase of the fishing effort (Sobrino et al. 2002; Vargas-Yáñez et al. 2009; Caballero-Alfonso et al. 2010; González et al. 2011; Rodhouse et al. 2014). Furthermore, intra-annual landings and population structure of *O. vulgaris* reveal a marked seasonality reflecting the octopus's annual life cycle in the study area: the migration of mature individuals to shallower waters for reproduction purposes in summer and followed by the dead of post-spawning specimens. The incorporation of recruitment of young individuals to the fishery is in autumn and their fast growth and

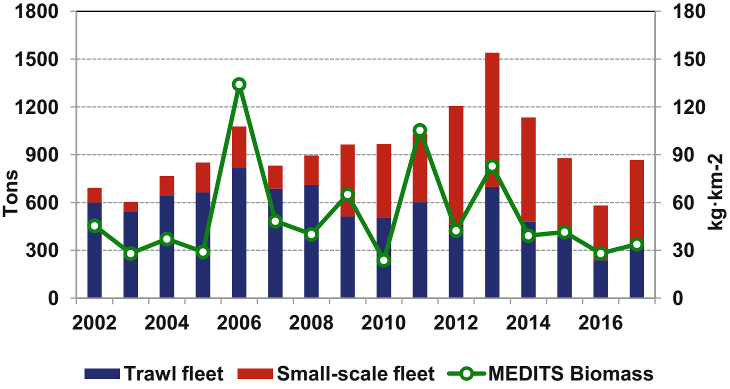

Fig. 18.22 *Octopus vulgaris* annual landings (in tons) and MEDITS abundance indices (kg·km^2) in GSA 01 through historical series analyzed (2002–2017)

migration from inshore to offshore in winter (Garcia-Martínez et al. 2017, 2018; Ciércoles et al. 2019). As with annual fluctuations, this seasonality in population abundance and structure of *O. vulgaris* could be modulated by environmental variables (Vargas-Yáñez et al. 2009; Puerta et al. 2016).

The maximum size reported in European waters is 40 cm mantel length (ML) (Guerra 1992; Pierce et al. 2010; Sanchez et al. 2015). In GSA01 *O. vulgaris* size landings range between 10 and 29 cm dorsal mantel length (DML) with an average of 16.36 cm (±2.88 SD) and modal size of 15 cm for a small-scale fleet. For trawl fleet size landings range between 5 and 32 cm DML with an average of 12.76 cm (±4.10 SD) and a modal size of 13–14 cm. Taking into account the landings of both fleets, the *O. vulgaris* size ranges between 5 and 32 cm DML with an average of 12.76 cm (±4.10 SD) and modal size of 15 cm. Regarding this biometric characteristics, pots catch large specimens associated with the selectivity of the gear and the octopus's annual life cycle (migration of mature individuals to shallower waters for reproduction), while trawlers catch all sizes, but especially the small ones probably owing to migration of young individuals to offshore (Quetglas et al. 1998). For MEDITS data, the size catches range between 1 and 21 cm DML with an average of 9.64 cm (±10.06 SD) and a modal size of 9 cm DML.

Males become mature at a smaller size (600 gr in the Northern Alboran Sea according to Tirado et al. 2003 and 9.67 cm DLM according to González et al. (2011) in adjacent areas Gulf of Alicante) than females (1000 gr in the Northern Alboran Sea according to Tirado et al. (2003) and 14.38 cm DML according to González et al. (2011) in adjacent areas Gulf of Alicante). Males are in the reproductive state throughout the year, while females are in sexual inactivity state most of the year (Tirado et al. 2003; González et al. 2011). Regarding the trawl fleet, *O. vulgaris* was one of the five most important species, being the third one in landings (8.33%) and the fifth one in economic value (7.61%) (Junta de Andalucía

2016). Also, *O. vulgaris* reported a significant increase in their economic value (from 4.5 €·kg^{-1} average in first sale price in 2012 to more than 7 €·kg^{-1} in 2017) making *O. vulgaris* an increasingly valuable resource (Ciércoles et al. 2019).

The fishery management is based on the establishment of a minimum legal weight of landed of 1 kg (National Order: APA/973/2002 - BOE 106, 3/05/2002- and Regional Order of 24 of February of 2016 - BOJA 41, 02/03/2016-). Also small-scale fleet has a closed season of 3 months (July until September) to protect spawning stock, a vessel census, and a gear limitation in the maximum number of clay pots or traps for boat and time regulation to control the fishing effort (Regional Order: 7 of April of 2004 - BOJA 76, 20/04/2004-).

Octopus vulgaris is a difficult resource to manage, and the traditional methods of fish stock assessment have generally been thought unsuitable for assessing cephalopods due to their biological characteristics (short life span, rapid growth, high natural mortality, and sensitivity to environmental conditions) (Pierce et al. 2010). In consequence there are no catch quotas and no formal stock assessment in the Northern Alboran Sea (like most octopus fisheries in European waters). In order to improve the situation, the ICES Working Group on Cephalopod Fisheries and Life History (WGCEPH) organizes some stock assessment workshops with the objective of providing the opportunity for European and invited non-European scientists to discuss assessment issues and methodologies (Pierce et al. 2010; ICES 2018 and others). Nowadays the production models and the model Catch-MSY seem to be the most appropriate for the *O. vulgaris* assessment. In adjacent areas the experts are working on applying these statistical models and including the effect of environmental factors (Quetglas et al. 2013, 2015; Sobrino et al. 2020).

18.5.4 Merluccius merluccius *("European Hake")*

Merluccius merluccius (Linnaeus, 1758) (Fig. 18.23) is one of the most important demersal species of the Mediterranean demersal ecosystem. It is a target species of the Mediterranean fishing fleets, largely overexploited in Europe (Casey and Pereiro 1995; Oliver and Massuti 1995; Mendoza et al. 2010; and references therein).

Fig. 18.23 *Merluccius merluccius* (redrawn from García et al. 2015)

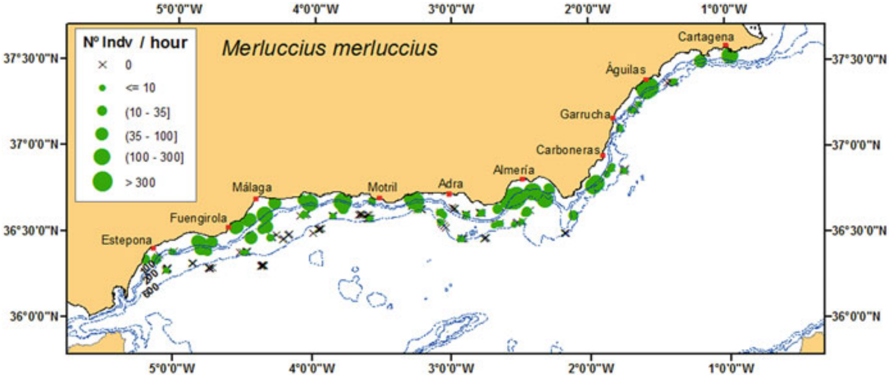

Fig. 18.24 MEDITS indices of abundance (individuals/hour) of *Merluccius merluccius* in GSA 01 from 2012 to 2018

It is a benthopelagic species that lives on muddy or mud-sand grounds on the continental shelf and slope, at depths between 50 and 370 m, although it can also be found between 30 and 1075 m depth (Lloris et al. 2005). In the Mediterranean Sea, the species is mainly abundant at depths ranging from 100 to 400 m, and the highest abundance values coincide with the 100–200 m depth zone in which most nursery grounds in the Mediterranean Sea are located (Orsi Relini et al. 2002). It occurs in the eastern Atlantic, from Norway and Iceland coasts to Mauritania coasts, in the Mediterranean Sea, and along the southern coast of the Black Sea (Cohen et al. 1990).

Two subspecies can be distinguished in the western Mediterranean Sea: *Merluccius merluccius merluccius*, with pectoral fins larger than ventral fins, and *Merluccius merluccius smiridus* with pectoral and ventral fins of equal size (Lloris et al. 2005).

During the MEDITS surveys carried out in the Northern Alboran Sea, species was caught between 30 and 700 m, but its abundance drops considerably below 300 m, and it is more abundant in the outer continental shelf (100–200 m), jointly with species as *Capros aper*, *Gadiculus argenteus*, *Maurolicus muelleri*, *Pagellus acarne*, *Micromesistius poutassou*, *Helicolenus dactylopterus*, and *Scyliorhinus canicula* (García-Ruiz et al. 2015). It is heterogeneously distributed throughout the Alboran Sea, being very abundant in the Almeria area declining sharply in Estepona (Fig. 18.24). The size of catches ranges between 1 and 80 cm total length (TL) with a general prevalence of small sizes and mean values of 14 (±7 SD) cm TL (MEDITS surveys).

The spawning period is long and varies according to population. In the Mediterranean, hake populations seem to have an active reproduction throughout the year in general (Reñones et al. 1995; Recasens et al. 2008), but mostly spawning fluctuates between January and April (García-Rodríguez 2005). Females reach maturity at 36 to 40 cm TL and males at 26 to 27 cm TL. In the western Mediterranean Sea, there are two recruitments per year, in the spring and in autumn, at between 50 and 250 m depth, with relatively stable oceanographic conditions. Fecundity is very high,

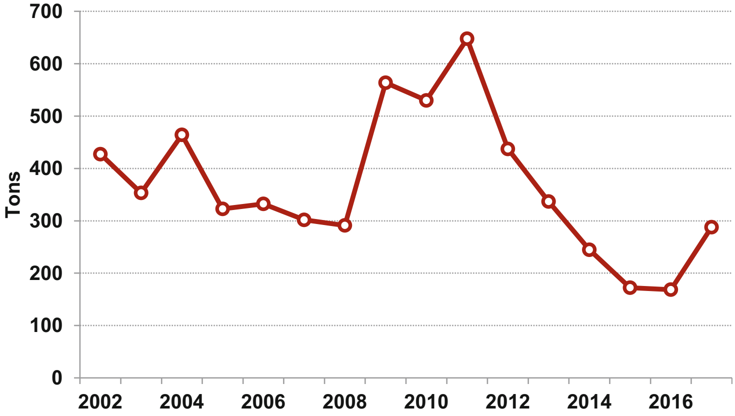

Fig. 18.25 *Merluccius merluccius* annual landings (in tons) by trawl fishery through historical series analyzed (2002–2017) in GSA 01

between 2 and 7 million oocytes per female (Lloris et al. 2005). Batch fecundity increases proportionally with the size of hake, and it should be noted that correlations between batch fecundity and energy reserves are still stronger than the correlations with hake size (Ferrer-Maza et al. 2014). According to Recasens et al. 2008, the total number of eggs per female increases with size, but in relative terms the egg production per gram of females is similar.

Prey comprises benthopelagic organisms with ontogenic changes in the diet. Morote et al. (2011) found that larvae presented a clear preference for adult calanoid copepods and they foraged even at low light intensity (Korta et al. 2015). Small juveniles prey on small crustaceans (euphausiids, natantian decapods, and mysids), while fish assume an increasing importance in the diet with increasing size of hake (Cartes et al. 2004). According to Bozzano et al. (1997), the main preys for hakes between 14.5 and 39.5 cm TL are anchovy and for hakes larger than 40 cm are sardine in autumn and winter and red bandfish (*Cepola macrophthalma*) in spring and summer. Hakes perform vertical migrations from near the bottom to mid-water or near the surface to feed at night (Pitcher and Alheit 1995). One of the components of the diet of adults is other hakes, which indicates the existence of cannibalism (Oliver and Massuti 1995).

Merluccius merluccius is a target demersal species of the Mediterranean fishing fleets. It is largely exploited in GSA01, mainly by trawlers on the shelf and slope (96% landings) but also by small-scale fisheries using set longlines (1%) and gillnets and trammel nets (4%) (average percent estimated between 2016 and 2017). The trawler fleet is the largest in landings (274 tons in 2017). The main ports in landings in GSA 01 during 2017 were Vélez-Málaga (50 t), Almería (47 t), Garrucha (40 t), Cartagena (32 t), and Fuengirola (30 t) (GFCM 2018b).

Landings have shown oscillations along the period of the data series (2002–2017), ranging between 427 and 288 tons, respectively, with a maximum in 2011 (648 tons) and minimum in 2016 (168 tons) and 2015 (172 tons) (Fig. 18.25).

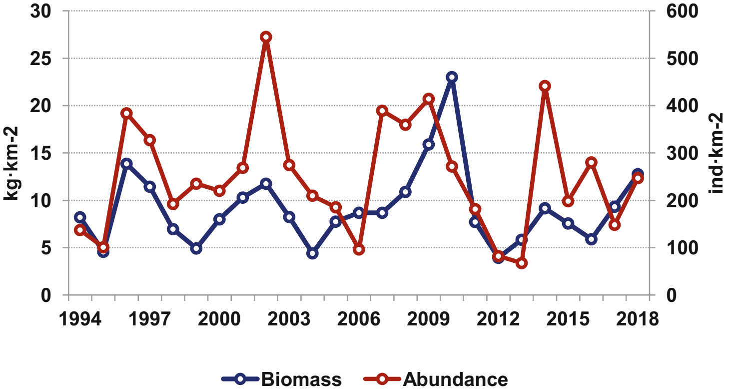

Fig. 18.26 *Merluccius merluccius* biomass and abundance indices in GSA 01 from the MEDITS surveys through historical series analyzed (1994–2018)

A sharp decreasing trend was recorded from 2011 onward (Fig. 18.25). Landing sizes ranged between 8 and 82 cm TL with a maximum of around 20 and 24 cm TL. Mean values are 24.19 (±8.02 SD).

Abundance and biomass indices from fishery-independent MEDITS survey (Fig. 18.26) do not reveal any significant trends since 1994 but interannual oscillations.

In the framework of the GFCM stock assessment as in previous years, the 2017 WGSAD session recognized that "European hake was the demersal species suffering from the highest fishing mortality. Therefore, the WGSAD recommended that the SAC consider immediate management actions to reduce the fishing mortality of European hake stocks in order to allow the stocks to recover. It was remarked that the current measures (minimum landing size, mesh size, etc.) were not providing tangible effects on the status of the stocks and that a series of measures should be adopted at the same time to reduce fishing mortality, improve fishing exploitation patterns and protect the most vulnerable life stages of the populations (i.e. juveniles and spawners in appropriate periods and areas)" (GFCM 2017). From 2016, stock assessment of the European hake was performed for GSA 01 and GSA 03 together. The joint assessment revealed that the stock was in overexploitation (GFCM 2016, 2017, 2018b). Previously, the individual stock assessment for the species in GSA 01 showed also the status of overexploitation (i.e., GFCM 2015; 2014).

18.5.5 Mullus barbatus *("Red Mullet")*

Mullus barbatus (Linnaeus, 1758) (Fig. 18.27) is a common demersal fish along the coasts of the Mediterranean Sea. This species has a high commercial value, and it is

Fig. 18.27 *Mullus barbatus* (redrawn from García et al. 2015)

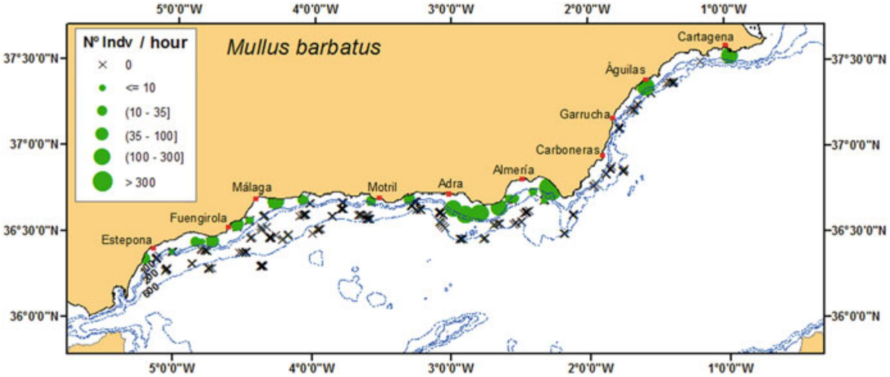

Fig. 18.28 MEDITS indices of abundance (individuals/hour) of *Mullus barbatus* in GSA 01 from 2012 to 2018

one of the main target species of many demersal fisheries operating in the Mediterranean Sea (Tserpes et al. 2002).

This species inhabits sandy and muddy bottoms, and it is distributed all around the Mediterranean basin, including the Black Sea, and also in the eastern Atlantic Ocean from Scandinavia to Senegal (Fischer et al. 1987). Its density is especially high at sites characterized by a wider continental shelf. In the Mediterranean Sea, it is reported between 5 and 300 m depth, with maximum population densities at 50–200 m while below 200 m depth catches are very low (Lombarte et al. 2000). During the MEDITS surveys carried out in Alboran Sea, species was caught between 35 and 250 m depth, and it is more abundant on the eastern part of the Alboran Sea (Fig. 18.28) and in the inner continental shelf (30–100 m), jointly with species as *P. acarne*, *Serranus hepatus*, *Boops boops*, *C. aper*, *Trachurus trachurus*, *Cepola rubescens*, *M. merluccius*, *Arnoglossus thori*, *Spicara maena*, and *Callionymus maculatus* (García-Ruiz et al. 2015). The size is 30 cm TL, usually 10–20 cm TL (Whitehead et al. 1986). In the Alboran Sea, the size of catches ranges between

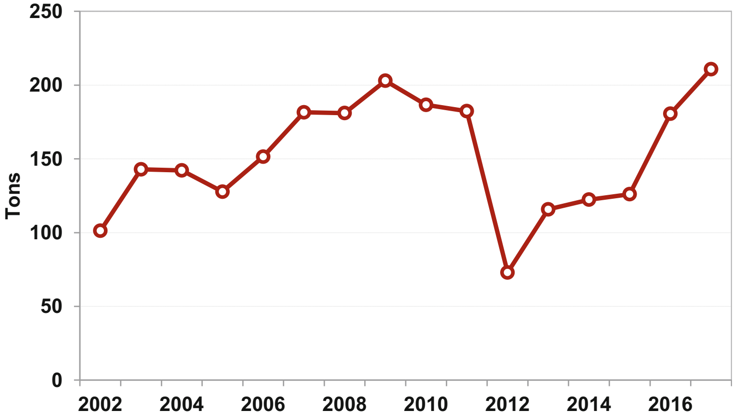

Fig. 18.29 *Mullus barbatus* annual landings (in tons) by trawl fishery through historical series analyzed (2002–2017) in GSA 01

10 and 30 cm TL, with a maximum at 13–14 cm TL. The mean values are 14.84 (±2.53 SD) cm TL (MEDITS surveys).

Sexual maturation begins in spring (in early summer most are mature individuals). Spawning occurs from March to June, and larvae are found in the plankton during June–July in the upper levels of the water column (Aguirre 2000 and references therein). The recruitment to fishery is in autumn (Suau and Vives 1957). The size at first maturity is around 13 cm TL at an age of 1.3 years (STECF 2015).

Most of the species consumed by *M. barbatus* are associated mainly with detritus, silts, and muds. Gharbi and Ktari (1979) found that, in *M. barbatus* diet, small polychaetes and crustaceans play an important role in the feeding of juveniles while larger crustaceans (decapods), mollusks, and polychaetes are the basis of the essential diet of adults (Aguirre 2000 and references therein). *M. barbatus* is characterized by having barbels with greater structural complexity and higher density of taste buds than *M. surmuletus*, a sympatric species of the same genus. Studies suggest the existence of adaptive morphological and anatomical characteristics that allow *M. barbatus* to exploiter sources from muddy and turbid bottoms better than its congeneric species that prefer more transparent and shallower waters (Lombarte and Aguirre 1997).

In Alboran, *Mullus barbatus* are among the most important target species for the trawl fisheries. It is largely exploited in all the trawlable areas, both sandy and muddy bottoms mainly by trawlers on the shelf and by small-scale fisheries in particular trammel nets (about 12% of the catches). The amount of discards reported is very low and considered to be negligible with the highest percentage in the catch of 3% in 2016 and an average of 1% throughout the years (STECF 2008). Over the period 2002–2017, annual landings for trawl fisheries oscillated between 101 and 211 tons, respectively, with maximum landings in 2017 (Fig. 18.29). Landing sizes range between 7 and 30 cm (2002–2017), maximum between 13 and 15 cm TL. The medium values are 14.86 (±3.31 SD) cm TL.

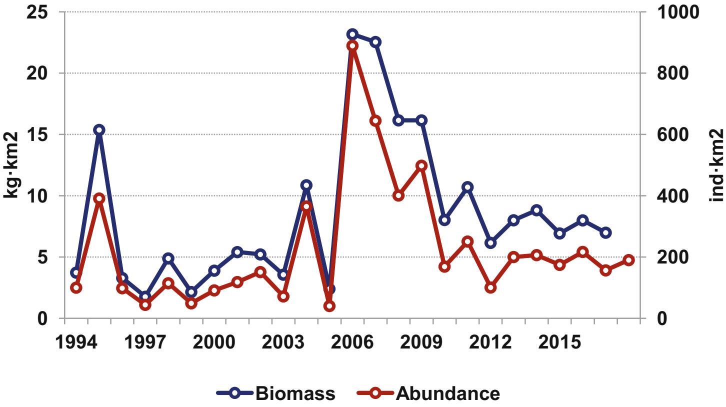

Fig. 18.30 *Mullus barbatus* biomass and abundance indices in GSA 01 from the MEDITS surveys through historical series analyzed (1994–2018)

Abundance and biomass indices from the fishery-independent MEDITS survey (Fig. 18.30) do not reveal any significant trends since 1994 but interannual oscillations with a maximum on the 2006 survey.

According to the Mediterranean stock assessment carried out by the Scientific, Technical and Econimic Committee for Fisheries (STECF 2018), "red mullet in GSA 01 is stable but is being overfished. Catches should be reduced by at least 85% to reach FMSY in 2019. The size composition of landings indicates that the exploitation is concentrated on age classes 1–2." Management recommendation advice was to reduce fleets' effort in order to avoid future loss in stock productivity and landings. This should be achieved by means of a multi-annual management plan taking into account mixed fishery considerations (STECF 2015).

18.6 Discards

The capture of non-target organisms has been globally acknowledged as an important issue for fishery resource management and ocean conservation. The catch of unwanted organisms and their subsequent discarding are significant in several European fisheries (STECF 2007). Such practices are a wasteful use of resources, both from an economic point of view, losing future opportunities of catch, and from a perspective of ecological sustainability, because the negative impact on the marine ecosystem (STECF 2008).

The United Nations Food and Agricultural Organization's (FAO) Fisheries Glossary (FAO 2018) describes discards as "the proportion of the total organic material of animal origin in the catch, which is thrown away or dumped at sea, for whatever reason. It does not include plant material and postharvest waste such as offal," and bycatch is defined in the aforementioned glossary "as the part of a catch of a fishing unit taken incidentally in addition to the target species towards which fishing effort is directed. Some or all of it may be returned to the sea as discards, usually dead or dying." The GFCM includes incidental catch of vulnerable species as a subset of bycatch, which includes species such as marine mammals, sea turtles, seabirds, and some elasmobranchs (FAO 2018).

In general, the main reason for discarding is the lack of commercial value of some caught species (Kelleher 2005), although it also sometimes occurs because the fish do not reach the minimum landing size, because catch quotas have been exceeded or because the fish are damaged. The incidence of discards in species with commercial interest is low, although part of the commercial catch may also be discarded to comply with fishing regulations (Uhlmann et al. 2014). It is estimated that 7.3 million tons of fish (usually dead or dying) are discarded annually by marine fisheries throughout the world, with the proportion of the catch discarded at sea estimated at 8% t (Kelleher 2005). In the Mediterranean a rough estimation of discards around 230,000 t, or 18.6% (13.3–26.8%) of the catch is produced (Tsagarakis et al. 2014).

In order to tackle the problem of discards in European fisheries, the new Common Fisheries Policy (CFP) (European Parlamient and Council Regulation (EU) 1380/2013), establishes as a conservation measure the monitoring and reduction of incidental catches and discards. This measure is part of the concept known as "ecosystem approach," which considers fisheries not only as a relationship between the resource and the fleet but also considers the ecosystem that hosts the resource and the socioeconomic scope of the fleet (Bellido et al. 2014). The new regulation establishes the obligation to land catches of stocks subject to minimum sizes, which is considered one of the easiest management instruments to apply and is established with the aim of discouraging the capture of juveniles, since although this type of regulation has influenced the sizes of the species landed, it has not done so in the sizes of the species caught, which leads to their subsequent discarding (Catchpole et al. 2005).

Under the Commission Delegated Regulation (EU) 2017/86 establishing a discard plan for certain demersal fisheries in the Mediterranean Sea, all catches of species subject to catch limits and catches of species subject to minimum sizes must be landed. An exemption from the landing obligation applies to bivalve mollusk scallops (*Pecten jacobaeus*), clams (*Venerupis* spp. and *Venus* spp.) in the Western Mediterranean Sea, as high survival rates can occur, taking into account the characteristics of fishing gears and practices and the ecosystem. This regulation provides for "*de minimis*" exemptions affecting demersal fisheries in the Alboran Sea. According to these exemptions, hake (*Merluccius merluccius*) and red mullet (*Mullus* spp.) may be discarded up to a maximum of 7% in 2017 and 2018 and 6% in 2019 of the total annual catch of these species by trawlers and 1% of the total annual catch of these species by vessels using gillnets.

In the Alboran Sea, demersal fisheries are multi-species, and it is very difficult to identify target species, which influences the level and diversity of discards generated (Eliasen and Christensen 2012) (Fig. 18.31). According to García et al. (2015) in the

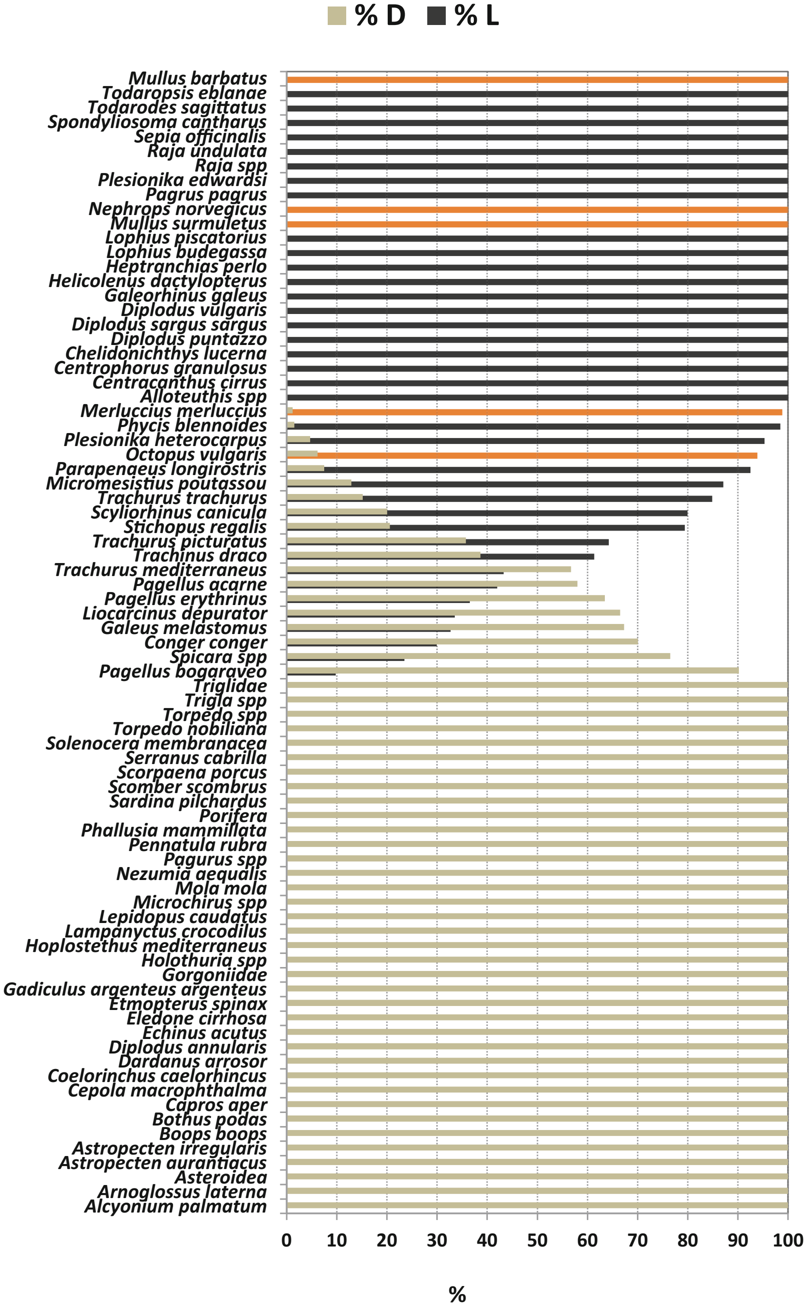

Fig. 18.31 Proportion of species weight in the commercial and discarded fraction of the metier OTB-DEF (Bottom otter trawl for demersal species) in Spanish waters Geographical Subarea 01 of the GFCM. %D, percentage discarded; %L, percentage landed. Highlighted in orange the target species of the metier. (Source: Bellido et al. 2014)

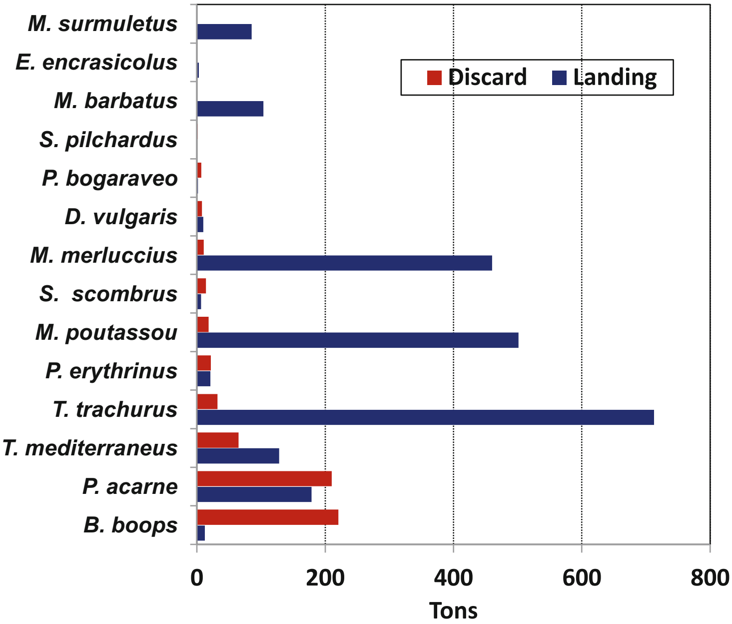

Fig. 18.32 Average total catch (tons) of the retained (commercial) and discarded fraction of the bottom trawl fleet during the period 2011–2012 (redrawn from García et al. 2015)

bottom trawl fleet, the discard of individuals above legal size is less than 20% by weight of the catch in the regulated species, with the exception of *Pagellus erythrinus* of which 44% by weight of specimens with legal size are discarded. In species such as *Merluccius merluccius*, 100% of discards are juveniles, although an analysis of their size distribution shows that a proportion of individuals traded are below the legal minimum size. Among the unregulated species, *B. boops* and *M. poutassou* have the highest percentages of discarded specimens with legal size with 98% and 85% by weight, respectively. The most discarded species was *B. boops*, constituting its discard 87% of its catches in weight in 2011 and 97% in 2012. Next in importance is *P. acarne*, a species that has a great impact on the catches of the demersal fleet since 75% in weight are small specimens (Figs. 18.32 and 18.33).

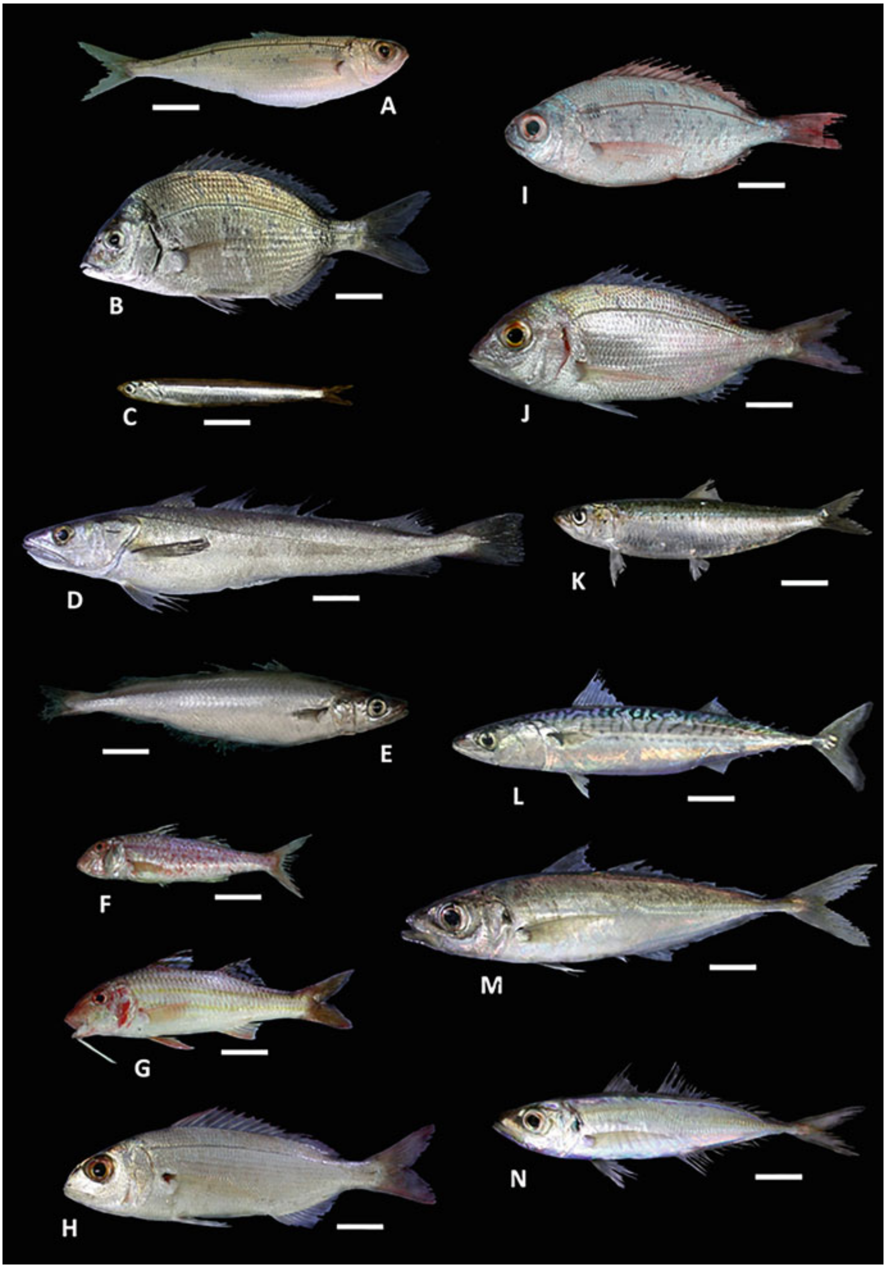

Fig. 18.33 Main species discarded by bottom trawl fleet (García et al. 2015): (**a**) *Boops boops*; (**b**) *Diplodus vulgaris*; (**c**) *Engraulis encrasicolus*; (**d**) *Merluccius merluccius*; (**e**) *Micromesistius poutassou*; (**f**) *Mullus barbatus*; (**g**) *Mullus surmuletus*; (**h**) *Pagellus acarne*; (**i**) *Pagellus bogaraveo*; (**j**) *Pagellus erythrinus*; (**k**) *Sardina pilchardus*; (**l**) *Scomber scombrus*; (**m**) *Trachurus mediterraneus*; (**n**) *Trachurus trachurus.* The scale bar represents 3 cm

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Chapter 19
The Blackspot Seabream Fishery in the Strait of Gibraltar: Lessons and Future Perspectives of Shared Marine Resource

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19.1 Introduction

Fish stocks commercially exploited are components of ocean ecosystems that are extremely complex to manage and plan. As a consequence of that, the abundance of the resources at a future time is related to a multitude of intrinsic and extra-compensatory and variable in time factors, frequently unknown and generally associated with a very high level of uncertainty, which greatly hinders the projections of abundance towards the near future. Among the intrinsic factors that influence the variation in abundance of a target species are their biological characteristics such as growth capacity, type of reproduction, natural mortality, and resilience to exploitation, among others (Clark and Marr 1955; Dragesund et al. 1980; Zhang et al. 2004). All these intrinsic factors are strongly influenced by a wide variety of external factors with different nature such as anthropogenic (type and level of exploitation), natural (environmental variability) (Kennedy 1990; Bigelow et al. 1999; Lehodey et al. 2006; Jghab et al. 2019), and geopolitical, which strongly condition the stability and sustainability of fish communities.

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The Blackspot Seabream (*Pagellus bogaraveo*) fishery is a clear example of the influence of the aforementioned factors on the abundance variability (Báez et al. 2014; Gutiérrez-Estrada et al. 2017; Sanz-Fernández et al. 2019). This species, found from the south of Norway to the Canary Archipelagos in the Atlantic Ocean and in the Mediterranean Sea basin (Desbrosses 1938), is one of the main exploited resources in the Strait of Gibraltar. This protandric hermaphrodite species lives in a depth range that varies between the surface and 700 m and is the target species in this area of two artisanal fleets belonging to two countries with very different fishing policies developing their fishing activity in a small area characterized by a high environmental complexity (Gil 2006; Czerwinski 2008). In this context there is no ideal methodology to manage and apply all available information and to provide an exact resource assessment, and therefore, the use of complementary procedures that allow to reduce the uncertainty associated to the obtained estimations is advisable. Thus, it would be possible to carry out an integrated management and ecosystem planning focused on the sustainability of the resource.

Therefore, this chapter describes the different approaches to assess the abundance of the Blackspot Seabream population in the Strait of Gibraltar. This way, using the joint data from Morocco and Spain, one classic method and two novel approaches were used to evaluate the current status of the stock. The first was based on the length cohort analysis (LCA) and virtual population analysis (VPA): from the obtained results, a yield per recruit (YpR) analysis was run to estimate ad hoc reference points (F_{MAX} and $F_{0.1}$). The second approach was carried out using the globally applicable area disaggregate general ecosystem toolbox (Gadget) model developed by Begley and Howell (2004), and finally the third approach was obtained by means of the SimFish methodology proposed by Gutiérrez-Estrada et al. (2017).

19.2 Description of the Fleets, Stock Identification, and Landings

The Blackspot Seabream is one of the principal demersal species targeted in the Strait of Gibraltar for its highest commercial value compared to other demersal resources. The Spanish fishery targeting the Blackspot Seabream has been developing along the Strait of Gibraltar area since the earliest 1980s. This is an almost monospecific fishery, with one clear target species which represents 74% of the total landed species (Silva et al. 2002). The main harbors are located in Tarifa and Algeciras (Spain) and Tangier (Morocco). Less important landings are also carried out at Conil and Ceuta ports (Spain).

In Spain the main fishing hook gear used is known as "*voracera*" (Gil 2006; Czerwinski 2008), although occasionally this species is also caught by means of traditional longliners. The "*voracera*" is a local mechanized handline baited with sardine. Fishing is carried out taking advantage of the turnover of the tides in bottoms from 300 to 600 m depth. Every boat uses a maximum of 30 lines per day (each line attached a maximum of 100 hooks, usually ±70) with a maximum legal length of 120 m. The legal dimensions of the hooks are a minimum length of 3.95 ± 0.39 cm and a minimum width of 1.4 ± 0.14 cm. The maximum number of boats (more than 100) decreased to less than 60 in the last years and its mean technical characteristics are as follows: length = 9.80 meters, GRT = 6.36, and HP = 47.23.

The most important Moroccan fleets targeting the Blackspot Seabream are the longliners based at the Tangier harbor and the artisanal fleet of the Strait of Gibraltar area. In the last years, the longliner fleet was more or less stable (78 to 101 vessels), but in 2016 the number of the longliners fleet was composed of approximately 84 and 76 artisanal boats. The number of hooks (size of the hooks is between 8 and 11) by boat is between 200 and a maximum of 2000.

The operational area of the Spanish and Moroccan fleets is approximately a sector between 6° 25'W to 5° 15'W and 35° 45'N to 36° 15'N, which correspond with the westernmost end of the Alboran Sea (Fig. 19.1) (Burgos et al. 2013). Some studies have analyzed the migration patterns using tagging surveys (Gil et al. 2001; Sobrino and Gil 2001). These studies indicate that juveniles showed displacements from nursery areas towards the Strait of Gibraltar fishing grounds. However, recaptures from tagged adults did not reflect big displacements, which are limited to feeding movements among the different fishing grounds where the fleets work (Gil 2006). There is not much information available on the stock structure of Blackspot Seabream. FAO COPEMEDII TRANSBORAN (Transboundary population structure of Sardine, European hake and Blackspot Seabream in the Alboran Sea and adjacent waters: a multidisciplinary approach) ongoing project based on genetics, otolith shape, and microchemistry analyses will be giving some clues in the next future.

In the case of the Spanish fleet, the analysis of the data provided by Location and Track System for Andalusian Fishing Vessels (SLSEPA) between August 2007 and December 2009 (Fig. 19.1) has allowed to identify the six main fishing areas (V-01 to V-06). On the other hand, the operation area of the Moroccan fleet is limited by the Cap Spartel (at the west) to the east of Benyounech which approximately matches with areas V-02, V-03, V-04, and V-06 from the Spanish fishing grounds. However, until now there is a lack of precise information on the geographical distribution, pattern distribution, and real stock boundaries of the Blackspot Seabream population caught in the Strait of Gibraltar.

The compiled information from the Spanish fleet indicates that Blackspot Seabream was significantly landed since 1983 (Fig. 19.2). Considering only the main Spanish ports (Tarifa and Algeciras), landings trend of the shows a big decline in the Spanish fishery from about 600 tons in 2009 to 104 t in 2016 (Table 19.1).

Catches from the Moroccan fisheries were low at the beginning to remain more or less stable until 2013 (Fig. 19.2). From 2013 onwards, it showed an increasing trend setting the highest value on 2015 with 219 tons and 159 t in 2016. The 2010–2016 mean production of this fishing resource is about 142 tons (Table 19.1).

From 2005 the fishing effort of Tarifa and Algeciras fleet was very high in comparison with the Moroccan one but since 2009 declined and reached the same

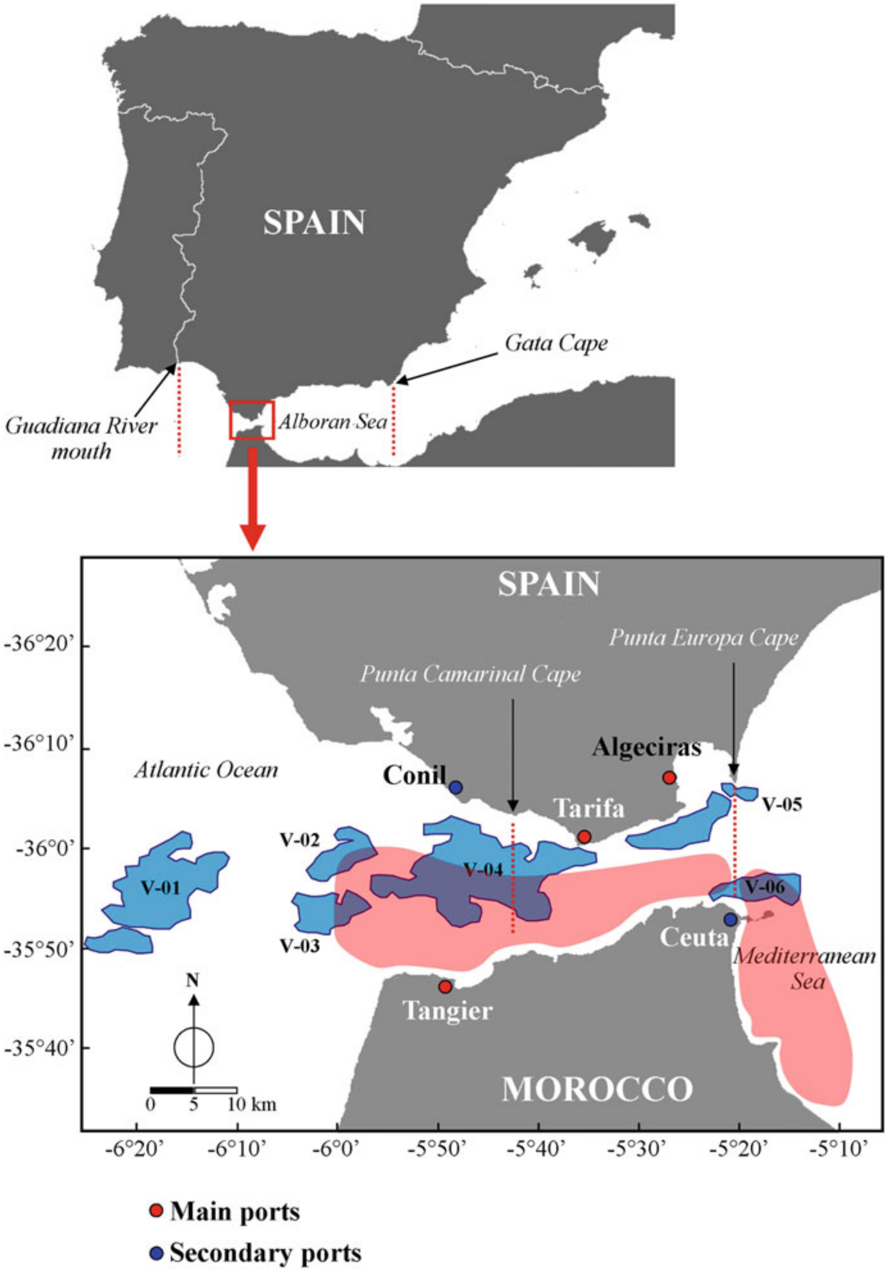


Fig. 19.1 Main fishing grounds of the Spanish (blue) and Moroccan (red) Blackspot Seabream fishery. Information of the Spanish fleet (V-01 to V-06) has been obtained from the Location and Track System for Andalusian Fishing Vessels (SLSEPA) of the Junta de Andalucía. The area between the meridian of Gata Cape and the meridian of the mouth of the Guadiana River and between Punta Camarinal Cape and Punta Europa Cape (dotted red lines) established by the Order APA/3323/2002 is shown

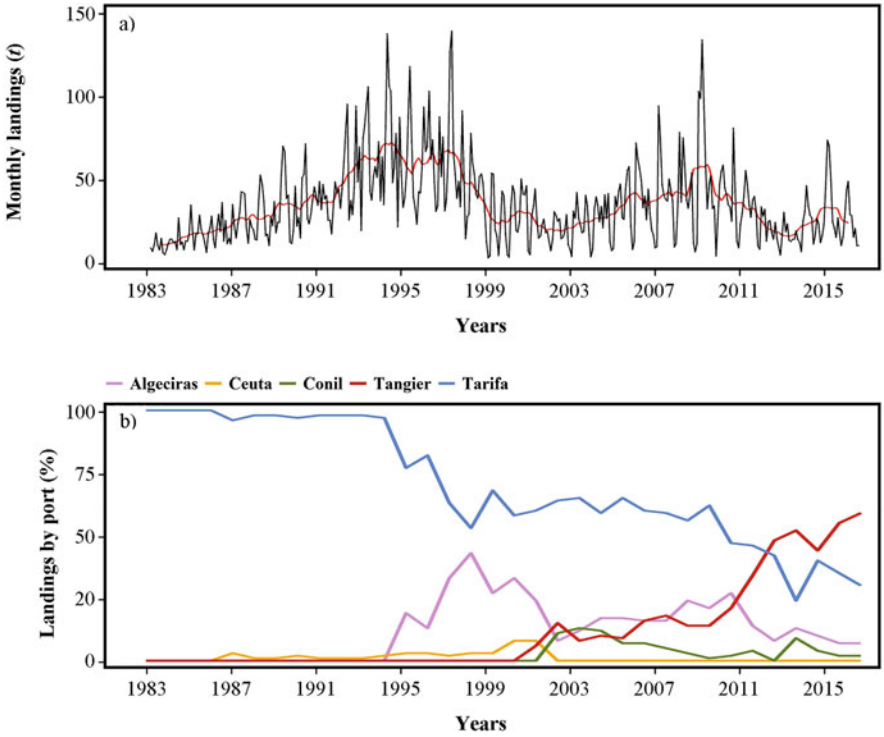


Fig. 19.2 (**a**) Time series (1983–2016) of blackspot Blackspot Seabream considering the ports of Tarifa, Algeciras, Ceuta, Conil, and Tangier. The red line is the annual moving average; (**b**) percentage contribution by port and year to Blackspot Seabream landings

Table 19.1 Annual landings and catches per unit effort (CPUE) in the Tarifa and Algeciras ports (Spain) and Tangier port (Morocco) from 2005 to 2016

	Tarifa and Algeciras ports (Spain)		Tangier port (Morocco)	
Year	Landings (t)	CPUE (kg/fishing day)	Landings (t)	CPUE (kg/fishing day)
2005	330	69	39	40
2006	346	71	74	39
2007	362	52	89	35
2008	416	52	76	34
2009	579	66	99	40
2010	366	53	105	38
2011	240	43	136	34
2012	126	36	122	32
2013	66	32	92	33
2014	138	40	118	33
2015	168	51	219	44
2016	100	43	159	34

level as the Moroccan one. Moroccan fishing effort has increased and became the highest in the last 2 years. However, the CPUE was more or less stable for both countries (Spain and Morocco) with an average of 51 and 36 kg/fishing trip, respectively (Table 19.1).

19.3 Management Regulations

In Spain, the legislation applied to the management of the Blackspot Seabream fishery has evolved from 1995 to 2016, in order to regulate the technical and biological aspects associated with the fishery.

The regulations relating to the technical characteristics of fishing gear began with the Order of June 17, 1998, which establishes the maximum length of the "*voracera*" (120 m), the number of maximum hooks allowed (100 per "*voracera*"), and the size of the hooks (length 3.55 ± 0.35 cm and width 1.3 ± 0.13 cm). These aspects have been modified by different management plans until today (APA/3323/2002 Order of December 20; APA/8/2006 Order of January 12; APA/274/2007 Order of February 7; APA/445/2008 Order of February 18; ARM/521/2009 Order of February 24; ARM/3536/2009 Order of December 23). The AAA/1589/2012 Order of July 17 establishes that the number of maximum hooks allowed is 2400 and its dimension not less than large 3.95 cm and width 1.65 cm. Nowadays this management plan regulates the fishery.

As regards fishing effort (understood as days at sea), there has been an increase of 20 days from 1998–1999 (160 days) (Order of June 17, 1998; Order of November 2, 1999) to 2016 (180 days) (AAA/55/2016 Order of January 26). The opposite case occurs with the census of vessels, which began with 148 (Order of June 17, 1998) and currently has 88 (AAA/1589/2012 Order of June 17).

With regard to the temporary closure of the fishery (understood as the prohibition of fishing in certain seasons), it is in 2002 when the obligation to stop the fishery from mid-January to March included is incorporated (APA/3323/2002 Order of December 20). After 2002 and until 2009, the months of temporary closure varied but were always from January to May, coinciding with the months in which the spawning takes place (APA/8/2006 Order of January 12; APA/274/2007 Order of February 7; APA/445/2008 Order of February 18; ARM/3536/2009 Order of December 23). In 2016, the obligation to carry out a temporary closure of the fishery acquires voluntary character (AAA/55/2016 Order of January 26).

Finally, the biological aspect of the fishery has been regulated by the minimum allowable catch length. The Blackspot Seabream is a marine resource whose life cycle takes place under two different maritime domains (Atlantic and Mediterranean). Besides, it should be noted that the Strait of Gibraltar Blackspot Seabream target fishery fishing grounds partially overlap areas from different regional fishery organizations/advisory bodies, namely, GFCM (General Fisheries Commission for the Mediterranean), CECAF (Fishery Committee for the Eastern Central Atlantic),

Table 19.2 Minimum catch size of Blackspot Seabream established for the Spanish fleet from 1995

Minimum size (in cm)	Year	Reference
25	1995	Royal Decree 560/1995, of April 7
$25^{(1)}/33^{(2)}$	2002	Order APA/3323/2002
$25^{(1)}/33^{(2)}$	2006	Order APA/8/2006
$33^{(2)}$	2007	Order APA/274/2007
$33^{(2)}$	2008	Order APA/445/2008
$33^{(2)}$	2009	Order ARM/521/2009
$33^{(2)}$	2009	ARM/3536/2009
$33^{(2,3)}$	2012	Order AAA/1589/2012

and ICES (International Council for the Exploration of the Sea). This fact causes its minimum landing size to be modified according to the area of capture.

The historical evolution of the minimum landing size of the Blackspot Seabream is shown in Table 19.2. Initially in 1995, the minimum landing size for the entire regulatory area was set at 25 cm. This size was maintained until the years 2002 and 2006, where depending on the area of capture, the size was 25 or 33 cm. From late 2006 to 2009, the minimum landing size was 33 cm for both the Atlantic and Mediterranean areas. Finally from 2012 to 2019, the minimum landing size and the annual total allowable catch (TAC) for Spain are determined by the European Union Regulation EU 2017/787 of 8 May 2017 which establishes that the minimum size for the Blackspot Seabream is 33 cm (total length).

In Morocco, the main regulation is in force since 1992 and the interdiction of fishing beyond 80 m depth in the area between Tangier and Al Hoceima and below 3 miles in the area between Al Hoceima and Saidia. The minimal landing size is established on 25 cm (fork length; about 28 cm total length) with trawl cod end mesh size $\geq$50 mm. The net regulation establishes that the maximum size must be 1000 m with a cod end mesh size of 70 mm. Also there is a regulation about the protection of marine areas and anti-trawling artificial reefs.

19.4 Life History and Biological Parameters

The Blackspot Seabream is a species belonging to the *Sparidae* family. It is a bentho-pelagic species with adults inhabiting depth ranges from 300 to 700 m throughout the eastern Atlantic and western Mediterranean. It is a sequential protandric hermaphrodite species, starting as males but changing into females at 30–35 cm, when they reach 4 to 6 years old (Alcaraz et al. 1987; Krug 1990; Gil 2006). They grow slowly to a maximum size of 70 cm, weight of 4 kg, and an age of about 15 years (Coupé 1954; Sánchez 1983; Krug 1994; Gil 2006). These biological

Table 19.3 Biological parameters of the *Pagellus bogaraveo* live history experimentally obtained for the Strait of Gibraltar population

Model, relationship	Parameters, values
Von Bertalanffy model*	L_∞, t_0, k
	58 cm, −1.1674 years, 0.169 year^{-1}* 62 cm, −0.3400 years, 0.162 $\text{year}^{-1\#}$
Length-weight relationship (cm-g)	a_{lw}, b_{wl}
	0.0140, 3.0140*
	0.0010, 3.2390§
Length-size standard deviation relationship (cm-cm)	a_σ, b_σ
	0.8591, 0.3663†
Length-fecundity relationship (cm-number of eggs)	a_{lf}, b_{lf}
	3·10–7, 4.26*
Month and spawn percentage (SP vector)	January(%), February(%)...
	(10n, 30n + 1, 60n + 2,. . .,0n + 11)*
Length-male and female proportion relationship (cm)	f_0, f_1, f_2
	390.48, 15.4290, 0.1524†

§ Czerwinski et al. 2008
† Gutiérrez-Estrada et al. 2017
aGil (2006)
[b] Gil et al. (2017) Combined data from the Spanish and Moroccan fleets

characteristics make this species very sensitive to disturbances introduced by fishing and confer a low level of resilience to exploitation.

Similar to the stock distribution information, there is relatively a few information about the growth and reproduction of the Blackspot Seabream in the Strait of Gibraltar. The parameters estimated on the growth model (von Bertalanffy growth function) were obtained by Gil (2006), and the parameters of the length-weight were reported by Gil (2006) and Czerwinski et al. (2008). Also, Gil (2006) analyzed and determined the length-fecundity relationship and the most probable month and spawn percentage (*SP* vector). Later, from the original database generated by Gil (2006), Gutiérrez-Estrada et al. (2017) determined the length-size standard deviation relationship and the length-male and length-female proportion relationship (Table 19.3).

19.5 Environmental Information

Nowadays there is a relatively wide knowledge about the environmental conditions in the Strait of Gibraltar which is available in different open databases. These databases record real and modeled data including on air and sea temperature, salinity, temperature flux, salt flux, current speed, chlorophyll a concentration, atmospheric pressure, rainfall, and freshwater discharge.

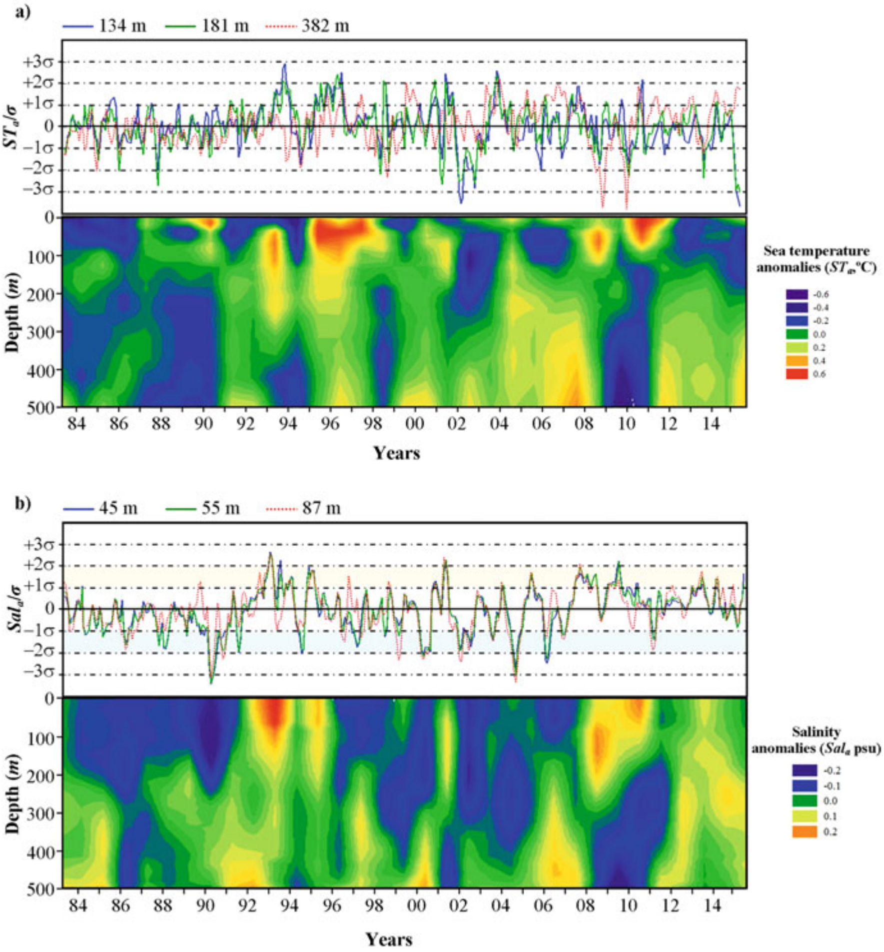


Fig. 19.3 Average sea temperature anomalies (**a**) and salinity anomalies (**b**) between 1983 and 2016 for a depth range between 0 and 500 m in the Strait of Gibraltar. For each variable, the average anomalies above and below one, two, and three times the standard deviation (σ) recorded for different depth are shown. Raw data has been obtained from Simple Ocean Data Assimilation (SODA) v 3.3.1 reanalysis data set (http://www.atmos.umd.edu/~ocean)

From an environmental point of view, the oceanographic conditions in which the biological parameters of the Blackspot Seabream population were obtained (Table 19.3) are conditioned by an oceanic current scheme that links the Atlantic Ocean with the Mediterranean Sea. The Strait of Gibraltar is characterized by an interchange of water masses with different temperature and salinity properties between the Mediterranean Sea and the Atlantic Ocean with an inward flow from the Atlantic Ocean which moves at a faster velocity in relation to the outward flow from the Mediterranean Sea in the bottom (Parrilla et al. 1986; García-Lafuente and Vargas 2000, Vargas-Yáñez et al., this book).

These average conditions undergo medium- and long-term changes that are reflected as significant variations of anomalies of some important parameters like sea temperature and salinity along the depth gradient (Fig. 19.3a and b).

Since the 1980s, the variations of temperature and salinity anomalies have been particularly important in some periods. For example, in the middle of the 1990s, sea temperature anomalies significantly higher than two times the standard deviations were detected in the most shallow layers of the sea. Also, this increase in the sea surface temperature was very clear between the years 2010 and 2012. Also, anomalies significantly low were observed in several periods along all depth gradients. This was particularly evident for some years in depths lower than 130 m (years 2002, 2008, and 2010).

A similar anomaly pattern was detected for the salinity (Fig. 19.3b). In this case the variation of salinity in the surface layers is notable in the early 1990s and between 2006 and 2010 where the anomalies oscillated between −3 and 3 times the standard deviation and − 2 and 2 times the standard deviation, respectively.

19.6 Population Status (Assessment Approaches)

19.6.1 Length Cohort and Virtual Population Analyses (LCA and VPA)

The cohort analysis or virtual population analysis (VPA) (Gulland 1965; Murphy 1965) is a widely known analysis in which it is assumed that the stock is composed of several annual cohorts, each of which is analyzed and followed separately. Therefore, VPA is based on backward calculations through time and ages in the function of all ages in the last year age group for all years and estimates the total abundance adding the number of individuals fished and lost by natural mortality during a year to the number of individuals at the end of the year.

The length cohort analysis (LCA) assessment was attempted using the VIT software (Lleonart and Salat 1992). The VIT program was designed to assess exploited marine populations caught by means of different gears and basically can obtain results based on catch data structured by ages or sizes. For this approach, the main assumption is that the population is in a steady state (equilibrium conditions) because the program works with pseudo-cohorts. Therefore it is not run with historic series. As a first step, VIT rebuilds the mortality vectors and population from the catch data. After that, the user can obtain comprehensive VPA results, including yield per recruit analyses based on the fishing mortality vector, analyses of sensitivity, and transitional analyses—outside the equilibrium—due to changes in the pattern of exploitation or recruitment. The stock size estimates, which include annual recruitment estimates, allow to analyze the yield per recruit (Gil-Herrera et al. 2017).

Spawning stock biomass per recruit (SSB/R) (Gabriel et al. 1989) and yield per recruit (Y/R) (Beverton and Holt 1957) analysis are procedures commonly used to test different management strategies. Particularly, these approaches are very useful when historical information on recruitment is limited.

On the other hand, the combination of length/age data over years provides the estimation of reference points for management purposes which also can be extended to analyze the contribution of a fixed number of individuals to the spawning component of population. This way, from the VPA outputs, a spawning stock biomass per recruit analysis and the yield per recruit analyses were estimated as the biological reference points (F_{MAX} and $F_{0.1}$).

19.6.2 LCA/VPA Input Data and Parameters

Before the analysis a smoothing process of the available data (harmonization) was carried out. Later, in order to check the stability of parameters, LCA-VPA backward test was applied for every 2 years separately. Finally, a 2014–2016 pseudo-cohort was generated for the last LCA run. Table 19.4 shows the length-frequency

Table 19.4 Summary of the pseudo-cohort 2014–2016 of Blackspot Seabream used in the Length Cohort Analysis (LCA)

lengthclass (2 cm)	Spain-Morocco			Pseudo-cohort (2014–2016)
	2014	2015	2016	
20	0	0	1169	390
22	0	110	468	193
24	203	1248	1656	1036
26	21,214	18,397	22,665	20,758
28	63,662	61,850	44,955	56,822
30	78,416	79,288	54,951	70,885
32	82,941	80,593	60,672	74,736
34	55,090	68,976	52,972	59,013
36	32,448	59,470	44,730	45,549
38	23,645	47,187	30,483	33,772
40	15,234	36,132	22,347	24,571
42	11,434	28,508	16,418	18,787
44	8238	22,430	12,562	14,410
46	6589	16,343	9136	10,689
48	5087	9458	5238	6595
50	3605	5413	2910	3976
52	2539	2195	1541	2092
54	892	464	476	611
56	311	142	42	165
58	242	61	65	122
60	363	0	32	132
tonnes	259	391	263	304

For this analysis, the parameters obtained from the combined data of Spanish and Moroccan fleets were used (see Table 19.2)

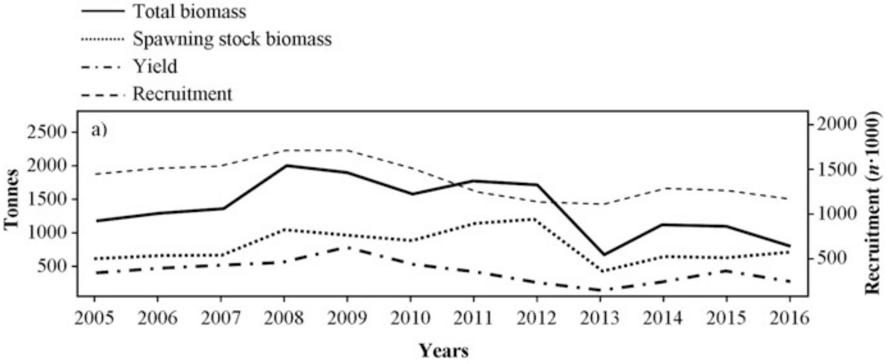
Table 19.5 Blackspot Seabream of the Strait of Gibraltar area—pseudo-cohort catch at age, mean weight at age (g), maturity ratio and natural mortality (M), number of specimens (n)

Class	Catches (n)	MeanWeight (g)	Maturity ratio	M
0	938	167	0.0	0.2
1	79,262	341	0.1	0.2
2	143,575	561	0.5	0.2
3	81,591	820	0.8	0.2
4	40,925	1098	1.0	0.2
5	21,778	1381	1.0	0.2
6	13,178	1656	1.0	0.2
7	7189	1918	1.0	0.2
8	3788	2163	1.0	0.2
9	2110	2387	1.0	0.2
10	1170	2590	1.0	0.2
11	385	2774	1.0	0.2
12	247	2935	1.0	0.2
13	90	3078	1.0	0.2
14	48	3203	1.0	0.2
15	41	3311	1.0	0.2
16	29	3405	1.0	0.2
17	22	3486	1.0	0.2
18	19	3556	1.0	0.2
19	16	3617	1.0	0.2
20	14	3669	1.0	0.2
21	12	3713	1.0	0.2
22	10	3750	1.0	0.2
23+	1	3785	1.0	0.2

distribution used in this assessment, and Table 19.5 presents the 2014–2016 pseudo-cohort age distribution resulting from the slicing procedure.

19.6.3 LCA/VPA Results

The results of LCA/VPA are shown in Fig. 19.4. The time series of recruitment and biomass obtained (Fig. 19.4a) showed a clear decreasing trend and were close to the lower values of the whole series. The spawning stock biomass (SSB) levels were relatively stable over the last 3 years analyzed (2014–2016), and their values were similar to the obtained in 2005 and 2006. On the other hand, fishing mortality (F_{4-11}) (Fig. 19.4b) fluctuated between 0.1 and 0.8 and decreased after the last peaks reached in 2013 and 2015. From the VPA, the reference points indicated that fishing mortality was approximately 0.3 ($F_{current} = 0.3$) which was above the values



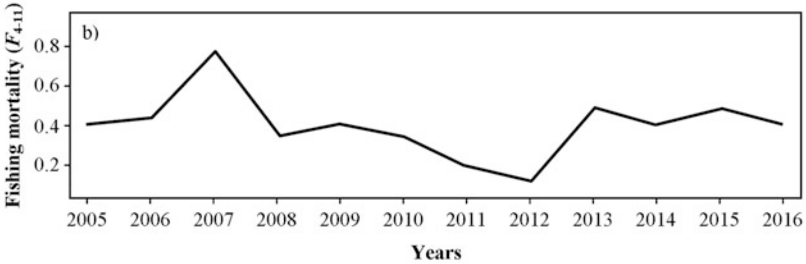


Fig. 19.4 (**a**) Total biomass, spawning stock biomass, yield, and recruitment; (**b**) fishing mortality (F_{4-11}) estimated by means VPA for the Blackspot Seabream in the Strait of Gibraltar area

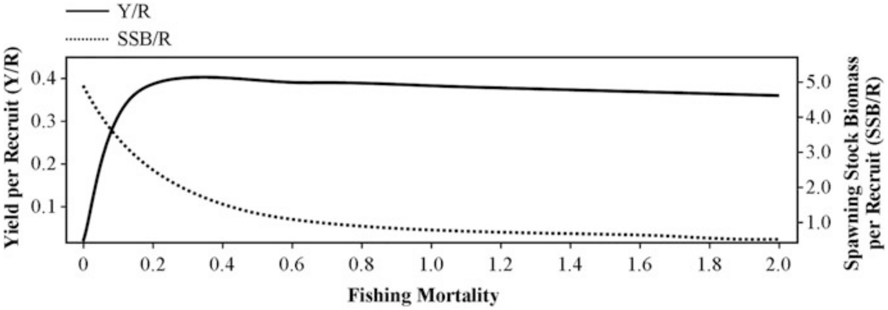


Fig. 19.5 Yield per recruit (Y/R) and spawning stock biomass per recruit (SSB/R) analysis curves performed using NOAA Fisheries Toolbox ((NOAA fisheries Toolbox [NFT] webpage http://nft.nefsc.noaa.gov/)

estimated for the mortality level for the maximum sustainable yield (MSY) (F_{MSY} proxy: $F_{0.1} = 0.14$) (Fig. 19.5).

19.6.4 Globally Applicable Area-Disaggregated General Ecosystem Toolbox (Gadget) Model

Gadget is a model considered to show the greatest potential to contribute to practical fishery management advice such as changes to total allowable catch (Plagányi 2007). It contains a flexible and powerful software tool that has been developed to model marine ecosystems, including both the impact of the interactions between species and the impact of fisheries on the populations. Gadget works by running an internal forward projection model based on many parameters describing the ecosystem and then comparing the output from this model to observed measurements to get a likelihood score (Begley 2005; Taylor et al. 2007).

In this model the processes are usually length dependent. The framework allows the creation of multi-area or multi-fleet models in which it is possible to include predation and mixed fisheries. Gadget has essentially three components: (a) an ecosystem simulator; (b) a likelihood function that takes the output (from the ecosystem simulator) and compares the data; and (c) a function minimizer (optimization routines to find the best set of the model parameters values). To work, Gadget needs initial estimates of recruitment (age 0) every year and initial abundances by age in the first year.

19.6.5 Gadget Input Data and Parameters

Particularly, to establish and project forward the population dynamic of the Blackspot Seabream in the Strait of Gibraltar, Gadget follows this order: fish are caught by the "*voracera*" fleet with five different selection patterns (one for Morocco and four for Spain); afterwards it dies by natural mortality and eventually growths and ages.

As is stated above, model parameters are estimated minimizing differences among observations and estimated values provided for the program. Gadget's probability processes the result of the ecosystem simulation based on aggregate dimensions: thus within this module, several datasets can be compared to the model output using a suite of different types of length distribution. Particularly, in the case of the Blackspot Seabream fishery, Gadget model takes into account four different types of data to enter the probability function: length distribution from commercial fleets (Morocco and Spain), age-length distribution and sex ratio at length (from biological samplings), and finally fleets' effort (in fishing days). Thus the likelihood or probability function included a total of 20 different components.

For a simulation with Gadget, it is necessary to assume that the Blackspot Seabream is a long-live species, so the maximum age is set at 17 (for males and females). While the model length range was from 0 to 62 cm, in 1 cm length intervals, with female population start at 20 cm. The period of simulation considered starts in 1983 and ends in 2016. On the other hand, in Spain four catch categories

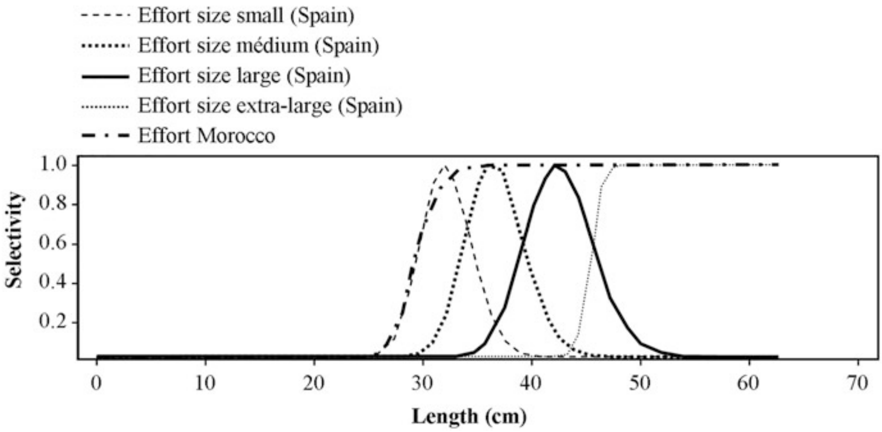


Fig. 19.6 Selectivity pattern for the "*voracera*" fleet of Spain and Morocco

(associated to market categories) are considered: small, medium, large, and extra-large. For Morocco, a single pattern describes the suitability of its fleet (Fig. 19.6).

19.6.6 Gadget Results

Considering the differences between fleets and market categories, the results of the Gadget model for the Moroccan fleet showed a good fit to the observed data (Fig. 19.7). A similar pattern was observed for the Spanish fleet (Fig. 19.8 a to d). This good fit also was observed when the proportions at age (from agreed otoliths readings) were compared with the model estimates for each market size (Figs. 19.9 and 19.10).

The model for the Blackspot Seabream splits the population into two components: males and females because of the species hermaphroditism. Larger individuals are generally females, and lower percentages in observed ratios were a consequence of the sampling level. Figure 19.11 shows the observed sex ratio and the estimated one by Gadget.

Figure 19.12 represents the estimated disaggregated catches (males and females) included in the model. The Gadget model showed that the catches and total biomass for both sexes decreased after having peaked at their highest level in the mid-2000s (Fig. 19.13). On the other hand, the evolution of the fishing mortalities indicated two peaks over 0.6 centered around the mid-1990s and 2010 associated to those periods in which the catch levels were higher.

Likewise, the recruitment estimates at age 0 provided by Gadget show a strong seasonal profile with a recruitment peak in 1990 and the first years of the 2000s. The values of the most recent years are close to the bounds of the parameter file and look unreliable or at least with a lot of uncertainty (Fig. 19.14).

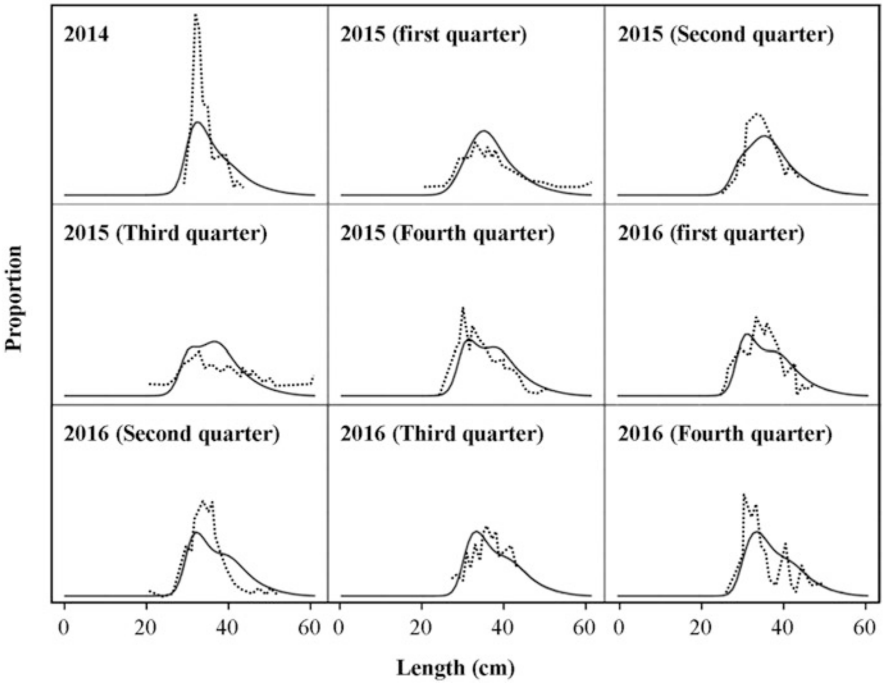


Fig. 19.7 Length distribution from Moroccan fleet from 2014 to 2016. Dotted lines denote the observed values while solid lines correspond to the model predictions

In short, Gadget indicates that Blackspot Seabream population of the Strait of Gibraltar shows a concerning biomass level and that the total biomass gets the lowest value in the last year analyzed (2016) (Fig. 19.15).

19.6.7 Simulation of Fish Populations (SimFish Model)

The simulation of fish population dynamics (SimFish model) is based on the model proposed by Gutiérrez-Estrada et al. (2017) which was compiled in its first version in the SimFish 1.0 program. An improved version has been implemented in SFish Subclass 1.1. SFish works under three basic assumptions: (1) over a sufficiently long period of time, the biomass of a fish population tends to reach a dynamic equilibrium that oscillates around an average value (persistence principle); (2) the environmental conditions under which the parameters of the general growth model calculated remain constant throughout the simulation and; and (3) under the premise of environmental invariability, the variation in the abundance of a population is linearly dependent on the abundance of the resource in the past and the number of catches, so it can be modeled through an autoregressive process of nonseasonal order p and seasonal order P (Gutiérrez-Estrada et al. 2020). Likewise, all simulations are developed in a spatially implicit context.

Like other computer programs, SFish allows to assess the variation of abundance or biomass during the exploitation period. However SFish is specifically designed to disaggregate the environmental effects of the fishing component. If it is assumed that throughout the simulation the environmental conditions remain similar to those found in the period in which the growth model was obtained (i.e., if the model does not incorporate extra-compensatory effects), then the variation in biomass at time t + 1 depends exclusively on the biomass and the catch made at time t, and therefore the biomass series over time can be adjusted to an autoregressive process.

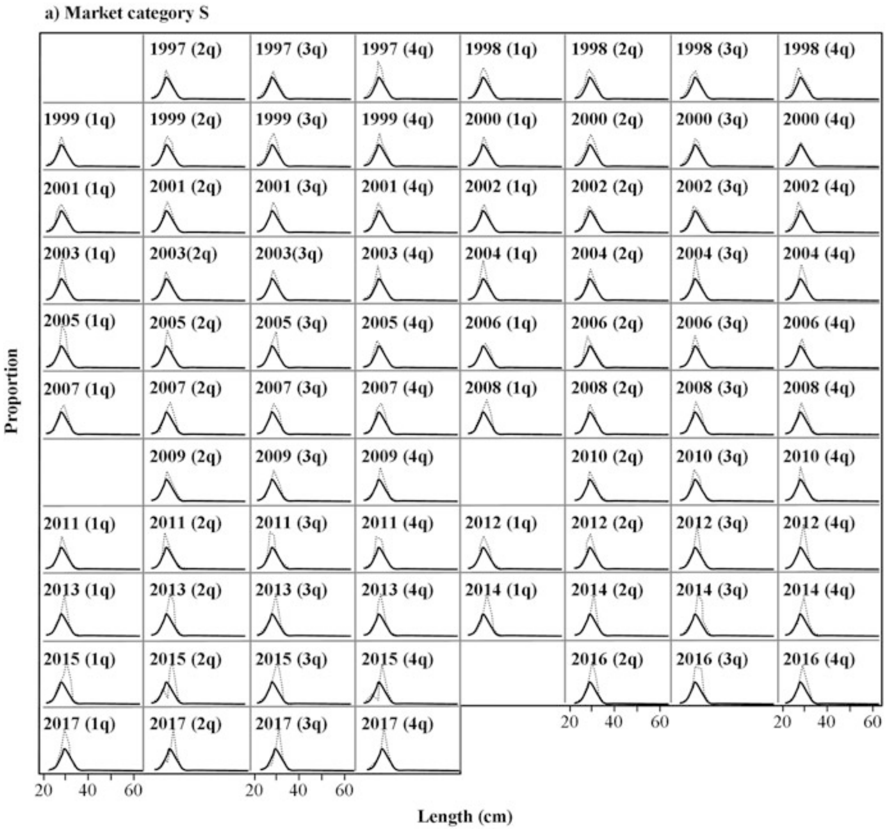


Fig. 19.8 (**a**) Length distribution from Spanish fleet (market category S). Dotted lines denote the observed values while solid lines correspond to the model predictions. (**b** & **c**) Length distribution from Spanish fleet (market category M and L). Dotted lines denote the observed values while solid lines correspond to the model predictions. (**d**) Length distribution from Spanish fleet (market category XL). Dotted lines denote the observed values while solid lines correspond to the model predictions

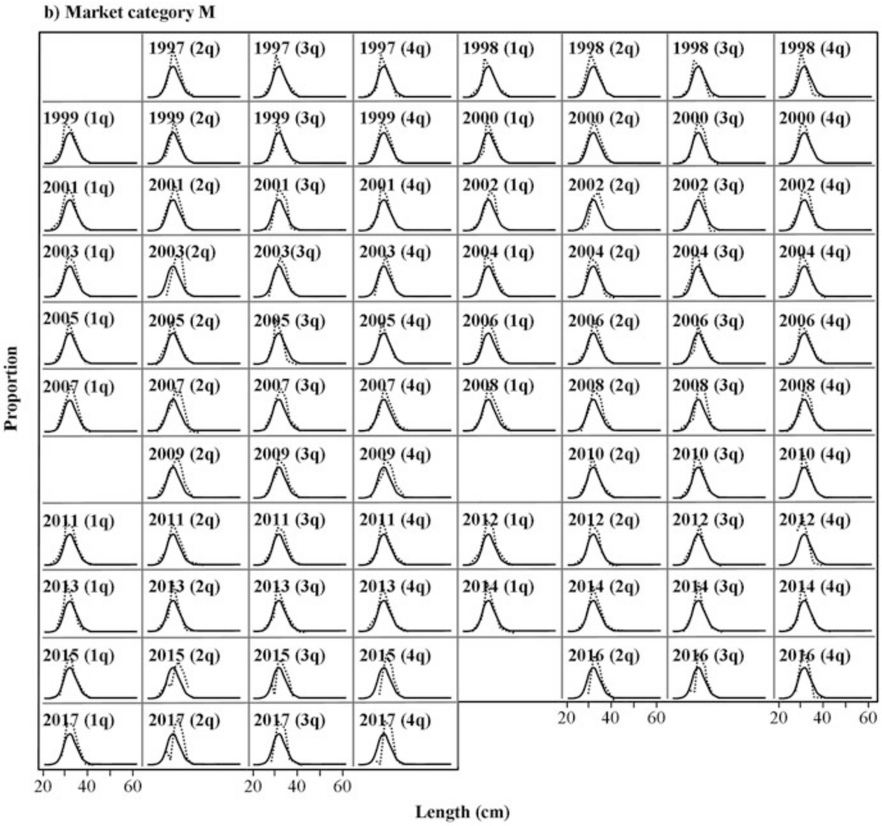


Fig. 19.8 (continued)

Under these assumptions, the lack of fit of the autoregressive model must be the consequence of exogenous factors to the fishery and biological parameters. In this way it is possible to find some type of correlation patterns (linear or nonlinear) between the autoregressive residual series and time series of environmental parameters.

19.6.8 SimFish Data, Parameters, and Simulations

Like Gadget, SimFish requires several parameters about the Blackspot Seabream biology like the population growth model or the population structure composition and different experimental relationships as the established between length and weight or length and fecundity. Additionally, it is necessary to take into account that the Blackspot Seabream is a protandric hermaphrodite species but is functionally gonocoric (Alcaraz et al. 1987). That is, the young individuals are functional

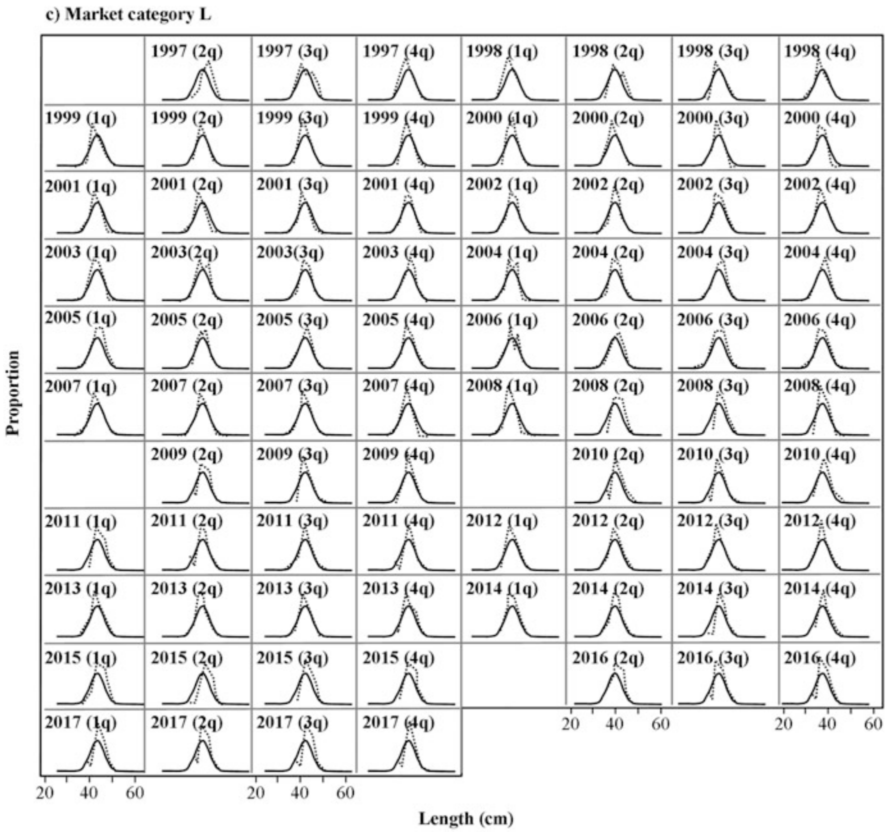


Fig. 19.8 (continued)

males that progressively develop their female gonads to become functional females; therefore it is necessary to know the relationship between length and the proportion of males and functional females. Also, an estimation of the natural mortality and the biomass of age class 0+ at the moment $t = 0$ is required (a complete and detailed description of the parameters required and the algorithms can be found in Gutiérrez-Estrada et al. 2017; Sanz-Fernández et al. 2019 and Gutiérrez-Estrada et al. 2020).

To simulate the abundance of Blackspot Seabream, SimFish requires the catch time series on a monthly scale. In this case, the catches of the Spanish and Morocco are considered jointly. If, in addition to evaluating the abundance or biomass of the population, we want to evaluate the effect of environmental variables, SimFish will require a different environmental database composed of historical series of oceanographic and climate indices.

Initially, the simulations of the Blackspot Seabream fishery in the Strait of Gibraltar were carried out under stability conditions, that is, in absence of catches and considering no effects of environmental conditions on the variation of biological parameters. This provided baseline simulations that allowed to obtain initial values

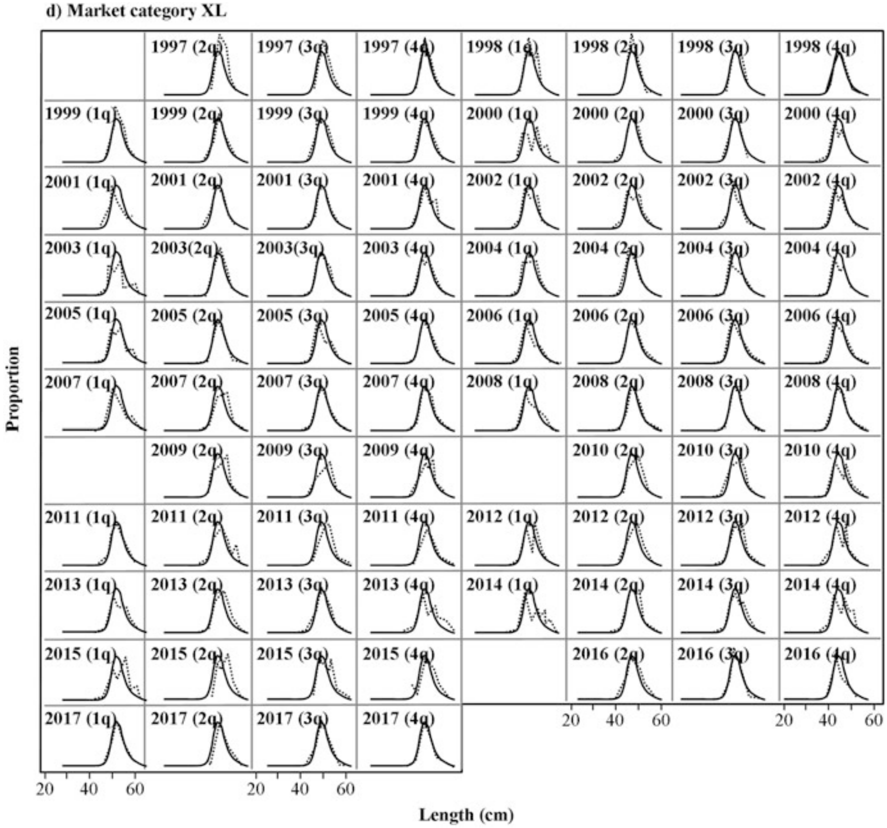


Fig. 19.8 (continued)

of the biomass of the class 0+ at the moment $t = 0$ and a mean natural mortality (M). Once established the parameters that provide a baseline simulation, the simulation process is repeated but subtracting the real catches.

Under this scenario of environmental stability, the variations in biomass at time $t + 1$ depend exclusively on the biomass and the catch made at time t, so autoregression behavior of the simulated biomass series is assumed. For that, ARIMA (Autoregressive Integrated Moving Average) models are used. These models assume that a time series is a linear combination of its own past values and current and past values of an error term. Later, the program calculates the residual time series between the abundance simulated and ARIMA estimation and correlates it with the different time series of environmental variables if these time series are available.

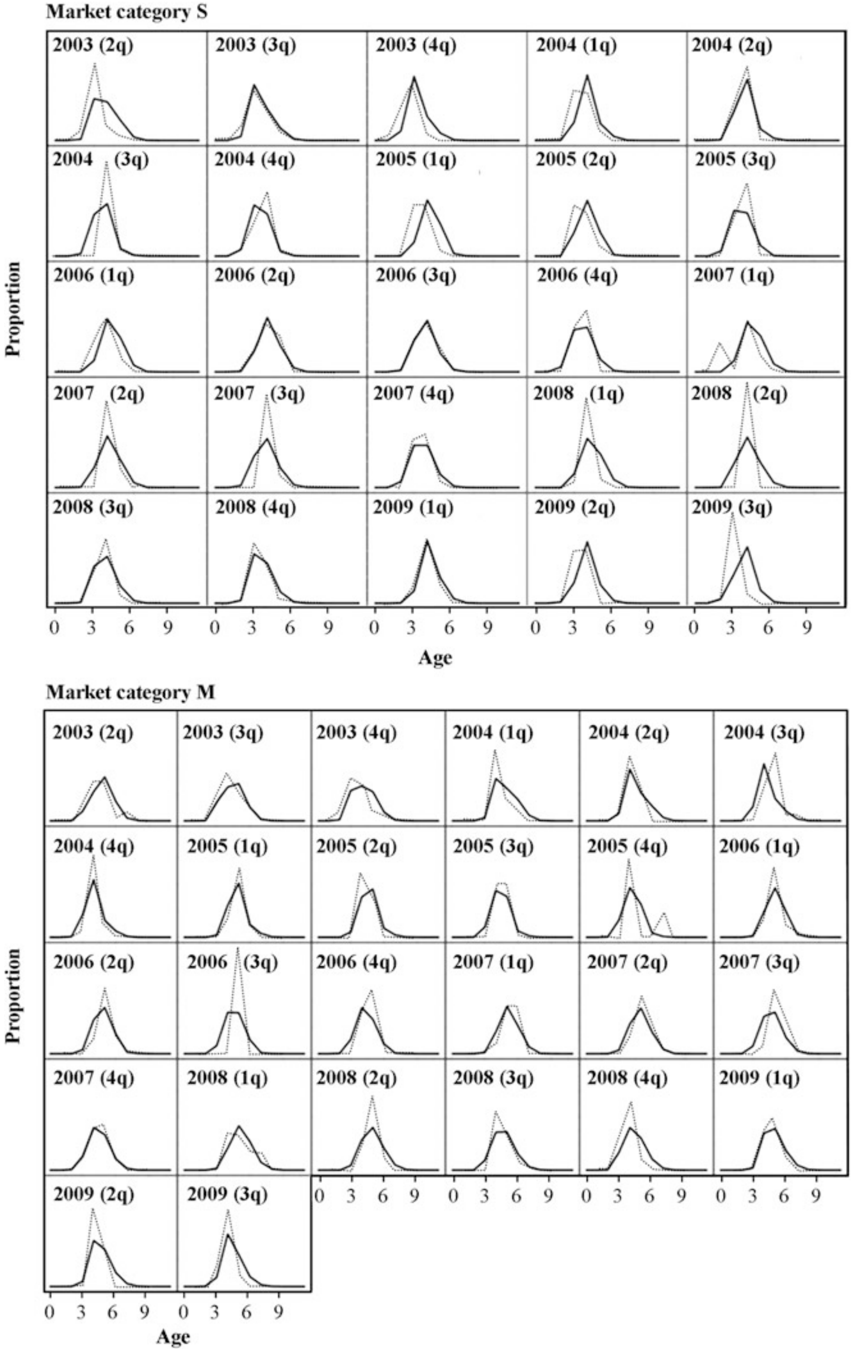


Fig. 19.9 Age distribution from Spanish fleet (market category S and M). Dotted lines denote the observed values while solid lines correspond to the model predictions

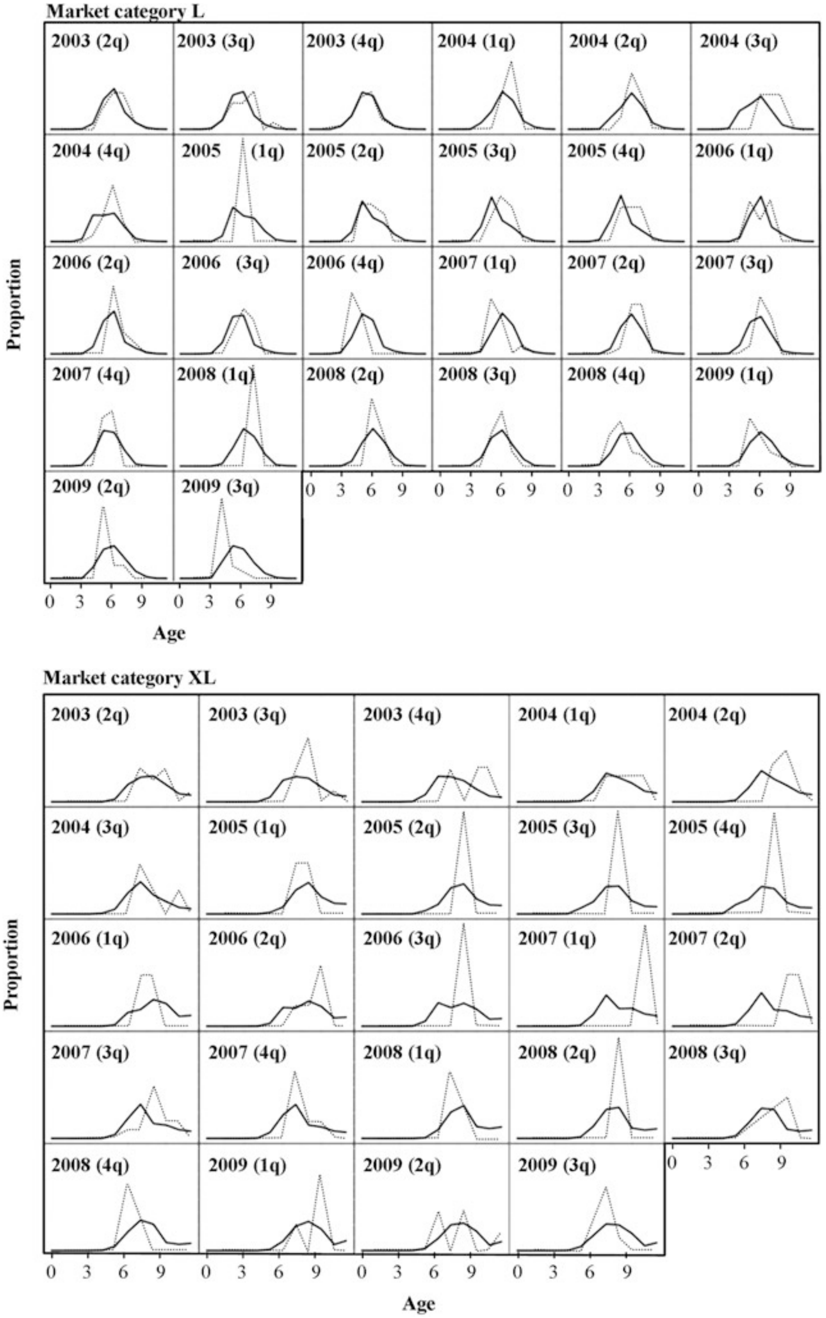


Fig. 19.10 Age distribution from Spanish fleet (market category L and XL). Dotted lines denote the observed values while solid lines correspond to the model predictions

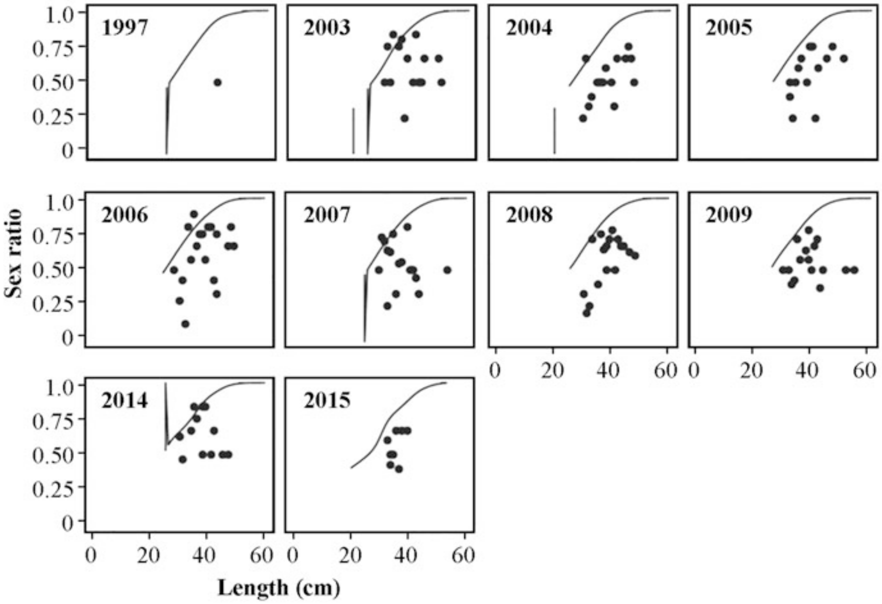


Fig. 19.11 Sex ratio at length distribution from biological samplings. Black points are the observed values while the continuous line represents the model estimates

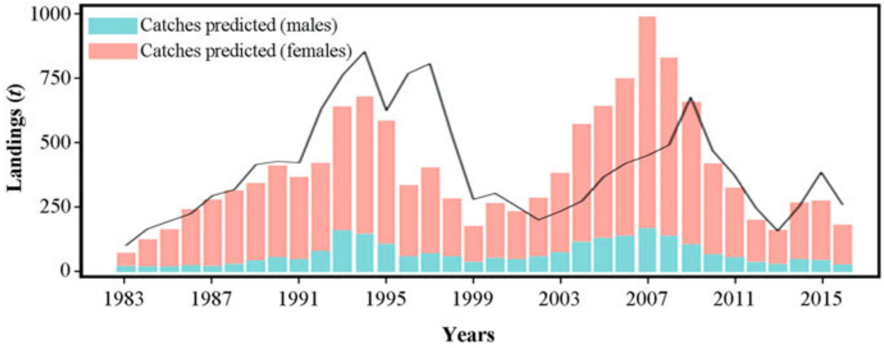


Fig. 19.12 Comparison between catches predicted from the Gadget model (blue and red bars) and the Strait of Gibraltar reported landings (Morocco and Spain) of Blackspot Seabream (black line)

19.6.9 SimFish Results

A total of 4032 simulations corresponding with 7 different bioecological scenarios were carried out. From these, 81.4% provided extinct stocks. The remaining were selected and grouped into 7 biologic-environmental scenarios. These scenarios were classified in function of the age classes (ranged from 15 to 20), the biomass of class 0

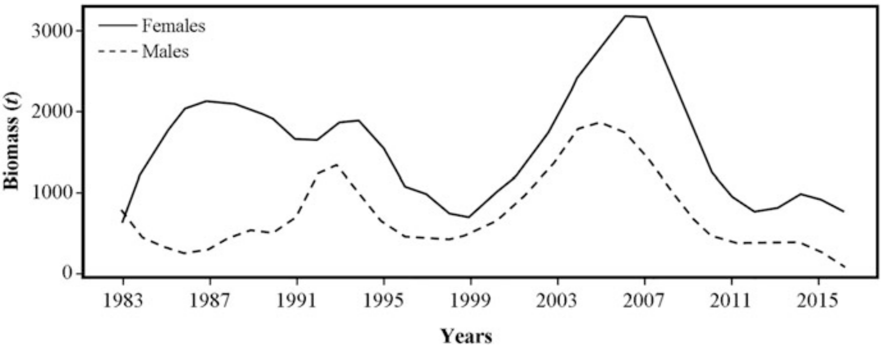


Fig. 19.13 Biomass estimates for the two components of the stock (males and females)

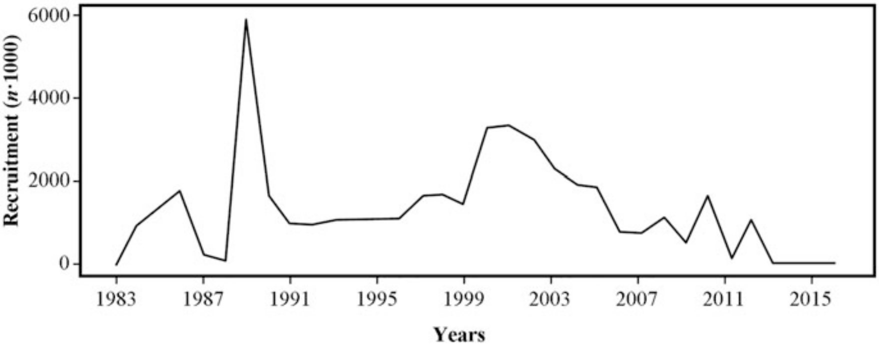


Fig. 19.14 Recruitment estimates at age 0

Fig. 19.15 Assessment summary provide for the Gadget model for the Blackspot Seabream of the Strait of Gibraltar fishery

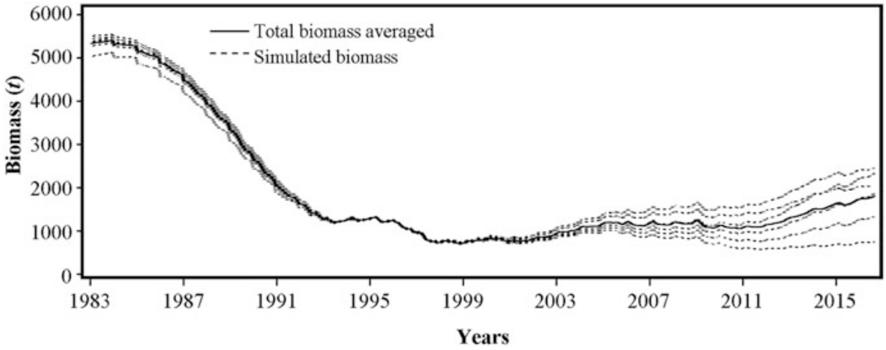


Fig. 19.16 Total biomass simulated obtained with SimFish. Continuous line is the total biomass averaged and dotted lines correspond to the total biomass calculated for simulations associated to different population structures (from 15 to 20 age classes)

+ at time $t = 0$ (between 20 and 45 t), the parameters of the Ricker stock-recruitment relationship, and the percentages of spawn in the spawning period (from January to March).

All the simulations resulted in a similar behavior until the early 2000s (Fig. 19.16). The evolution of the total biomass started at the maximum biomass point around 5300 t. From this year the total biomass decreased to its minimum in 1999 (618 t). From this year, each biological scenario provided different estimations and with a maximum variance at the end of 2016. In this year SimFish estimated that the total biomass of Blackspot Seabream oscillated between a little more than 500 t and 2500 t, which supposed a 9.5% and 47% of the initial biomass, respectively.

When all simulations were averaged, SFish indicated that the biomass at the end of 2016 was 1900 t (35.8 of the initial biomass).

The annual forecasting of ARIMA models for these simulations provided good fits. In the case of the averaged simulations, the average of annual explained variance was 64% and a root mean square error (RMSE) slightly higher than 80 t/year. Therefore, SFish indicates that 36% of the biomass variation could be explained as a consequence of the effects of different environmental factors.

19.7 State of Exploitation and Scientific Advice

The shift towards sustainable fishery management strategies in a context of climate change involves making decisions with strong social and economic implications. How can managers make these decisions taking into account the uncertainty associated with existing information on fisheries and the environment while assuming the principles of sustainable management and planning to short and longer term? It seems evident that the answer to this question involves the use of different types of models, and this is evidenced in this work.

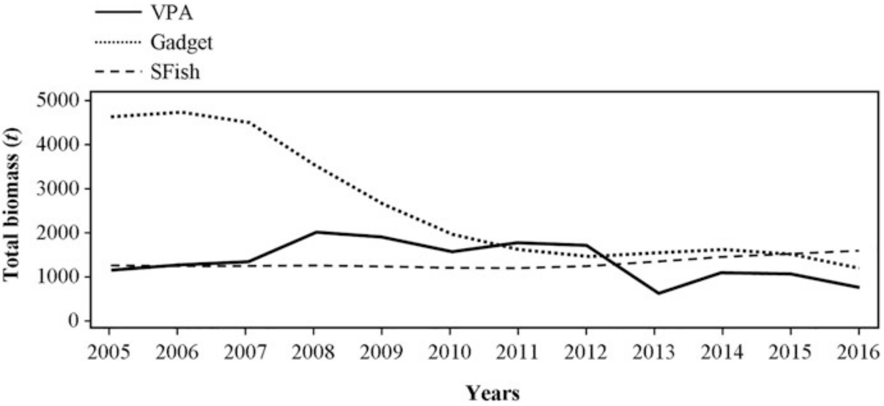


Fig. 19.17 Comparison of results from three different approaches (VPA, Gadget, and SimFish) used for the assessment of the Blackspot Seabream population of the Strait of Gibraltar

The results of this study support the idea that the main factor responsible for the changes in the abundance of Blackspot Seabream in the Strait of Gibraltar is the fishery component. The three approaches used to estimate the total biomass of this species indicate that from 2010 the stock is kept at very low levels that oscillate between 900 and 1600 t (Fig. 19.17). SimFish estimates that at least 64% of the biomass variation is a consequence of fishery component. On the other hand, estimates of the reference point ($F_{0.1} = 0.12–0.17$) from two of the models (LCA-VPA and Gadget) are far above from current fishing pressure (about 0.3) which reinforces the idea of a clear overexploitation of the resource.

On the basis of the above, the level of fishing effort should be reduced in order to set the level of fishing mortality at a more sustainable level. This could be gradually achieved by means of multiannual management plans that foresee a reduction of fishing mortality through fishing limitations. However, nowadays there is no specific/joint management plan implemented for the Blackspot Seabream of the Strait of Gibraltar. Both countries have different management measures on the target fishery, but there are not any common ones towards its sustainability. There is a recent recommendation to establish an adaptive multiannual management plan for the sustainable exploitation of Blackspot Seabream in the Alboran Sea (GFCM/43/2019/2). Its operational objective shall be to maintain fishing mortality for Blackspot Seabream within agreed precautionary reference points in order to reach and maintain as soon as possible a fishing mortality level consistent with the MSY.

Therefore, the stock assessment of the Strait of Gibraltar Blackspot Seabream target fishery is still subjected to a benchmark process within the GFCM. The objective of the benchmark is to perform a full analysis and review of the information and methods used to provide advice on the status of the stock, focusing on the consideration of old and new data sources as well as old and new (or improved) assessment models and assumptions (WGBS 2018). Once this process is closed, the next tool/step might be the development of management strategy evaluation (MSE) to simulate the fishery system and allow scientists, managers, and stakeholders to test whether potential harvest strategies can achieve pre-agreed management targets. Only in this way, the Blackspot Seabream fishery in the Strait of Gibraltar (as other fisheries around de World) will move toward management based on the harvest strategies to increase its long-term sustainability, stability, and profitability.

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Chapter 20
Aquaculture in the Alboran Sea

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20.1 Introduction

Aquaculture is the farming of aquatic organisms. Although it started hundreds of years ago, its boom began in the second half of the twentieth century. The annual production of aquaculture was less than 1 million tonnes in 1950 and 20 million

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tonnes in 1985, and 30 years later, in 2016, production exceeded 110 million tonnes, accounting for almost 55% of total world aquatic production (FAO 2018). Fish account for around half of the aquaculture production, algae close to 27%, and mollusk about 15%.

During this last period, the year-over-year growth of aquaculture oscillated at around 8%, and marine aquaculture has progressed and outperformed freshwater aquaculture. However, this situation differs among countries. Thus, within the European Union, aquaculture represents only 20% of aquatic production, with the harvesting of just under 1.3 million tonnes in 2016. Year-over-year growth in aquaculture has not reached 1%, and regarding the data since 2000, production has even decreased slightly. Production focuses almost exclusively on fish (53% of the total) and mollusks (46%). While fish production experienced a slight but sustained rise, mollusk production has fallen about 1% annually during the last 20 years. The main species of farmed fish are Atlantic salmon (*Salmo salar*), rainbow trout (*Oncorhynchus mykiss*), gilthead sea bream (*Sparus aurata*), sea bass (*Dicentrarchus labrax*), and common carp (*Cyprinus carpio*). Regarding mollusks, the main cultured species are mussel (*Mytilus galloprovincialis*), followed far behind by Portuguese oyster (*Magallana gigas*) and Japanese clam (*Ruditapes philippinarum*).

The situation is similar in Spain. In 2016, 1.2 million tonnes of aquatic products were obtained, of which 284,000 t came from aquaculture, with mussel, sea bass, rainbow trout, and sea bream being the main cultivated species, and in 2018, the total production reached 349,000 t due to an important increase in mussel production (APROMAR 2019). Annual growths in Spain are very scarce, as in the case of all of the European Union. However, there are important differences according to the species; thus, regarding marine aquaculture, while mussel production does not differ much from what was obtained 30 years ago (around 250,000 t per year on average but with significant fluctuations), there has been a significant growth in marine fish production. This occurred mainly throughout the 1990s and in the first decade of the 2000s, reaching about 50,000 t in 2009 and stagnating thereafter.

In Morocco and Algeria, the production is significantly lower, with over 1200 t and 1400 t produced in 2017, respectively. In Morocco in the 1990s, marine production experienced a significant increase, reaching almost 3000 t (1000 t of which was marine aquaculture) in 1999. But production dropped below 1000 t at the end of the first decade of the 2000s, and since then it has maintained a slight rise. In Algeria, the production increase occurred later, reaching 2800 t in 2008 and subsequently decreasing to stabilize in recent years at 1400 t (of which approximately 500 t corresponds to marine aquaculture).

The Alboran Sea is located in the western part of the Mediterranean Sea. It lies among Spain, in the North, Morocco and Algeria, in the south, and the Strait of Gibraltar in the west. The eastern limits are the Cape de Gata (Spain) and the Cape Fegalo (Algeria).

The Alboran Sea is the first one receiving Atlantic waters flowing eastward at the surface, and it is gone through by deeper saltier water flowing westward coming from the Mediterranean Sea to the Atlantic Ocean. Nevertheless, the Alboran Sea circulation is highly variable due to several reasons (see Chap. 4). In general terms, temperature and salinity values of the Alboran Sea upper layer are those of the waters in the Gulf of Cadiz, more or less modified. The degree of modification will depend on the distance to the Strait of Gibraltar and on the water circulation in the different areas within the Alboran Sea.

The currents in the Alboran Sea are mainly driven by the Mediterranean thermohaline circulation, which is modulated by the Coriolis force, winds, and bathymetry. As a result, there is fast Atlantic water current flow in the surface through the Strait of Gibraltar into the Alboran Sea. Although the speed of this current can be modulated within the strait by the tidal currents, its average value is around 1 m/s (Perkins et al. 1990).

As it is shown in Chap. 4, salinity is lower in summer and autumn, which means an increased influence of Atlantic waters. This is in agreement with the higher difference between temperatures in the Alboran Sea and in the Mediterranean Sea in those seasons (see Fig. 20.4 of this chapter).

Industrial aquaculture activity in the Alboran Sea began at the end of the 1970s in Ceuta with a facility devoted to bluefin tuna fattening. After this, in the mid-1980s in Morocco, another company was established in the coastal lagoon of Nador (Morocco). This company was initially devoted to the culture of flat oyster (*Ostrea edulis*), although shortly after it was diversified to include clam (*Ruditapes decussatus*), shrimp (*Penaeus kerathurus* and *Penaeus japonicus*), gilthead sea bream (*Sparus aurata*), and sea bass (*Dicentrarchus labrax*).

In Spain at the end of the 1980s, two very different projects started: a platform for fish culture in the bay of Algeciras and a land-based culture facility for brine shrimp artemia (*Artemia salina*) and shrimp (*Penaeus kerathurus)* near Cabo de Gata. Over the period of the 1990s, other installations to culture sea bream and sea bass were built along the coast of Granada, while mollusk farming using floating structures and longlines began in 2000. In recent years, the number of cultured species has increased (amberjack, sole, octopus, microalgae, anemones, etc.), although most of them are still in a pre-industrial phase.

Currently there are around 20 aquaculture companies authorized in the Spanish area of the Alboran Sea, most of them dedicated to the culture of mollusks in the province of Malaga, although there are also land-based facilities and sea-based cages for culturing fish. Not all these companies are running, and in 2018 there were 15 companies with activity in that area: 12 facilities for mollusk culture, 2 for fish culture, and 1 for other species. The main cultured species were sea bass (1500 Tm) and mussel (close to 800 Tm).

In Morocco 22 facilities dedicated mainly to shellfish culture are running nowadays. According to ANDA, production in Morocco during 2015 was 470 Tm (oyster and sea bass as the only species). In 2018 in the Alboran Sea, there were four facilities, one of them culturing sea bass (production of 121 t), two farms starting commercial production of mussels (there are some problems with regulations restrictions) and with a production of a few tens of tonnes, and the other one dealing with culturing red algae (*Gracilaria gracilis*). In Algeria, there are 30 facilities dedicated to 50% fish and 50% mollusks, and 8 of them (3 shellfish farms and

5 fish farms) are placed in the Alboran Sea. According to the Directorate General of Fisheries (DGF) of Algeria, overall production in 2017 was 1543 t, and the cultured species were sea bream, sea bass, and mussels.

However, it is noteworthy that in recent years there has been a diversification of the cultured groups. In Spain there are projects for farming octopus, sea cucumbers, and anemones, and in Morocco there is a project for culturing red seaweed.

Long-term changes in the temperature and salinity of the water masses that fill the Alboran Sea have also been observed since, at least, the mid-twentieth century, showing a warming and salting of the whole water column (see Chap. 4). This warming, in accordance with climate change, could lead to new chances for aquaculture in this area.

20.2 Main Cultured Species

As it has been pointed out before, numerous species have been cultured in the Alboran Sea. The main cultured fish species in the Mediterranean and also in the Alboran Sea are sea bass and sea bream. According to APROMAR (2019), the sparid gilthead sea bream, *Sparus aurata*, is currently the most produced fish species in the Mediterranean Sea (247,000 t in 2018), and it is cultured both in land-based (lagoons, tanks) and offshore facilities (cages and platforms). The European sea bass, *Dicentrarchus labrax*, is the most cultivated fish species in Spain (22,500 t produced in 2018), mainly in sea cages. Its production reached 196,000 t in the Mediterranean Sea last year and 1500 t in the Alboran Sea.

There have been attempts to culture other species: Atlantic bluefin tuna (ABFT), *Thunnus thynnus*, is a teleost belonging to the Scombridae family. Although its life cycle has been closed in captivity, ongrowing from hatchery-reared tunas is still in a pre-industrial phase. The industrial activity consists of a semi-culture where purse seiner-caught tunas are transferred to sea cages and fattened for a period of 3 to 7 months (De la Gándara et al. 2016). The first tuna farm in the Mediterranean was established in Ceuta in 1979 (Miyake et al. 2003), where tunas coming from a trap (Spanish term is Almadraba) were fattened. Seriola or yellowtail, *Seriola dumerili*, is a pelagic fish that belongs to the family *Carangidae*, very sensitive to ciliated parasites and monogenea trematodes. There is a hatchery in the contiguous Atlantic area, close to the Alboran Sea (in Cadiz province), but despite several attempts made to culture them, there is not yet a reliable production in the Alboran Sea. Sole, *Solea senegalensis*, is a flatfish with a high commercial value. Its culture is undertaken in land-based facilities and ideally in recirculation systems, under temperature and culture parameters controlled, since sole is very sensitive to infections and it requires high-quality water and careful handling. The meagre, *Argyrosomus regius*, is a very appreciated sciaenid which presents some problems derived from diseases, mainly granulomatosis, a disease of unknown etiology that affects a large percentage of the population. Currently, meagre is not being cultivated in the Alboran Sea; however, there are two nearby rearing farms, and it is widely cultured in Spain and Portugal.

Other fish species cultured in the past, mainly in lagoons in Morocco, are common dentex (*Dentex dentex*), white sea bream (*Diplodus sargus*), sharpsnout sea bream (*Puntazzo puntazzo*), red porgy (*Pagrus pagrus*), spotted sea bass (*Dicentrarchus punctatus*), blackspot sea bream (*Pagellus bogaraveo*), and European eel (*Anguilla anguilla*).

The most cultured mollusk in the Alboran Sea is mussel (*Mytilus galloprovincialis*), a black bivalve slightly triangular and with two elongated symmetrical valves. Mussel farming can be considered to be undertaken in an extensive regime, because despite the high density, no food is provided. Mussel seeds are obtained from the wild and successfully cultivated in floating structures like rafts, rigid wooden structures equipped with large floats, or longline, longitudinal ropes attached to several floats. Vertical ropes that hold the mussels hang from both systems. The rafts are located in protected locations and constitute the main mussel farming system in Galicia (NW Spain).

Other cultured mollusks are different members of the scallop genus *Pecten* (*Bivalvia: Pectinidae*) including king scallop, *Pecten maximus*; black scallop, *Mimachlamys varia*; and queen scallop, *Aequipecten opercularis*. There have also been attempts, mainly in Morocco, to cultivate flat oyster, Japanese oyster, and different species of clams.

For several years there has been a growing interest in the culture of common octopus (*Octopus vulgaris*). This cephalopod is a species of high growth and great commercial value, and the reduction of catches observed in recent years has intensified the interest in its culture. It is a semi-culture that consists of the capture of adult individuals (minimum weight in Andalusia is 1 kg), and they're ongrowing during a period of 3–4 months. In this they can reach up to 3–4 kg in weight.

Among the other cultured species, of note, are microalgae (*Tetraselmis*, *Nannochloropsis*, *Isochrysis*, *Dunaliella*), macroalgae (*Ulva lactuca* and *Gracilaria gracilis*), rotifers (*Brachionus plicatilis*), holothuriae, anemone, sea urchin, Mediterranean brine shrimp (*Artemia salina*), and shrimps (*Penaeus kerathurus* and *Penaeus monodon*).

20.3 Aquaculture in Spanish Coasts

Aquaculture in the Alboran Sea in Spain is still ongoing. Although numerous projects have been started, currently there are only two cage facilities, twelve mollusk farming facilities (in rafts and in long lines), a gilthead sea bream nursery, and another two onshore facilities that deal with experimental rearing of octopus and holothuria. There is a web page from the Spanish Ministry of Agriculture, Fisheries and Feeding (https://servicio.pesca.mapama.es/acuivisor/) which shows the facilities running in 2018.

The Regional Government of Andalusia (Junta de Andalucía) publishes yearly a document on the production of marine aquaculture in Andalusia. The last one could be found in https://www.juntadeandalucia.es/export/drupaljda/20190612%

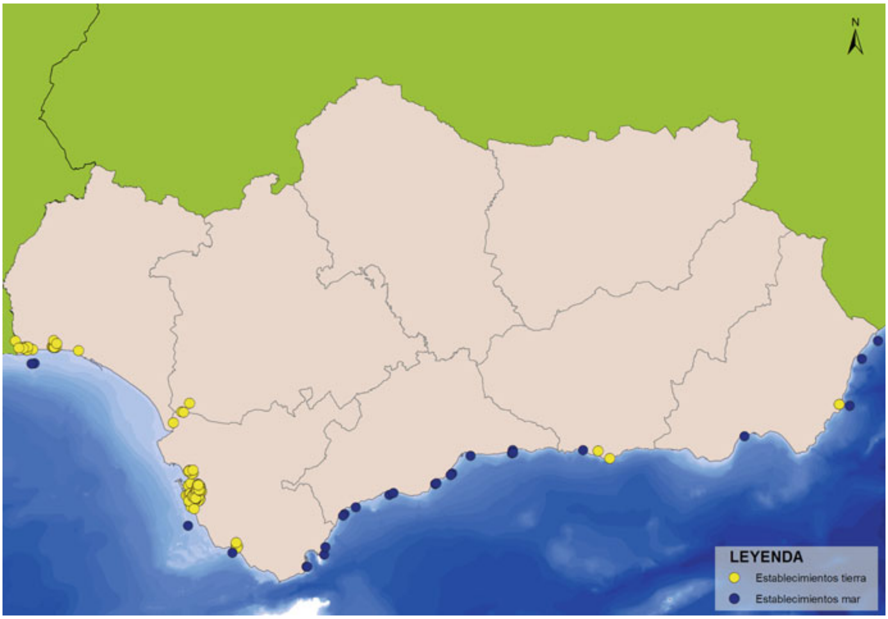

Fig. 20.1 Facilities existing in Andalusia in 2018. Blue points mean offshore facilities, and yellow point means onshore facilities (AGAPA 2019)

Table 20.1 Main cultured species in aquaculture (AGAPA 2019)

Species	Tonnes
Dicentrarchus labrax	3963
Thunnys thynnus	1178
Mytilus galloprovincialis	968
Sparus auratus	763
Solea senegalensis	492

20Acuicultura%20Marina%20Andaluc%C3%ADa%202018.pdf. Active facilities (onshore and offshore) during 2018 are shown in Fig. 20.1.

Table 20.1 shows the main cultured species in Andalusia in 2018. These five species account for more than 95% of the total production. Other cultured species are *Palaemon varians*, *Crassostrea gigas*, *Argyrosomus regius*, *Mujil* sp., and different microalgae (*Nannochloropsis gaditana*, *Tetraselmis chui*, etc.). Most of these species are not cultured in the Alboran Sea, where the main production comes from sea bass, *Dicentrarchus labrax* (about 1500 t), and mussel, *Mytilus galloprovincialis* (close to 800 t).

Periodically the Regional Government of Andalusia also publishes a document dealing with the areas for developing aquaculture. The last published review was

"Localización de Zonas Idóneas para el Desarrollo de la Acuicultura Marina en Andalucía" (Zurita et al. 2014). This document deals with the ideal location areas to develop marine aquaculture, to identify places which could be declared as areas of aquaculture interest, and to develop a database for further planning of activities in shoreline areas.

20.3.1 Fishes

20.3.1.1 Marine Fish Culture History in the Mediterranean Coasts of Spain

Aquaculture in the Alboran Sea began at the end of the 1980s with the installation of a platform for the culture of sea bream and sea bass in the Bay of Algeciras, Spain. The company named PISBARCA S.A. was operating for several years. The platform housed seven cages, and it was capable of producing yearly about 500 t. (Fig. 20.2).

The profitability of this great platform was low, and in the decade of the 1990s, offshore facilities consisting of floating round cages of polyethylene, with variable diameters in the range of 16 and 24 m., began to be installed. These cages were located in places close to the coast, with a variable depth in the range of 25 to 40 m. Among these companies there were Acuaisleta S.L. and Adrapec S.L. in the province of Almeria, Azucarera de Guadalfeo S.A. in Granada, Costa del Sol Fish Farm

Fig. 20.2 Platform for fish culture (Pisbarca, 1989) (photo by Javier Villa)

Fig. 20.3 Azucarera de Guadalfeo 2018, cages for sea bass and sea bream (photo by Javier Villa)

and Los Mellizos Fish Farm in the province of Malaga and ALMINA FISH S.A., and the Iberian Aqua System platform (which only worked for a couple of years and then ended operations) in Ceuta (Fig. 20.3). All of them produced sea bream and sea bass, with production capacities that reached 1000 t per year and per installation. Due to various difficulties, all of the aforementioned facilities ceased their farming activities, most of them in the first decade of the 2000s.

It is noteworthy that an attempt to cultivate turbot, *Scophthalmus maximus*, was carried out at the beginning of 2000 by a company, Granja Piscícola Costa del Sol, in submerged cages that were designed for that specific purpose, but due to different reasons, the project was unsuccessful.

In terms of onshore installations, aquaculture began at the end of the 1980s with an ongrowing facility for sea bream and sea bass (CIBERTEM S.A.) located in Carchuna (Motril municipality). This was acquired by PROMAN Fish Farm in the early 1990s, and after some reforms, the plant was dedicated to pre-ongrowing and ongrowing of sea bream and sea bass. A few years later, the ongrowing process was abandoned due to the impossibility of making it profitable, and they focus only on pre-ongrowing, which consists in growing juvenile fish from 0.5–11 g average weight to 10–15 g. The process takes 2 or 3 months, and then fish are sold to cage facilities.

In April 2000, the abovementioned facilities received a batch of juveniles of sole (*Solea senegalensis*) from CUPIMAR Fish Farm; hence, for the first time, they were undertaking the intensive worldwide culture of this species, that until then it was only harvested in the estuaries of the Gulf of Cadiz. The success of the culture, regarding growth and survival, allowed to commercialize the first Senegalese soles bred totally in captivity, giving a rise to a stake in this species. In the 2001, problems derived from the water quality caused pathologies to arise. Thus, contacts were initiated with the Department of Microbiology at the University of Malaga for the development of probiotics and autovaccines for the species, which produced interesting results.

In 2002, PROMAN began operating as a hatchery, developing larval cultures of sole from fertilized eggs that were supplied by the Fisheries and Aquaculture Research and Training Centre of El Toruño (Puerto de Santa Maria, Cadiz) and forming their brood stock. Soles started to reproduce in 2003, and natural spawning was obtained twice by year, in autumn and spring, that allowed PROMAN to supply their own hatchery. The production of sole continued until 2010, when the company closed, although since 2007 the culture was mostly carried out in recirculation systems that allowed good growth and survival rates of more than 90% on average, from the weaning to a stable commercial size.

In 2003, a project concerning seriola (*Seriola dumerili*) was undertaken by PROMAN. In June of that year, PROMAN begins to transport the first specimens from a nearby fishing trap, to form a batch of brood stock. In the spring of the following years, the fish showed a behavior associated with spawning, but the females did not mature, and no spawning occurred. In 2006, spawning was hormonally induced, and several viable batches of good-quality eggs were obtained, producing the first juveniles. The following year, the number of obtained fertilized eggs was more abundant, and around 20,000 juveniles were produced, although a high mortality rate occurred during transportation to the cages. In 2008, natural spawning was obtained without the need for hormonal induction, and many juveniles were successfully transferred to be fattened in cages. The process was repeated in 2009, and about 35,000 juveniles were produced. Every year, some thousands of juveniles were ongrown in tanks until they reached 3–5 kg of average weight; hence, they were the first commercialized specimens born in captivity outside of Japan.

In 2010, the economic difficulties of the business group led the company to bankruptcy and to sell all stocks, including brood stock. A few years later, PROMAN was acquired by Aldalmar Biotech which dedicated its endeavors to the ongrowing of common octopus (*Octopus vulgaris*).

Another nearby fish farming company was Azucarera de Guadalfeo S.A., which, using hot water from a sugar production plant, was dedicated to the pre-ongrowing of sea bream and sea bass, while also having a nearby facility offshore for the ongrowing of these species in the sea. Azucarera de Guadalfeo S.A. started its activity in 2001 and remained active until 2010. Later, Azucarera de Guadalfeo S.A. was acquired by other entrepreneurs and currently belongs to Aquaculture of Granada.

20.3.1.2 Current State and Overview

At present, fish aquaculture in cages in the Spanish Alboran Sea has its focus almost exclusively on sea bass, and there is only a facility running in Almeria. There is also another installation in Granada belonging to the Aquaculture of Granada that in 2016 launched a project concerning the integrated multitrophic aquaculture (IMTA) of sea bream in floating cages and also of mussel on longline but currently only produces mussels. Another facility located in Malaga was recently closed.

There is also a nursery that pre-ongrows sea bream and sea bass fingerlings to sell them to nearby facilities. In these last years, they focus on gilthead sea bream (about 7 million juveniles in 2017 and 10 million juveniles in 2018).

The main problem concerning fish culture in the Alboran Sea is the lower temperature of the water in relation to the temperature that exists on the coasts of northern Gata Cape, of Murcia and Valencia regions. This difference in water temperature, which can reach more than 2°C with respect to the annual average, is higher close to the Strait of Gibraltar, and it is especially pertinent in summer, when the differences can reach 3–4°C. However, in winter and at the beginning of spring, the differences are practically non-existent (Fig. 20.4). This means that sea bream and sea bass will take 1 or 2 extra months to reach the commercial size in the east of the Alboran Sea and even more in the west part, close to the Strait of Gibraltar. This is one of the reasons why large business groups may prefer the warmer waters of the Spanish eastern coasts.

There are different equations to estimate the growth of gilthead sea bream and sea bass. Figure 20.5 shows the growth for sea bass, introduced in early June in these three different locations, estimated according to Jover (2000). Another estimation of the growth of gilthead sea bream based on Mayer et al. (2012) is shown in Fig. 20.6.

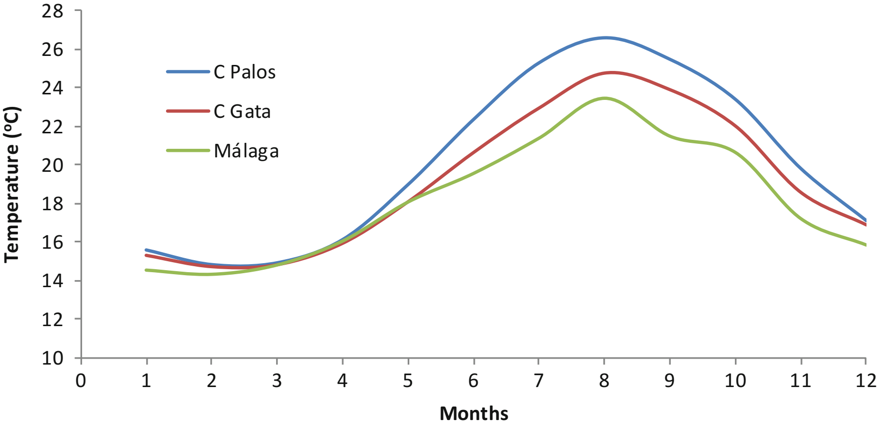

Fig. 20.4 Comparison of average monthly temperature as registered by the maritime stations of Cabo de Gata (36°43'N; 2°12'W), Cabo de Palos (37° 40'N 0°40'W), and Málaga (36°41'N; 4°25'W) throughout the last 5 years (2014–2018). Data from Puertos del Estado (http://www.puertos.es/es-es/oceanografia/Paginas/portus.aspx)

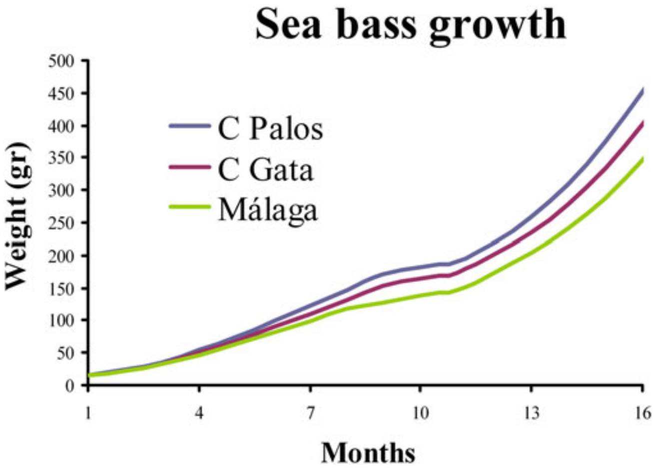

Fig. 20.5 Estimation of sea bass growth according to Jover (2000)

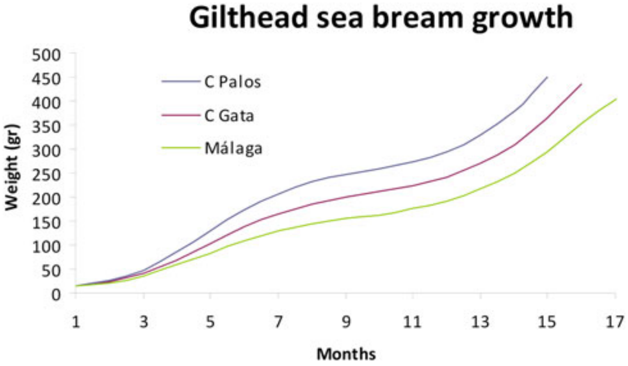

Fig. 20.6 Estimation of sea bream growth according to Mayer et al. (2012)

In view of this situation, it will not be easy for aquaculture of sea bream and sea bass to develop in this area. Notwithstanding, two aspects can play in its favor: the existence of some places where windy and stormy days are not prevalent. In the Mediterranean, aquaculture is developing mainly in the open sea, and on days of heavy weather, fish cannot be fed. Areas with lower hydrodynamic have a beneficial effect on the growth of these fish so that they can achieve more days of feeding, which could in part compensate for the lower growth rate caused by lower temperature. And on the other hand, climate change can be a chance for these colder waters, since there would be an increase in fish growth within them. More than that, this warming could be detrimental to the aquaculture of some of the species in the warmer areas in the Mediterranean Sea.

With regard to amberjack, *Seriola dumerili*, the European project Diversify has shown that, even when some improvements are still needed, the culture of amberjack could be an alternative nowadays. There is a hatchery in Andalusia, and despite the fact that young fish prefer temperatures over 25°C, some studies (DIVERSIFY 2018a) have shown that fish greater than 350 g grow at a higher rate at temperatures between 21 and 23°C. Meagre (*Argyrosomus regius*) is another species that could be cultured in this area. There are some hatcheries close to the Alboran Sea, and, according to some authors (DIVERSIFY 2018b), it seems that temperatures above 25°C could be detrimental for growth and feeding conversion rate. More than that, some pathological problems affecting amberjack (ciliated parasites like *Cryptocaryon irritans* and monogenea trematodes like Neobenedenia and Zeuxapta) and meagre (systematic granulomatosis) could be more harmful at higher temperatures in summer.

Atlantic bluefin tuna could also be an option since, besides the cages placed in Ceuta in 1979, a couple of farms have been running in Cadiz and Almeria, only a few miles away from the Alboran Sea. In 2018, a facility in Barbate (Cadiz) fattened more than 1100 Tm of tuna. There are not any technical problems in this semiculture, the only drawback is to transport tunas from Almadrabas in Cadiz, where tunas are captured, to the Alboran Sea through the Strait of Gibraltar.

Apart from these considerations, aquaculture of some fish from colder waters could be considered, and, in this sense, the culture of emerging species like the blackspot sea bream, *Pagellus bogaraveo*, and maybe first stages of ongrowing of wreckfish, *Polyprion americanus*, could be an interesting alternative in the next future.

As it has been stated before, a land-based facility for pre-ongrowing of sea bass and sea bream is running in this area. Pre-ongrowing is needed for cage development so that fish are usually introduced in the cages when they are 10–20 g on average, and these facilities could be useful for nearby cages.

By the last, sole could also be a candidate to be cultured in land-based facilities, as it was demonstrated some years ago. In both land-based facilities, recirculating aquaculture systems (RAS) could improve the obtained results, keeping good-quality water as well as an adequate temperature during all the culture. In addition, facilities with RAS techniques are considered to be less detrimental to the environment.

20.3.2 Mollusk

20.3.2.1 Bivalve Mollusk

The culture of bivalve mollusks in the Alboran Sea is undertaken extensively, through the capture of postlarval stage and their fattening to commercial size. The whole farming cycle takes place mainly in the open sea, since there are few sheltered areas. In addition, due to the strong demographic pressure that exists in the area, there are increasingly fewer freely available areas to install facilities to culture mollusk.

Experiments have been carried out in the Alboran Sea to determine the viability of the culture of mussel (*Mytilus galloprovincialis*), banded carpet shell (*Venerupis rhomboids*), and three members of pectinids: king scallop (*Pecten maximus*), black scallop (*Mimachlamys varia*), and queen scallop (*Aequipecten opercularis*). Studies have also been conducted with regard to their reproductive cycle, the intensity of seed capture in the natural environment through collectors, and their fattening using floating systems.

The first attempt to culture bivalve mollusks in the Alboran Sea was carried out in La Herradura (Granada) at the beginning of the 1990s, whereby a raft was installed to cultivate mussels, but results were not good, and the platform was raised. Subsequently, in 1997, an experimental project for the culture of mollusks in the Alboran Sea began. This project was funded by the Regional Government of Andalucía and was carried out by the Spanish Institute of Oceanography to assess the viability of the culture of pectinids (king scallop, black scallop, and queen scallop) along the coast of Fuengirola, province of Malaga. Later, the project was extended to the coasts of Marbella and Estepona (Province of Malaga), with funding from the National Plan for Scientific Research, Development and Technological Innovation.

In 1999 longlines were installed on the coast of Marbella to assess the viability of mussel farming in this area and its exploitation in an industrial manner. Later, some rafts were placed in Velez Malaga (Province of Malaga), although due to their location, they neither function, and they were also raised. Furthermore, another company installed rafts in La Linea de la Concepcion (Cadiz) in a sheltered location with good results, and they are still working

Mussel Culture

Mussel (*Mytilus galloprovincialis*, Lamarck, 1819) is a bivalve mollusk dioecious species, reaching maturity as males, but as they age, a great percentage of individuals change their sex to become females (protandric hermaphroditism). It is cultured from the mid-1900s in Spain, mainly in Galicia (Pérez Camacho et al. 1991).

In the Alboran Sea, mussel seed is obtained by using collector ropes anchored in the same raft in spring and autumn and then taken off between March and July, when they are in the range of 5–20 mm in height or by collecting the seed from the rocks in spring when they have similar sizes. In the Andalusian Mediterranean coast, the fixation of the seed shows a seasonal pattern with a greater abundance between mid-spring and early summer, although there is an abundance of seed throughout the year. It is advisable to anchor the collecting ropes at the beginning of spring and at depth to increase seed collection (JACUMAR 2011). In spite of spat recruitment showing a vertical gradient, differences according to location are founded (Leon et al. 2009). Obtained mussel seeds are moved to growing facilities, mostly to longlines in several locations (Fig. 20.7) but also to rafts placed mainly in La Linea de la Concepcion (Cadiz) (Fig. 20.8).

The surface longline consists of a main line with a series of plastic, polyester, or polyethylene buoys, which are joined by longitudinal lines arranged horizontally to the surface of the water. Vertical ropes that support the mussels are fixed to these longitudinal lines. The rafts are rigid floating structures anchored to the bottom. They consist of a grid of polyethylene beams assembled on a float system (Esteban

Fig. 20.7 Mussel culture in longlines (photo by Juana Cano)

Fig. 20.8 Mussel culture in rafts (photo by Juana Cano)

et al. 2013). In Andalusia, they are being used in the open sea with floats that allow them to submerge when a strong storm occurs.

Mussel seeds are attached to a nylon rope (dimensions of 12 m in length and 2.5 cm^2 thick) by winding the seed onto the rope, using a biodegradable cotton mesh. This mesh decomposes within a few days, but this provides enough time for the mussel seed to produce a new byssus, with which it has been attached to the rope. This process is similar to those described by Pérez Camacho et al. 1991in Galicia (NW Spain).

The pre-ongrowing lasts between 4 and 5 months, and the mussel attains about 40–50 mm in height. After this time, it is necessary to thin out the ropes: from each of these ropes, an average of three new ropes with transferred mussels are obtained. This ongrowing period takes about 10 months, and the harvest is carried out when mussels get a size of 60–80 mm in height. The greatest growth is observed in winter, and the duration of the culture period is 14 months in Marbella, 16–18 months in Caleta de Vélez, and 10–12 months in La Linea de la Concepcion. Studies have also been carried out in Ceuta. Commercial size (> 70 mm) is reached within 10 months of culture, starting from an initial average size of 45 mm. The highest growth rates are obtained in July and September. Ceuta can be considered a suitable area for ongrowing, but it has a limiting factor that is the shortage of seed (in accordance with JACUMAR).

One of the main problems for the development of mussel farming is the possible lack of native seed, although in recent years the number of facilities and the production output has increased, this latter reaching 2250 t in 2014.

Pectinid Culture

King scallop (*Pecten maximus*) and queen scallop (*Aequipecten opercularis*) are simultaneous hermaphroditic species, whereby both the female and the male gonads mature simultaneously. Black scallop (*Mimachlamys varia*) shows alternating hermaphroditism, changing sex erratically, with separated sexes.

Pectinid cultivation takes place in three phases: seed collection, detachment of the seed, and pre-ongrowing and ongrowing of the scallop to commercial size. All phases of pectinid culture are carried out at sea. Both the collectors for seed collection and the growing structures are anchored to the longlines.

The scallop seed can be obtained in large quantities from the natural environment. The collectors are anchored and consist of an outer polyethylene bag (Raschel knitted type or monofilament type) filled with two Netlon bags inside, since the larvae at the end of their planktonic life seek a filamentous substrate (algae, hydrozoans, bryozoans) where they can fix themselves by the byssus and carry out the metamorphosis. These collectors are tied in groups on a rope, forming a line (Cano and Campos 2003a, b). The outer bag allows the passage of water, larvae, and food but prevents the seeds from escaping when they break the byssus. King scallop and queen scallop break the byssus when they reach 13 mm, whereby they are detached from the inner substrate upon which they are fixed, while black scallops maintain the ability to produce the byssus throughout their lives, since they live in areas with strong currents.

In the Alboran Sea, collectors must be submerged from January to May, when larvae of the three species are most abundant in the water column. The collector needs to be immersed for approximately 1 month for its maturation before the spat settlement. Five months after immersion, the surface of the collector is no longer suitable due to the aging process (Campos et al. 2007; Cano-Pérez et al. 2009; Lozano-Fernández et al. 2009).

The optimal time for deploying the collectors depends on the species: the three species are settled together in the collectors. Although settlement occurs throughout the year, the main fixing peaks take place during the months of June and July for the king scallop, from April to June for the queen scallop, and from May to July for the black scallop.

The seed of the three species must be detached from the collectors between the months of August and November, when the average shell height is between 10 and 20 mm, as they are easier to handle.

Once detached, the three species are placed in structures for pre-ongrowing and ongrowing to commercial size: oyster baskets (Fig. 20.9) for the three species or bags, like the collector bags, mainly for black scallop and queen scallop, due to the small size of the spat when detaching.

King scallop can be ongrown in baskets at high densities (40 scallop/basket) during the first 6 months of culture. Following this period, culture density should be reduced. King scallop reaches a height of 80 mm between the months of November and December, after 1-year growing period (when they are 17 months old). Mortality

Fig. 20.9 Baskets to scallop culture (photo by Juana Cano)

in the baskets is negligible, about 2% (Cano and Campos 2003a, b). The basket should be cleaned every 3–4 months.

The growth of queen scallops in baskets is high, reaching 57 mm after 1 year of culture, with negligible mortality (Cano et al. 2006). The results obtained in bags are worse: queen scallop increases their size from 23 mm to 40 mm in 12 months, and the mortality rate is higher. Nevertheless, survival could be increased if scallops are passed to baskets in July or August (Campos and Cano 2004).

The black scallops grow quickly in both baskets and bags, but bags are used to ongrow spat smaller than 5 mm. Black scallop reaches commercial size (40 mm) at 5 months of fattening in baskets (40 individuals/basket) and at 8 months of fattening in bags (100 to 200 variegated scallops/bag). In both cases mortality is low at 12% for baskets and at 9% for bags (Cano et al. 2006).

The culture of pectinids is undertaken via suspension, because in this way the entire water column is used. Bottom longlines are used for the cultivation of scallops, so that both, spat settlement and growth, are improved 1–10 m above the bottom. It also prevents temporary damage to the installation without affecting the structures at anchor. In addition, the method allows for a greater density of lines, without problems of entanglements or for navigation since the mother line is at the bottom, and on the surface only the buoys that mark the ends of it can be seen. In this way, the number of surface buoys decreases, the possibility of theft or sabotage is hindered, and these lines are more secure than the temporary lines (López et al. 2005a, b).

Perspectives for the culture of scallops in Andalusia are promising, since large quantities of seed of the three species are obtained and, subsequently, growth rate is very fast, with low mortality rate and high population densities.

The main disadvantage for the development of the culture of pectinids is the proliferation of biotoxin episodes, being mainly those that are produced by *Gymnodinium catenatum* (paralytic shellfish poisoning, PSP) and *Pseudo-nitzchia* (amnesic shellfish poisoning, ASP), especially in the case of great Atlantic scallop as it takes a long period of time to eliminate such toxins. Another problem is the abundance of biofouling, with a very intense fixation of barnacle (*Balanus* sp.) on all surfaces in contact with the sea, such as buoys, ropes, baskets, and even on the king scallops.

In addition, sometimes a very high mortality rate is observed, which is associated with the presence of crabs, *Liocarcinus depurator*, *Liocarcinus corrugatus*, and *Necora puber*, particularly concerning *Liocarcinus depurator*. Other species of decapods, fish, and octopus could also be present but in smaller quantities. These species come into the collectors and culture baskets as larvae, and once they grow, they cannot leave these structures, and consequently they feed on mollusks.

Clam Culture

Banded carpet shell (*Venerupis rhomboides*, Pennant 1777) is a species of clam that, years ago, was abundant in the area. At present, there are only a few natural banks with this species, and this could have been due to overexploitation or to the changes in the environmental conditions of the bottom. The culture of this species is, therefore, interesting with respect to both supply markets and the repopulation of natural banks.

In the collectors anchored in Fuengirola for the capture of pectinid seed, in addition to king scallop seed, a large quantity of banded carpet shell seed has been collected. It has been proven that this seed grows quite well in the systems which are used for these pectinids.

The removal of the collectors has revealed that the maximum fixation of seed has occurred in the collectors which are set in the months of December, January, and February, with this fixation decreasing in the following months. It has been observed that the most suitable collector to capture this type of seed is a monofilament sack, which captures approximately 80% of the seed set.

Following detachment, the seeds are grown in bags and baskets (Fig. 20.10). The growth of the banded carpet shell is not constant throughout the year, and it almost ceases in the summer months. Mortality is relatively low in all cases. The highest mortality detected was 5%, and this was associated with fattening in collector bags at high densities of culture. In most of the culture lines, mortality has been zero (López et al. 2005a, b).

Current State and Overview

There has been a significant development in mussel farming in the Alboran Sea in recent years. Mussel production in Andalusia exceeded 2200 t in 2015, but then it decreased as much as 900 t (657 t in the Alboran Sea) in 2017, due to the numerous episodes of biotoxins and heavy storms which damaged the facilities. In that year, the Association of Mollusk Producers in Andalusia (Spanish acronym is APROMO), constituted by a score of companies from the provinces of Huelva, Cadiz, Malaga, and Granada, was created. Currently, the main production takes place in the province of Malaga, and the total mussel production in 2018 increased to 968 t in Andalusia (785 Tm in the Alboran Sea). Most of this production is destined for direct consumption, and it could be improved if mollusk purification plants were available, which would allow the supply to be controlled.

The case for pectinids is very different from the case for mussels. Several companies have installed longlines for the culture of scallops in Marbella and Estepona, and they have obtained good results both in terms of seed collection and growth rates but also with problems due to biotoxin, mainly for king scallop. In spite of several companies that have licenses to culture scallops, the production is practically zero.

Regarding prospects, the production of bivalve mollusks in the Alboran Sea can be increased by the implementation of new projects for mussel farming in the provinces of Malaga and Cadiz. These projects are subsidized by the Ministry of Agriculture, Fisheries and Rural Development of the Directorate of Andalusia through funds from the European Maritime and Fisheries Fund for the period of

Fig. 20.10 Baskets to clam culture (photo by Juana Cano)

2014–2020. The financing of these projects is aimed at acquiring the necessary equipment for the start-up and installation of the anchoring systems to produce mussels. Furthermore it is also aiming to install facilities in the province of Granada.

APROMO aims to develop a research program to analyze which are the most suitable structures for mollusk farming in this area: rafts need to be installed in shelter areas, and the surface longlines suffer serious damage with storms; hence placing the installations at greater depth would be more effective.

Diversification of culture species is another objective of the organization. Currently, mussel production means practically 100% of the total production; therefore starting to culture other species is a short-term priority. As it was stated before, the culture of scallops is technically viable, and king scallop, black scallop, and queen scallop adapt well to these waters. But there are important challenges due to the problems with toxins coming from dinoflagellates, and it is necessary an important impulse on the part of the administration in applying the European legislation on the evisceration of the pectinids, so that their commercialization is possible.

With regard to oyster, although there is no evidence of the presence of natural banks for flat oyster (*Ostrea edulis*), they have been found on the ropes of mussel culture and on the buoys and baskets for the culture of scallops (source: APROMO).

Other species that could be capable of culture in the Spanish Alboran Sea are *Magallana gigas* which is currently cultured in Andalusia in Huelva and Cadiz and *Venerupis pullastra*.

20.3.2.2 Octopus Culture

The absence of octopus juveniles that are reared in captivity and the lack of formulated feed have been established as the main drawbacks for the development of a large-scale cephalopod aquaculture (Iglesias and Fuentes 2014; Sánchez et al. 2014). In spite of reproduction in captivity which has been achieved, the low survival of the paralarvae, associated with feeding and the lack of an appropriate zootechnical protocol, still makes the culture of octopus nonviable. However, a significant increase in larval survival has been attained recently by the Spanish Institute of Oceanography, which could mean an important step to full-cycle aquaculture.

At the moment, *O. vulgaris* culture is based on catching subadults weighing about 750 g from the sea, keeping them in floating cages (Fig. 20.11) and feeding with bycatch (low-cost fish or crustacean species) from trawling, until they reach their commercial size (2.5–3.5 kg) after 3–4 months (Rodríguez et al. 2006; Sánchez et al. 2014). As it was stated before, one facility is nowadays devoted to try to ongrow octopus, but their production in 2017 and 2018 was negligible.

For industrial-scale production, obtaining a low-cost diet would be essential. García García and García García (2011) carried out financial and economic analyses of the feasibility of octopus fattening in cages, estimating that feeding with natural diets would represent the most important cost of production (38–40% of the total). Over the last decade, the formats, the nutritional composition, and the formulation of feed for fattening have been improved (Morillo-Velarde et al. 2012; Martínez-Montaño et al. 2018), and some studies recently published show interesting results (Cerezo Valverde and García García 2017; Cerezo Valverde et al. 2019).

Octopus Fattening in the Western Mediterranean

In the Mediterranean, there are two factors that stand out above all other factors, and that must be taken into account for the culture of octopus: the high temperature during the summer months and the factors related to the coastline that could force the

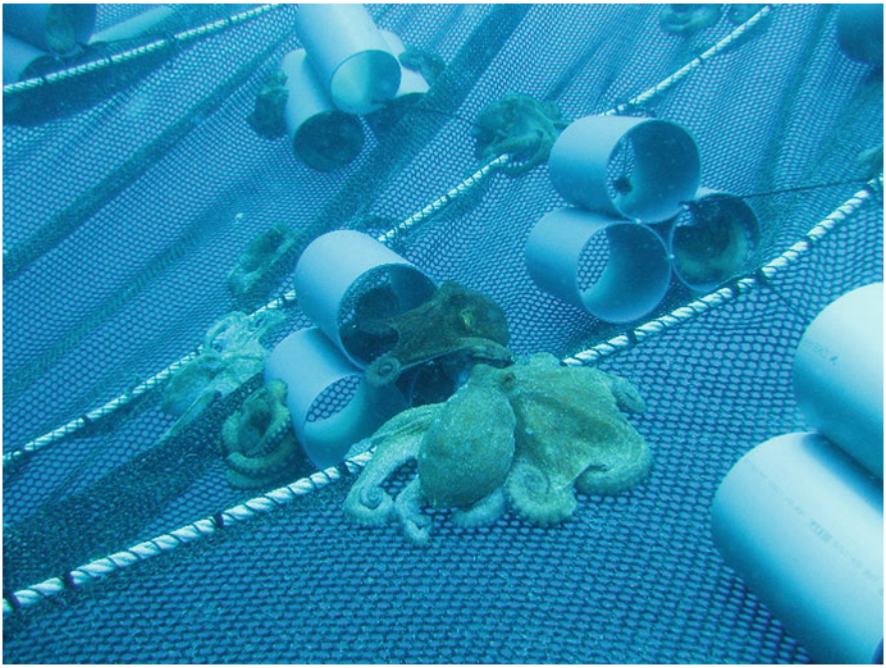

Fig. 20.11 Cages for octopus culture (photo by Jesus Cerezo)

use of facilities in the open sea. However, land-based facilities could also be a viable alternative, depending on the geographical location.

A simulation of growth and survival in a floating cage in the open sea in the Mediterranean can be made from the algorithm that was developed by García García et al. (2009), taking into account the variables such as temperature, weight, size dispersion, and significant wave height. The optimal temperature was established in the range of 14–21°C. Mortality increased significantly with the dispersion of sizes and particularly in smaller specimens.

Subsequently, Cerezo Valverde et al. (2019) published the results of an octopus fattening project in the same area via the supply of formulated feeds. The main differences between the two studies were the diet (natural vs. formulated feed) and the type of cage (rectangular stainless steel with animals on the surface vs. circular with animals at 10 m depth). The obtained results suggest that keeping the octopus at a certain depth could improve the yield and that the natural diet based on fish and crustaceans could be replaced by a formulated feed, without diminishing performance in fattening. Survival was around 75% in both studies (Fig. 20.12).

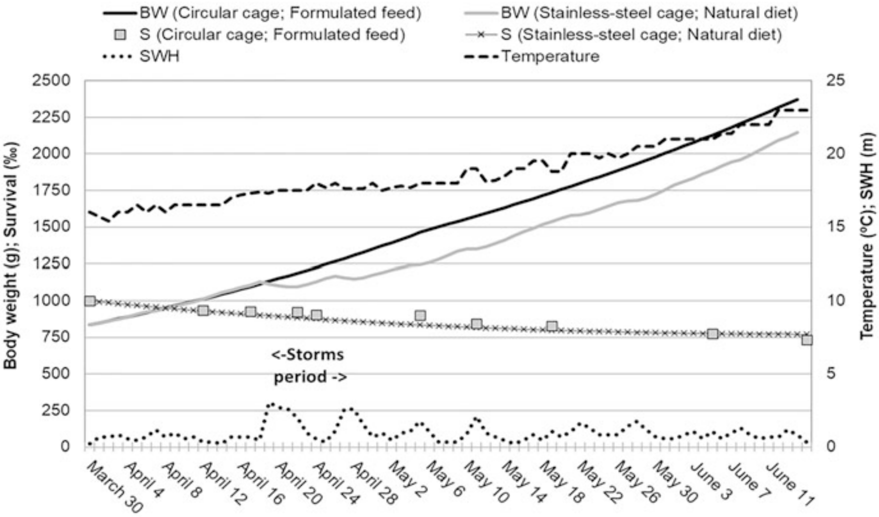

Fig. 20.12 Temperature, significant wave height (SWH), and body weight (BW) of octopus fed in the open sea in a circular cage (10 m depth) using a formulated feed (Cerezo Valverde et al. 2019) and values estimated for specimens kept in a floating cage fabricated of stainless steel and fed with fish and crab (estimated data for the same conditions of weight, temperature and SWH, according to García García et al. (2009))

Estimation of Octopus Growth in the Alboran Sea

The average monthly temperature in three different areas, Bay of Malaga, Cabo de Gata in the Alboran Sea, and Cabo de Palos, throughout the last 5 years is shown in Fig. 20.4. During the winter and early spring (December–April), temperatures were similar in the three areas (range of 14.3–16.1°C). However, from May there is a differentiation with greater increases in temperature as we move eastwards, reaching maximum average temperatures in August of 26.6°C, 24.8°C, and 23.4°C in Cabo de Palos, Cabo de Gata, and the Bay of Malaga, respectively. With regard to significant wave height, the worst conditions during the last 5 years were in Cabo de Gata, while the best conditions, with a mean significant wave height lower than 0.5 m, were found in Malaga. Of the three areas studied, the Bay of Malaga presents the best location for octopus fattening, characterized by a lower incidence of the prevailing winds in the area, as well as temperatures more suitable for octopus fattening for longer, nearly 11 months a year. In Cabo de Gata and Cabo de Palos, the high temperatures during the months of July, August, and September would limit this activity to the period between October and June.

Figure 20.13 is a representation of the estimated growth during two cycles of fattening of octopus subadults fed with natural diet and kept in offshore conditions within the areas studied. During the winter, starting in November with an initial body weight of 0.5 kg, 2,0–2,2 kg could be reached by the end of February in Cabo de Palos and Cabo de Gata, while in the Bay of Malaga, 2.9 kg could be reached. In

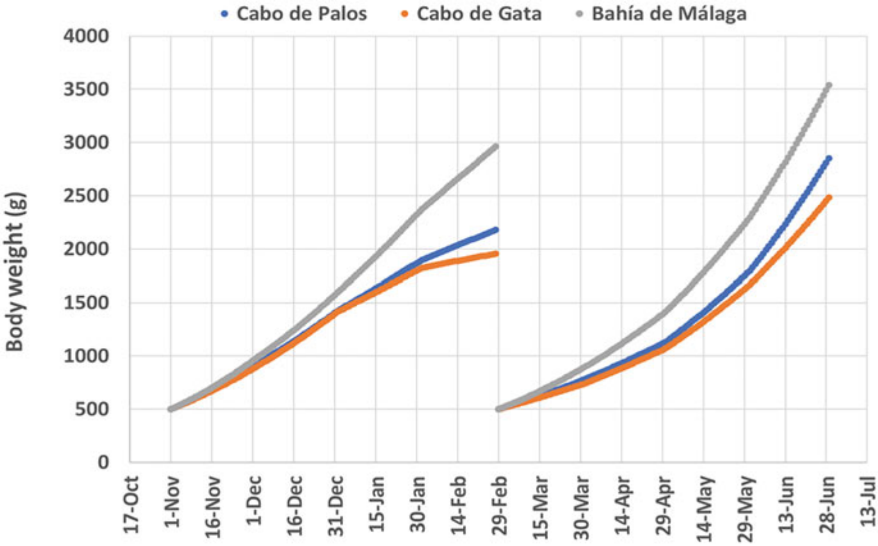

Fig. 20.13 Values for estimated body weight during two cycles of octopus ongrowing during winter and spring. The weight values are estimated for the average temperature and SWH as recorded by the instrumented buoy at Cabo de Gata, Cabo de Palos, and Bay of Málaga and according to the equations described by García García et al. (2009)

spring cycle, the most suitable area would also be the Bay of Malaga (3.5 kg at the end of the fattening), followed by Cabo de Palos (2.8 kg) and Cabo de Gata (2.5 Kg). These observed differences in growth could be attributed to the beneficial effect of the lower hydrodynamics in the Bay of Malaga, rather than the effect of temperature. It is observed how the presence of strong storms in March and April would prevent proper growth, which is probably caused by the strong movement of the cage on the surface or even the impossibility of feeding for several consecutive days. Although animals may fast for two or even three nonconsecutive days per week, without growth or feed conversion being affected (Rodríguez-González et al. 2018; Cerezo Valverde et al. 2019), if there is prolonged fasting, then cannibalism will occur, and this practice will mainly affect the smaller octopuses. If the ongrowing cycle is prolonged until June, the possible negative effect of reproductive processes should be also taken into account.

Overview

The fattening performance of octopus under open sea conditions in the Alboran Sea area would be strongly influenced by environmental parameters. The temperature of the water would be appropriate between October and June. However, in spring the commonly occurring storms would have a significant negative effect. In this sense, land-based installations that are equipped with a water supply having temperatures in the range of 14–21°C would also be an interesting alternative. Considering the three areas studied, the Bay of Malaga is proposed as the best option for octopus culture.

20.3.3 Marine Microalgae

20.3.3.1 Recent Advances and Current Global Trends in Microalgae Production and Use

The last decade has witnessed important advances in the aquaculture technology supporting marine microalgal production at various levels of intensification. Such development was to a great extent promoted and subsequently economically supported by a misinterpreted perception about the real options that microalgal mass production had as a feedstock in the biofuel sector. Despite noticeable advances achieved, current production costs are still far distant from those that would be needed for cultured microalgal biomass to become a real option to the use of other energy sources. The current technology is unable to produce a positive energy balance in comparison to other fuel sources (Dassey et al. 2014). It has to be, nevertheless, recognized that, as a consequence of such efforts, more efficient outdoor mass production systems are now available both in open ponds (Kumar et al. 2015) and in closed photobioreactors (Pereira et al. 2018). These advances have allowed a growing number of new companies to operate and generate novel aquaculture products from cultured microalgae. In this regard, the current state of microalgal production has surpassed the traditional concept of auxiliary food support to some aquaculture practices and can nowadays be contemplated in a wider concept as an independent and well-differentiated aquaculture option.

Significant progresses in several applications of either the entire microalgal biomass or selected extracted compounds (Liang et al. 2018) are now uncovered, offering new biotechnological products in important markets as, among others, those of the food manufacturing, nutraceuticals, and cosmetics. Technological advances are concerned with a wide range of microalgal production systems, but applications depend to a great extent on whether marine or freshwater species are involved. So, the systems used for the two traditional freshwater microalgae (Chlorella and Spirulina) that represent most of the current world microalgal production are not running with marine microalgae. On the other hand, typical uses in nutrient recycling from urban wastewater treatment plants (Cai et al. 2013) or in any other human land-based activity generating excess nutrient load can be more complicated to perform when marine microalgal aquaculture is the choice. Within this context, it is postulated that short-term progress on marine microalgal production has to build prioritizing either on the expansion of already developed activities involving marine species (e.g., Dunaliella) or the development of new products of generally elevated commercial value.

20.3.3.2 Environmental Conditions in Relation to Marine Microalgal Production in the Alboran Sea

A relevant peculiarity of microalgal outdoor mass production concerns its specific dependence on key environmental factors for photosynthetic production as are solar irradiance and temperature. Most of the Alboran Sea coastline is characterized by having very high annual solar radiation, thus satisfying one of the main requirements for the phototrophic production of marine microalgae. The availability of such a naturally elevated and widespread solar irradiance makes this essential parameter to be less limiting than other factors. It has to be, nevertheless, stressed that daily elevated fluctuations associated to solar irradiance in the area result in punctual periods of extreme intensity that can lead to photoinhibition or even photodamage. Microalgal production systems have therefore cope with this phenomenon by providing adequate solar protection when needed. Temperature in the Alboran Sea coastline follows the typical seasonal pattern of the Mediterranean climate and that implies marked variations throughout the year are expected to noticeably condition microalgal production. This mostly temporal variability in temperature, with a minor spatial variability component, is not supposed to exert a strong influence at the time of site selection. Seasonal changes in temperature will significantly affect microalgal biomass production yield and will likely recommend the use of a seasonal species selectivity strategy. Evaporation is another important factor that needs special attention when setting up a microalgal production plant since replenishing of daily evaporative losses may represent an important cost due to the freshwater demanded, especially by open systems like paddle-wheel tanks. Evaporation positively correlates with solar irradiance, and any additional spatial coincidence with strong winds of different nature in some specific places may restrict the utilization of some open systems for microalgal aquaculture.

The fact that microalgal production technology has been developed for both open and closed systems enables this activity in adapting to diverse places with different intensities and types of land use. This acquires special relevance in the Alboran Sea where the north coast, characterized by a very high urban and agriculture pressure, presents less space availability than the south coast. It seems thus reasonable thinking that the more intensive and less space-demanding closed production systems will better adapt in the north coast. On the other hand, the more land-demanding open tank production systems would be apparently easier to set up along the south coastline. This theoretical approximation can, in any instance, be altered in the event that any specific association of microalgal production with any other economic activity is carried out.

20.3.3.3 Facts and Options in Relation to Marine Microalgal Production in the Alboran Sea

As in any economic activity, marine microalgal aquaculture must identify and work with products which are economically feasible to generate and are also accepted or demanded by the market. With the current knowledge and in the short term, selecting high-value products from microalgal biomass seems to be the best option. Integrating such a kind of compounds with others of different economical value produced by the same microalgal source represents an ideal situation for best use of the biomass. However, achieving this goal, after some years of study, seems complicated in the short term due to the little success obtained at the moment with the biorefinery strategy (Gifuni et al. 2018). It has also to be stressed that the need for specific culture medium conditions when the product is destined to human consumption (Enzing et al. 2014) demands special quality standards for nutrients. Current microalgal aquaculture in south Spain is characterized by a growing industry focusing on the generation of elevated value products derived from highly controlled phototrophic production systems. This particular aquaculture sector is led by the company Fitoplancton Marino (Fig. 20.14) which, among other products, is commercializing a new product based on the marine microalgae *Tetraselmis* that has achieved the novel food recognition (Picó et al. 2013), and it is characterized by the

Fig. 20.14 Outdoor photobioreactors for culturing microalgae from Fitoplancton Marino Co. (photo by Carlos Unamunzaga)

elevated antioxidant capacity exhibited by this genus (Sansone et al. 2017). Other important products are obtained from the freeze-dried biomass of *Nannochloropsis* and *Isochrysis* with direct applications as aquaculture larval feeds and in the cosmetic field. Microalgal biotechnology in the area shows an interesting progress that will enable expanding products to new markets as they become available and technology is refined. An interesting example in this respect is the work carried out to develop the production of extremely high-price biocompounds as are those toxins derived from cultured dinoflagellates (Gallardo-Rodríguez et al. 2012). In general terms, the requirements for maximal control on culture conditions in order to optimally obtain microalgal biomass rich in high-value compounds recommend the preferential use of closed production systems in photobioreactors.

Outdoor open production systems, mainly those using paddle-wheel tanks, can also find their place in the Alboran Sea coastline. Concerning high-value products, the clearest evidence for developing microalgal aquaculture activities in the zone can be found in the well-consolidated *Dunaliella* mass culture in other regions of the globe. Adaptation of this technology does not seem to be complicated since similar growth conditions for *Dunaliella* have been described in the zone (García-González et al. 2003). The fact that this coastline is known as a climatically favorable region to perform aquaculture of the most abundantly produced marine microalgae contrasts with the absence of industrial initiatives. Other factors than climatology, or even technical development (Prieto et al. 2011), might thus explain why *Dunaliella* production has not advanced in the region. In this regard, techno-economic and marketing studies are missing, and their availability could likely help to get a clearer grasp of the actual chance for *Dunaliella* commercial production along the Alboran Sea coastline.

Alternatives for microalgal aquaculture practices destined to obtain lower-value products need to be associated to other economic activities acting as a nutrient source due to nutrients acquiring in this instance higher relevance in total production costs. Despite the challenging complexity in linking freshwater nutrient-rich sewages to marine microalgal aquaculture, the feasibility of this approach has been occasionally commented (Jiang et al. 2011). In the Alboran Sea coastline, there are several high nutrient-generating industrial- and urban-related activities in which environmental sustainability would be improved from their integration with microalgal production systems. In this regard, a particularly advanced situation does exist in the zone where recent pilot-scale studies have demonstrated the feasibility of using a medium containing 20–30% of municipal wastewater centrate as the nutrient source to produce marine microalgae (Ledda et al. 2015; Romero-Villegas et al. 2018). Typical applications of the microalgal biomass produced following this approach are in the aquaculture feeds (Vizcaíno et al. 2018), other animal feeds, and biofertilizer fields.

20.3.4 Sea Cucumber

Sea cucumber (Fig. 20.15) is a highly valued resource mainly in China and Japan, where it is considered a delicatessen with optimal nutritional profile and bioactive substances for human health. The increasing demand of this product from Asian countries and its very difficult fishery management led to the sea cucumber aquaculture in China 50 years ago. Later, other countries like Japan, India, Indonesia, Australia, and Madagascar also started with this activity. In Spain, this resource has been poorly exploited under legality, except for the catches of *Parastichopus regalis* in Cataluña, Baleares, Comunidad Valenciana, and Murcia, where sea cucumbers are caught by catch in trawl vessels or in Galicia where *Holothuria forskali* is caught (González-Wangüemert et al. 2018a). However, some illegal catches were registered mainly on Andalusia coast during the last years.

Under this framework, the development of the sea cucumber aquaculture in the Mediterranean Sea and NE Atlantic Ocean has been focused on different species *Holothuria arguinensis* and *Holothuria mammata* (Atlantic and Mediterranean) and *Holothuria polii* and *Holothuria tubulosa* (Mediterranean). All these species are inhabiting the Alboran Sea (Domínguez-Godino et al. 2015; Domínguez-Godino and González-Wangüemert 2018a, b, c; González-Wangüemert et al. 2018a, b).

It is important to highlight the importance of *H. arguinensis* culture, because it is a species with high economical value and optimal nutritional profile and harboring useful bioactives for human health including antioxidant, anticancer, and UV protection (González-Wangüemert et al. 2018b, 2019; Roggatz et al. 2016). This species also presents some features very useful for its aquaculture including high growth rates, optimal response to lyophilized algal diets, reduced production of ammonium, low mortality rates by sickness, quick response to natural treatments

Fig. 20.15 *Holothuria arguinensise* (photo by Mercedes González-Wangüemert)

(based on bioactives from green algae such as *Ulva lactuca*, or terrestrial plants as *Carpobrotus edulis*), low requirements to oxygen, resistance to high temperatures, and absence of aestivation (Cánovas et al. 2019; Domínguez-Godino and González-Wangüemert 2018a, b, 2019, 2020). Also, *H. arguinensis* can be cultured on polyculture systems with another commercial species as *Ulva lactuca* and *Paracentrotus lividus* (Domínguez-Godino and González-Wangüemert 2018c) and used on IMTA (Integrated Multitrophic Aquaculture) systems allowing the reduction of organic matter levels on sediments under fish cages (sea bream and sea bass) or under mussel/oyster batting.

The biotechnology which has allowed the aquaculture of this target species has been a perfect example of knowledge transference from a research center to a company, resulting in the start-up of Guatizamar S.L., whose aquaculture installations are located in Chiclana de la Frontera (Cadiz). It is important to highlight that it is the first European company focused on sea cucumber aquaculture (larva and juvenile production, fattening, and processing) and the first world company on aquaculture production of *H. arguinensis.*

20.3.5 Others

In August 1986, ACUINOVA (a company from the Pescanova group) started a project to culture *Artemia salina* in several outdoor and indoor tanks (Fig. 20.16).

Fig. 20.16 Raceway to shrimp culture (photo by Gabriel de Lara and Avelina López)

The project intended to produce biomass and cyst of *Artemia salina* fed with culture microalgae and subsequently dealt with kuruma prawn production, *Penaeus japonicus*. It also assayed formulated food to sea bream, sea bass, and kuruma prawn. After some years, the company ended their activity, and there have not been any more attempts to culture crustacean in the Spanish Alboran Sea, mainly due to the high price of the land in this area, which means that profitability of extensive cultures is quite difficult.

Other species which are able to be cultured are sea urchin (*Paracentrotus lividus*), some species of seaweed as *Ulva lactuca*, and some sea anemones like *Anemonia sulcata*. This last one is starting to be cultured in a farm in Granada, iMare Natural, which is also dealing with sea cucumber, sea urchin, and samphire (*Salicornia europaea*).

20.4 Aquaculture in Morocco

The history of marine aquaculture in Morocco began in the 1950s on its Atlantic coasts and in the 1980s on its Mediterranean coasts, although aquaculture couldn't be sufficiently developed according to the national coast potentiality level. According to Catanzano (1999), Morocco has not a strong aquaculture tradition, and Moroccan aquaculture, both continental and marine, shows a weak development, particularly the marine branch (Orbi et al. 2011), which represents less than 0.1% of the national fishery production. Facing this situation, Morocco established, in September 2009, a new development strategy for the maritime fishery sector, known as "Halieutis Plan" (http://www.maroc.ma/fr/content/halieutis). This strategy aimed to reinvigorate, in a sustainable manner, fisheries and aquaculture development and make them more competitive and more efficient. It provided a harmonious development of means of fishery production, improving the living and working conditions of fishermen, preserving natural resources and their exploitation sustainability, and encouraging marine aquaculture development. Therefore, marine aquaculture in Morocco started a new phase characterized by aiming at ensuring all necessary development conditions. In this context, a new institution called "National Agency for the Development of Aquaculture (ANDA)" was created and dedicated to marine aquaculture development promotion (https://www.anda.gov.ma/fr/connaitre-l-anda).

Since the implementation of this new strategy (Halieutis Plan), various studies have been launched in different maritime regions of Morocco to identify and select potential sites for aquaculture and to elaborate aquaculture activity development plans upon a participative approach and an integrated and harmonious procedure. Two aquaculture development plans have been achieved covering all the Mediterranean coasts of Morocco (ANDA 2019a, b). Identified projects are in fact still in the process of being implemented, and they will eventually allow the national marine aquaculture production to know an important upward trend.

20.4.1 Marine Aquaculture History in the Mediterranean Coasts of Morocco

According to FENIP (2010), Orbi et al. (2011), and Nhhala (2018), the history of marine aquaculture in Morocco's Mediterranean coasts can be, in general, characterized by three types of aquaculture development: lagoon, onshore, and open sea aquaculture.

20.4.1.1 Lagoon Aquaculture

This aquaculture represents the first commercial-scale operations on the Mediterranean coast in Morocco; it was established in the Nador lagoon for the cultivation of the European flat oysters, *Ostrea edulis*. In the early 1980s, as part of the implementation of the FAO project for the promotion of marine aquaculture in Mediterranean countries (MEDRAP Project), some studies on the assessment of aquaculture potential of the Nador lagoon were conducted by FAO experts and Moroccan researchers from the ISPM (Scientific Institute of Maritime Fisheries which became the current INRH –National Institute of Fisheries Research – since 1996) (Nhhala et al. 2015). These studies concluded that this lagoon had a strong production potential, particularly in terms of shellfish culture and fish farming. So, in 1985, they contributed to the creation of the first marine aquaculture farm on the Mediterranean coast of Morocco, called Marost (Moroc Ostréiculture). The transfer of technology and professional know-how and the reinforcement of required skills and capacities were provided by the FAO MEDRAP Project (Bruno 1987). In this way, the development of "what was called" a modern lagoon aquaculture in Morocco was initiated taking as reference some examples and experiences of European countries in the Mediterranean region. Originally designed to produce flat oysters (*Ostrea edulis*), Marost was rapidly forced to diversify its aquaculture production by including the European clam (*Ruditapes decussatus*) in 1986; the Mediterranean shrimp (*Penaeus kerathurus*) in 1987, which was 1 year later replaced by the Japanese shrimp (*Penaeus japonicus*); the European sea bass (*Dicentrarchus labrax*) in 1988; and the gilthead sea bream (*Sparus aurata*) in 1989. It also tried other fish species like the spotted sea bass (*Dicentrarchus punctatus*) and the sharp snout sea bream (*Diplodus puntazzo*), but in spite of the successful experimental production, their commercial-scale production did not sustainably develop. Marost also started to produce some tonnes of European eel (*Anguilla anguilla*) from fishes supplied by local artisanal fishermen and those on the north Atlantic coast (Kenitra-Larache). These eels were kept in extensive breeding tanks (raceways) for a few weeks, and then they were sold alive on the Italian market.

On a technical level, Marost opted for aquaculture techniques adapted to local conditions, particularly physical environmental conditions. Thus, flat oyster farming techniques were based on fixed rafts (oyster tables built by railway rails and wooden bars) and on floating longlines lines while growing techniques were based on farming parks for clam, culture enclosure for shrimps, and floating and fixed cages for fish. Shellfish and fish were raised in areas of 6 to 8 m in depth and shrimps and clams in areas bordering the lagoon and having 0.5 to 1.5 m in depth. In addition, Marost established three hatchery-nursery units, one in 1986 for shellfish producing oyster and clam spats, the other in 1987 for crustaceans producing shrimp postlarvae, and the third in 1988 for fish producing sea bass and sea bream fingerlings.

In 1990, Marost decided to centralize its production on fish farming (Catanzano 1999), to give up shrimp farming revealing uncompetitive on target markets and to reduce shellfish culture to a minimum level, mainly according to national market needs. Export of cultured fish (sea bass and sea bream) was a required recourse since fish feed was imported under temporary admission and the regulations in force obligated in this case to export 90% of imported food equivalent in produced fish.

Marost fish production increased significantly during the 1990s, reaching a peak of around 1210 t in 1994. During a production period of 16 years, since 1990 until 2005, the average annual production was about 394 t for sea bream, 349 t for seabass, and 39 t for eel, with an annual overall average of about 781 t. Most of this production was exported to the European market, mainly Italy. However, during the 2000s, Marost's profitability was highly affected by the collapse of sea bass and sea bream prices, and at the end of 2005, Marost went into bankruptcy and ceased its activity in January 2006 (Nhhala et al. 2015).

20.4.1.2 Onshore Aquaculture

This kind of aquaculture began in the early 1990s in the coastal area of Saidia (northeast of Morocco), close to the edge of the Moulouya estuary. A marine farm, called "Moulouya Aquaculture Society" (SAM), was created in 1990 and was originally aimed to produce Japanese shrimp in earthen ponds. Facility design and technical training of staff were carried out by a French office of aquaculture consulting called "France Aquaculture."

Located near Moulouya river estuary, on an area of 110 ha of land-based ponds, SAM tried to culture shrimp in earthen ponds using juveniles produced in its local hatchery. SAM's shrimp production was very low, not exceeding 35 t in its first year of production (1991) and decreasing year by year.

Since shrimp culture showed problems of competitiveness and profitability, SAM attempted to use earthen ponds for marine fish culture, and it converted shrimp hatchery to sea bass and sea bream fingerling production. This attempt was technically succeeded, and the obtained production reached 240 t, but due to several reasons, it could not ensure the company's sustainability. SAM was constrained to cease its farming activities in 1997 and then went into bankruptcy in 2000 (FENIP 2010; Orbi et al. 2011; Nhhala 2018).

20.4.1.3 Open Sea Aquaculture

Open sea aquaculture began during the late 1980s, with the development of a commercial fattening operation of bluefin tuna caught by traps in M’diq Bay (INRH 2000). This operation was carried out by a local fish trap, called “Principe,” which worked in cooperation with Japanese partners. Bluefin tunas were fattened in flexible floating cages, with a dimension of 120 m in length, 30 m in width, and 15 m in height (net depth). The net was maintained in flotation by a series of different types of buoys. The purpose of this activity was to improve the meat quality of bluefin tunas and consequently to increase their market value. These tunas, caught by the trap on their way back to the Atlantic Ocean after migration in the Mediterranean for reproduction purposes, were low-fat. During their fattening process, they were fed cheap fishes, mainly mackerel, and they increased their fat content. In the early 1990s, fattening activity in M’diq Bay was stopped due to the lack of bluefin tuna capture.

In December 1993, an experimental joint venture project focused on bluefin tuna farming was undertaken in M’diq bay. This bluefin tuna project (BFT project) was developed by the Overseas Fishery Cooperation Foundation (OFCF) from Japan in partnership with the National Institute for Fisheries Research (INRH) and Maritime Fisheries Department (DPM) from Morocco (INRH 2010). The purpose of this project was to breed and reproduce wild-caught breeders in captivity. During the first 3 years, the former fattening facility was reused by BFT project, and then they acquired its own cages.

Two breeders’ groups were reared by this project, and very interesting results were obtained in terms of growth, but reproduction was very constrained. The experimental hatchery, built in 1996 and initially designed according to BFT project needs, was later converted and used for marine finfish aquaculture diversification purposes by INRH and renamed as “Aquaculture Research Center” (INRH 2010). Among the achieved research works made by this center since 2000, three important fish species, red porgy (*Pagrus pagrus*), common dentex (*Dentex dentex*), and meagre (*Argyrosomus regius*), have been studied in terms of captive breeding, pre-growing, and growing.

The BFT project served as a demonstration and, in a practical way, an effective promotion and enhancement of open sea aquaculture technology, particularly at the local level. It had a beneficial effect on the development of sea bass and sea bream farming in conventional floating cages, in M’diq Bay and in Martil bay, and a couple of fish farms (Coprim-M’diq” later Aqua-M’diq in M’diq Bay and Doraloup in Martil Bay) were created at the end of the 1990s (Nhhala 2018). These two farms had concessions of about 8 hectares each and farming facilities composed of floating cages with 12 m in diameter (Fig. 20.17). They initially targeted sea bass and sea bream production and their production capacity were about 200 t/year. Their farming process relies on fingerlings and fish feed imports from Europe, especially France and/or Spain.

Fig. 20.17 Floating cages used for sea bass and sea bream farming in by M'diq Bay and Martil bay (photo by Aqua-M'diq)

Doraloup went into bankruptcy in December 2002, but Aqua-M'diq continued their activity, and it established a cooperation agreement with INRH in order to provide it with technical support in terms of servicing and maintenance of the mooring system of floating cages and a partial production of sea bass fingerlings in the experimental fish hatchery of the Aquaculture Research Center in M'diq. It also opted for an effective participation in research efforts for fish feed development using local ingredients in a joint partnership between Aqua-M'diq, a private livestock feed factory interested in feed production in Kenitra, INRH Aquaculture Center in M'diq, and Agronomic and Veterinary Institute Hassan II in Rabat. So, it was possible to locally supply Aqua-M'diq with sea bass fingerlings from INRH Aquaculture Center in M'diq from 2004 to 2009 and with feeds produced by a commercial factory in Kenitra since 2005 and further with sea bass extruded feeds produced by another animal feeds located near Tangiers. This enabled this fish farm to survive and continue its aquaculture activities, to sell its products on the national market, and to create its own distribution network at the regional and national level. This network has been gradually reinforced with marketing development through large commercial surfaces installed in different cities of Morocco.

Local fish fry production and locally produced fish feeds have led to overpass a critical period due to prices falling of sea bass and sea bream on the European market and fierce competition of other Mediterranean countries. This has allowed to provide production which, although small, has ensured farm viability, enhanced sales on the national market, and overcame difficulties and constraints related to the two inputs import (fry and feed).

The phase of 2006–2010 was very critical but also very important for the survival of the only fish culture farm still being in operation on the Mediterranean coast of Morocco. This is important because there were other fish farms (Marost, SAM, and Doraloup) which ceased their activities. Aqua-M’diq has considered sea bass as its flagship product although it has attempted other fish species production such as sea bream and meagre. The results obtained for sea bream were less important compared to sea bass, notably in terms of growth. Sea bass seems to be more suitable for breeding in M’diq Bay than sea bream, mainly especially with regard to the local thermal profile.

In general, the annual production average of Aqua-M’diq in terms of sea bass, as the main produced fish species, is about 100 t during the period from 1999 to 2015, with a maximum of 181 t registered in 2015.

In April 2006, another aquaculture farm named “Mejilloneras Del Norte” (MDN) was created. It was located in the northern area of M’diq bay, and it cultured mussel (*Mytilus galloprovincialis*) in floating structures (rafts).

This mussel farm had a concession divided into two close areas, but they both were managed as one area. A total of seven floating rafts were installed. They consisted of two metal floats (big tanks) connected by a quadrant of 13x13 m in dimensions and composed of metal bars and wood (Fig. 20.18). The wooden bars served as support for the mussel ropes. A floating raft was able to support up to 80 mussel ropes of 12 m long each. The production capacity of this mussel farm was around 250 t of mussels. However, the production achieved (in terms of sold quantities) was only a few tonnes.

The commercial fund of this shellfish farm was sold to another company called “Mediterranean Aquaculture Company” or “MAC” in an abbreviated version. However, the site used for mussel farming was abandoned for expropriation reasons (of public utility purposes). But as the northern area of M’diq Bay was reserved as an anchorage area for merchant ships waiting for Tangier-Med port clearance, the company was asked to relocate its mussel farming structures.

Mussel farming was also the subject of an experimental project in Cala Iris bay in 2011. This bay is located in the south of Al Hoceima, in the central part of the Mediterranean coasts of Morocco. This project was implemented in joint cooperation between INRH, Japanese Agency for International Cooperation (JICA), DPM, and artisanal fishing cooperative of Cala Iris. In fact, due to the socioeconomic importance of marine aquaculture, this cooperative was interested in mussel farming. Mussels exist naturally in this area. An experimental trial of mussel culture was first undertaken in Cala Iris bay and has yielded very encouraging results. The adopted culture technique in Cala Iris bay was based on the suspension culture system under floating longlines, which gave satisfactory results at the pilot production scale. Currently, the cooperative is making necessary administrative procedures to move this project from the experimental phase to a commercial phase, with an expected production target of 40 t. Despite the weakness of this production, artisanal

Fig. 20.18 Floating raft used for mussel culture in M’diq Bay (photo by INRH)

fishermen’s expectations are to diversify their local activities, enhance employment, and generate income for the local population. The transition from experimental phase to commercial production phase is conditioned by an environmental impact study and an area study aiming at the sanitary classification of the breeding site, both achieved. Sanitary classification of this mussel culture farm is B, and then a purification station is under construction supervised by ANDA (ANDA 2019a, b).

20.4.2 Main Constraints of Aquaculture Development

According to the above history of marine aquaculture on the Mediterranean coasts of Morocco, it appears that, despite the progress made in terms of species diversification and breeding techniques, the formation of skilled staff through training programs, and the mastery of aquaculture techniques, particularly intensive farming systems, including hatchery, nursery, and growing, this activity has not been able yet to develop in accordance with existing potentialities and generated a sustainable increase that can support the national production.

Moroccan aquaculture farms have encountered major problems, particularly in terms of competitiveness and cultured product sales both in foreign and domestic markets, impeding their development and constraining their survival (FENIP 2010; Orbi et al. 2011; Nhhala 2018). Restrictions in terms of sanitary measures adopted by the European Union since the end of the 1980s, in particular for cultured shellfish, have seriously affected national aquaculture production. Bivalve culture development, such as flat oysters and clams, have been limited for reasons of commercial precautions. This was the case of Marost farm, whose production consisted mostly of small quantities intended for domestic market needs.

Fish culture, mainly sea bass and sea bream, has experienced major marketing difficulties on the European market. Domestic marketing possibilities were constrained by the specific regulations governing the importation in temporary admission way of aquaculture inputs (fry and feed). In addition, the European market was considered as a very interesting alternative for its high prices, especially during the 1980s, but the price depression experimented in the 1990s affected seriously the production. Despite its technical progress, Moroccan marine aquaculture farms have been very vulnerable to European aquaculture farms' competitiveness. In addition to the declining sale prices of these major aquaculture products, Moroccan aquaculture farms could not be competitive, particularly because they did not receive any subsidies or benefits from national authorities such as European Union aquaculture farms.

20.4.3 Current State and Overview

Aquaculture production during the last years is shown in Fig. 20.19. In this moment, according to ANDA (2019c), there are 22 facilities dealing with marine aquaculture in Morocco, most of them culturing oysters on the Atlantic coast. In the Alboran Sea, the current situation is characterized by the existence of four facilities: one fish farm

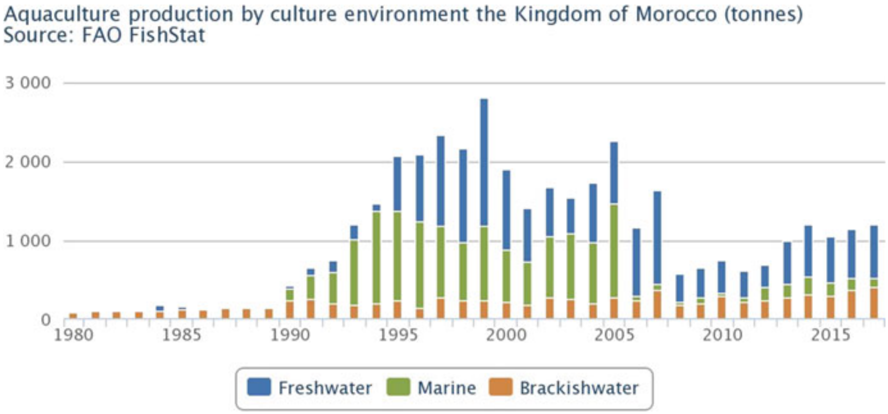

Fig. 20.19 Aquaculture production in Morocco (FAO. Fisheries and aquaculture country profiles http://www.fao.org/fishery/countrysector/naso_morocco/en)

producing sea bass in M’diq Bay, two shellfish farms producing mussels, both managed by artisanal fisheries cooperatives, one in Cala Iris Bay and the other in open sea located of “Water Cap” and one seaweed farm located in Marchica Lagoon which started working in 2016. In 2015, the total production in Morocco was 470 t in 2015: 290 t of oyster in the Atlantic area and 180 t of sea bass in the Alboran Sea. A short production of red seaweed (*Gracilaria gracilis*) and mussels (*Mytilus galloprovincialis* but also African mussel, *Perna perna*) is produced since 2016.

To boost aquaculture development in Morocco, fishery department established in 2009 a national strategy for fisheries and aquaculture sector (Halieutis Plan), and it created ANDA. The Halieutis Plan considered aquaculture as a major driver for marine fishery sector development and defined strategic objectives for 2020, particularly in terms of expected aquaculture production estimated to be of 200,000 t. ANDA has undergone many studies to establish integrated aquaculture plans according to the allowed aquaculture zone concept. This planning approach reconciles environmental, social, and economic imperatives and provides a visibility for sustainable aquaculture development in selected areas. Aquaculture polygons have been defined with the delimitation of exploitable concessions, identification of potential species for aquaculture, and proposal of suitable techniques.

On the Mediterranean coasts of Morocco, two aquaculture development plans have been elaborated. Many sites have been selected and were subjected to calls for expression of interest (https://www.anda.gov.ma/). Also, several applicants have made their requests. Implementation of selected aquaculture projects is under preparation, and production activities will begin in the next few months or years.

In the marine area of “Tanger-Tétuan-Al Hoceima” region (located in the west and center parts of the Mediterranean coast of Morocco), there are 13 shellfish culture sites of 15 or 20 ha each and 12 fish culture sites of 25 or 40 ha each (ANDA 2019a). In marine areas of the “oriental” region (located in the east part of the Mediterranean coast of Morocco), there are 6 shellfish culture sites of 15 ha each, 4 shellfish/algae culture of 15 ha, and 46 fish culture sites of 25 ha each (ANDA 2019b).

In conclusion it can be said that the Mediterranean coasts of Morocco located in the Alboran Sea area present a high potential for aquaculture activities. Integrated aquaculture planning has been made following an “allowed zone for aquaculture” concept, and considerable development potentials have determined. The implementation of these aquaculture planning should contribute to enhance the aquaculture production in Morocco.

The development of aquaculture production in the Mediterranean region has led to a higher total seafood supply, lowering cultured species product prices and generating price instability and unpredictability. This has jeopardized farm durability, especially the small-scale ones and those situated on the south side of Mediterranean Sea, such as Morocco and Algeria.

So, alternative possibilities to strengthen aquaculture farms in Alboran south area may rely on boosting of quality improvements and new product development, improving business doing way in terms of market orientations (potential demand, value-added presentations, new markets), reducing risk of price instability and unpredictability (production costs, competitive sale prices), and optimizing marketing mainly in terms of logistics (airfreight, cold transport network). Aquaculture products are still based on a small number of species and markets. Studies on market integration between capture fisheries and aquaculture are scarce in south Alboran countries (Morocco and Algeria). In this regard, the national development strategy “Halieutis Plan” will allow the capitalization of aquaculture potentialities and alleviate the constraints. The development of aquaculture production would certainly help to meet increasing seafood demand in Morocco both from consumers and from restaurant and hotel sectors (DEPF 2006). The aquaculture sector has been analyzed through its development opportunities and obstacles encountered; it has shown an enormous potential for development (DEPF 2008). Moreover, the demand for seafood is in continued increase at the national level, resulting particularly from demographic growth, change of eating habits, development of catering and tourism, and also deployment of mass distribution at the national level, forecasting a promising future for the aquaculture sector (DEPF and ANDA 2018).

20.5 Aquaculture in Algeria

In the western basin of the Mediterranean, Algeria’s coastline stretches along a coastal strip of 1280 km to the south. Twelve percent of this area, about 150 km between Cape Falcon in the East (35° 46′23“ N, 0°47’29” W) and Marsa Ben M’hidi in the West (35°5′0“ N, 2°12’16” W), is part of the Alboran Sea. With one of the largest continental shelves in the country, particularly at Ghazaouet (around 90 km), and relatively rich waters thanks to the influx of the modified Atlantic water, this part of the coastline is the most productive for fishing. In fact, about 40% of the national product of sea fishing (86,600 t in 2013) comes from the Alboran Sea. It is also in this sea that aquaculture has developed the best in Algeria, with more than 27% of the projects being exploited, both for fish and shellfish farming.

The width of the submarine coastal border of western Algeria is variable (Rosfelder 1955; Maurin 1962); it is 10 km off Cape Falcon and nearly 90 km off Ghazaouet. Up to 5 to 6 nautical miles from the coast, the bottom consists of sand and rocks, followed by a muddy (soft and grayish) area 2 to 3 miles wide and then a mixture of coarse shell sand and mud. The major component of the sediments on the Algerian west coast is represented by the limestone that lines the coastal shelf and the continental rim precisely in Oran Bay and its surroundings; as for siliceous sediments, these are poorly represented (Leclaire 1972).

The hydrodynamics on the Algerian coast of the Alboran Sea is influenced by the modified Atlantic water, slightly salty and cold, which enters the surface through the Strait of Gibraltar. This current crosses the Alboran Sea along the Moroccan coast and then enters the Algerian basin forming the Algerian coastal current (Millot 1997). It makes a cyclonic course in the western Mediterranean in a layer of a hundred meters thick from the surface, during which, subject to evaporation and mixing, it gradually gains in salinity and density. Its salinity thus goes from about

36.5 psu in Gibraltar to 38.0–38.3 psu in the northwest Mediterranean. The average temperature of the Atlantic water along the Algerian coast is 20.5°C; it is between 10.8 and 15.5°C in winter and between 20 and over 24°C in summer (Zemenzer 2011).

20.5.1 History and Progression of Aquaculture

Aquaculture in Algeria began in 1920 in the Mellah lagoon (8°20′E, 36°54'N) through the installation of a system of weirs (bordigues) to extensive aquaculture. After some decades, in 1980, an extensive aquaculture based on the stocking and restocking of a hundred inland water bodies with imported species, mainly Cyprinids from Hungary, was developed. Current aquaculture deals with intensive fish farming (sea bass and sea bream in cage and pond) and shellfish farming (mussels and oysters) (Kara et al. 2016). A ministry responsible for fisheries and aquaculture was created in 2000. Several public aquaculture projects have been planned for demonstration purposes and to support production, and private projects are also underway for the establishment of marine and inland shellfish and fish farming businesses.

In 2005, a plan for the development of aquaculture through to 2025, with a production target of 53,000 tons a year, was published. A total of 450 favorable sites for both marine and freshwater aquaculture have been identified and distributed across 9 branches of aquaculture: tuna fattening, shellfish farming, marine fish farming, crustacean culture, exploitation of natural resources, continental fishing, freshwater fish farming, seaweed aquaculture, and ornamental fish farming (MPRH 2008). This master plan also addresses environmental considerations, as well as possible land use conflicts, so that several of the selected sites of interest for aquaculture are located in tourism development areas and protected areas (marine parks, marine reserves) or near hydraulic structures. The goal is to harmonize land use to ensure the sustainable development of the industry (IUCN 2009).

20.5.2 Current State and Overview

Algerian aquaculture has grown from an average of about 300 t between 2000 and 2007 to an average of 2300 t beyond 2008 (Fig. 20.20). Most of this production comes from inland fisheries with around 60% in 2014. The contribution of shellfish farming remains low, while intensive fish farming is growing positively, particularly with regard to its marine component.

According to the Directorate General of Fisheries (DGF) of Algeria, in 2016, of the 43 recorded shellfish aquaculture projects, 15 were active with a production capacity of 1650 t and an effective production of only 31 t. The number of marine finfish aquaculture projects submitted was 130, of which 10 were active with a

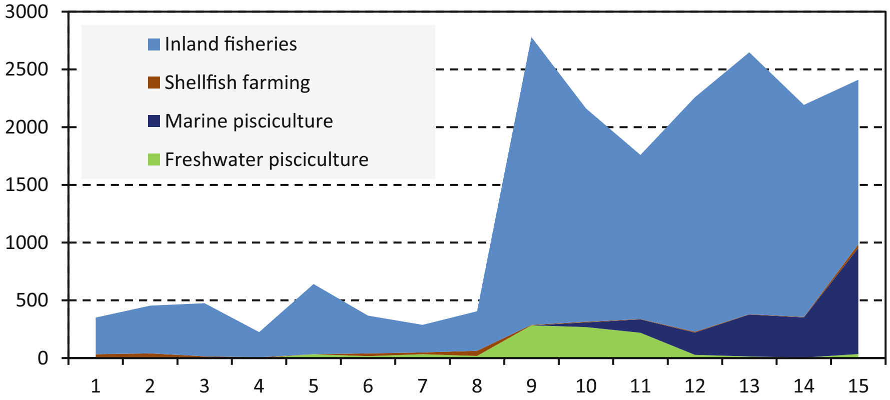

Fig. 20.20 Evolution of aquaculture production in Algeria between 2000 and 2014

Table 20.2 Geographical distribution of the number of aquaculture projects in production on the Algerian coasts (places in bold are located in the Alboran Sea)

Place		Shellfish culture	Fish culture	Total
East	Jijel	1	0	1
	Béjaïa	3	1	4
Center	Tizi-Ouzou	1	1	2
	Boumerdes	0	1	1
	Alger	1	0	1
	Tipaza	3	1	4
West	Chlef	1	4	5
	Mostaganem	2	2	4
	Oran	**2**	**1**	**3**
	Ain Temouchent	**1**	**4**	**5**
	Total	15	15	30

production target of 7000 t and actual production of 920 t. Total aquaculture production in Algeria in 2017 was 1543 t: 970 t of sea bream, 407 of sea bass, and 166 of mussels. Nevertheless, statistics data in 2014 from FAO point out a lower production (http://www.fao.org/fishery/countrysector/naso_algeria/en).

Table 20.2 gives the geographical distribution of the production sites in 2018. A total of 30 marine aquaculture projects were in production, 15 in shellfish culture (mussels, oysters) and 15 in fish farming (sea bass, sea bream, Fig. 20.21). Forty percent of shellfish farming projects and 73% of fish farming projects were located on the Algerian west coast between Chlef and Ain Temouchent. The shores of the Alboran Sea which represent 12% of the length of the total Algerian coastline accounted for 20% of shellfish projects and 33% of fish projects, i.e., around 27% of all aquaculture facilities.

Fig. 20.21 Ongrowing cages of sea bass and sea bream at Ain Temouchent farm (photo by M. Hichem Kara)

Several indicators from the AQUAMED project's surveys (http://www.aquamedproject.net) make it possible to assess the research's support capacity in relation to the size of the aquaculture sector and its performance. In general, Algeria has many specialized research structures in aquaculture. Four university departments, two institutes, and a national research center (CNRDPA) are in charge. The number of researchers involved is low, considering the development objectives, the extent of the territory, the diversity of the subjects to be mastered, the techniques to be transferred, and the innovation needs to ensure the mastery of the farms. In all cases, there is a lack of coordination between aquaculture stakeholders and a relatively weak technical training and monitoring of producers.

In Algeria, aquaculture has not had the expected development, despite the political will and real strengths, particularly in terms of financial and fiscal benefits. The hoped-for development seems to depend first of all on the ability to set up an organization in coherence with realistic objectives. The current effort to restructure the entire industry, including training and finalized research (MPRH 2014), needs to be highlighted. Table 20.3 summarizes the strengths and weaknesses of marine aquaculture in Algeria.

Table 20.3 Forces and constraints to shellfish and fish farming activities in Algeria

Strengths	Constraints
Common	
Very low fee of the concession (1 Da/m^2 on land and 1800 Da/ha at sea) over 25 years tacitly renewable	Absence of aquacultural activity zones on land
Exemption from all taxes during the first 3 years of entry into production	Congested ports and conflicts of use with other activities
Total interest rebate on operating credits (which is in the order of 8%)	Lack of technical and practical experience
Decentralization and lightening of regulatory procedures and establishment of an insurance policy for aquaculture	Weaknesses of health surveillance and biosecurity systems
Substantial demand from the domestic market, lack of competition and proximity of European markets	Lack of associations and aquaculture professionals federation
Shellfish culture	
Very good quality of coastal waters, especially under the microbiological profile	Low trophic level of coastal waters
	Very limited natural capture of spat to ensure farm self-sufficiency
	Problematic supply of fry
	Presence of the lower quality *Perna perna* species compared to *Mytilus galloprovincialis*
	Farm structures not resistant to the exposure conditions of selected coastal sites
	Many of equipment and consumable materials not available
Fish culture	
Exemption and downward revision respectively of customs duties and VAT for the import of food	Problematic supply of fry and food
	Complex import modalities incompatible with proper management of a fish farm

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Chapter 21
Marine Megafauna and Charismatic Vertebrate Species

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21.1 Introduction

Marine megafauna typically include large pelagic sharks, sea turtles, seabirds, and marine mammals (Lewison et al. 2004; Zydelis et al. 2009). These animals are long-lived with slow growth and late maturity and are mainly associated with pelagic

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ecosystems through which they undertake long-distance migration. For these reasons marine megafauna are particularly vulnerable to non-natural mortality due to fishing, and depleted populations may take decades to recover (Musick 1999). Nevertheless, marine megafauna play a key role as apex predators in most ecosystems. Moreover, for social reasons, and within frameworks for the management and conservation of natural environments, marine megafauna are considered flagship (charismatic) species (Zacharias and Roff 2001; Albert et al. 2018). Thus, marine megafauna capture public attention and raise conservationist concern for reasons related to their role in marine biodiversity. Given the phenomenon of global climate change, they also increase public awareness of the need to conserve marine species or protect their future.

As mentioned, marine megafauna are mainly associated with pelagic ecosystems and long-distance migrations. The Alboran Sea connects the Atlantic Ocean and Mediterranean Sea and is thus a relevant hotspot for marine megafauna (Coll et al. 2010). In this area, the overlap between various human activities—such as marine traffic or fisheries on the north and south coasts—and pollution has a strong negative impact on their populations.

The areas of the Alboran Sea and the adjacent Strait of Gibraltar have been included in various EU Directives and in different international agreements such as the Barcelona Convention, the Convention of Migratory Species (CMS), the Bern Convention, and CITES. The Alboran Sea is also a priority area according to the Regional Activity Centre for Specially Protected Areas (RAC-SPA) established in 1985 by decision of the Contracting Parties to the Convention for the Protection of the Mediterranean Sea Against Pollution (Barcelona Convention) within the framework of the Mediterranean Action Plan (MAP) of the United Nations Environment Programme (UNEP).

21.2 Large Pelagic Sharks

Twenty-five shark species are included in the Shark Species Group of the International Commission for the Conservation of Atlantic Tunas (ICCAT). According to their definition of pelagic, oceanic, and highly migratory sharks, just 12 species have been reported in the Alboran Sea (https://www.mapama.gob.es/es/costas/temas/proteccion-medio-marino/biodiversidad-marina/habitats-especies-marinos/default.aspx). These species are included in the following families: Alopiidae (Lamniformes), Carcharhinidae (Carcharhiniformes), Cetorhinidae (Lamniformes), Lamnidae (Lamniformes), and Sphyrnidae (Carcharhiniformes). The most common species are the blue shark (*Prionace glauca*), the shortfin mako (*Isurus oxyrinchus*), and the thresher sharks (*Alopias* spp.).

Alopiidae (thresher sharks) are an easily identifiable family. They are characterized by the length of the upper lobe of the caudal fin, which is as long as the rest of the body (Moreno et al. 1989). Of this family, the most common species in the Alboran Sea is the common thresher (*Alopias vulpinus*). Moreno et al. (1989)

suggested that the Alboran Sea and nearby areas could be a postpartum bycatch area for the common thresher. This suggestion is in line with observations of kayak sport fishing bycatch, where juvenile individuals are taken as bycatch next to the coast (Báez et al. 2016). Regarding bigeye thresher (*Alopias superciliosus*), scientific studies have suggested the existence of a nursery area in waters off the southwestern Iberian peninsula (Moreno and Moron 1992).

The Lamnidae family (Lamnidae) includes important charismatic species such as the white shark (*Carcharodon carcharias*). This species uses the Alboran Sea as an occasional route rather than as a residential area as it follows sea turtles and cetaceans from Atlantic waters (Morey et al. 2003). The shortfin mako is the best representative of this family. Although the fishing fleet was less industrialized in the past than nowadays, these sharks were eagerly sought by fishermen because the dried meat of shortfin mako was considered a delicacy and was often served as swordfish (Báez 2001). Since ancient times, surface longliners have been called "marrajeras" (and their crew "marrajeros"), a name derived from the word "marrajo", which was the common Spanish name of shortfin mako. Because of the decrease in its numbers, current captures are always sporadic, and therefore the sale of this species is not profitable. In fact, when longliners were targeting shortfin mako for commercial purposes, wire leaders instead of nylon leaders were used on the snoods—as currently used in the Mediterranean—which were more resistant to shark bites (Báez 2001).

The basking shark (*Cetorhinus maximus*, Cetorhinidae) crosses the Alboran Sea, including near the coast, during January, March, and May (Valeiras et al. 2001). Using data collected in the south of Portugal, Couto et al. (2017) showed that the occurrence of basking sharks in this area was related to the beginning of the upwelling season and that the inter-annual changes were related to lower sea surface temperatures. These results suggest that basking sharks are associated with the expansion of cold waters following upwelling events in the region, which is probably due to the aggregation and increase of zooplankton (Couto et al. 2017). Greater concentrations of basking sharks in the south of Portugal are associated with increased numbers passing through the Alboran Sea.

The Carcharhinidae family includes the blue shark, which is the most abundant pelagic shark in the Alboran Sea. For a few weeks of the year, several longliners based in Alboran ports target blue shark. Although their sale price is low, this is compensated for by their great abundance and proximity to landing ports. Muñoz-Chápuli (1984) observed that juvenile blue sharks remain in nursery and feeding areas and do not migrate until they reach an average length of 130 cm. The average size of blue sharks caught in the Gulf of Cádiz and the Mediterranean is 111 and 153 cm, respectively. These individuals are clearly immature, given that adult specimens are fertile after reaching a length of 217 cm (Macías et al. 2015). Thus, the Mediterranean and adjacent waters could be functioning as a juvenile nursery and feeding area. Macías et al. (2015) found that females predominate in the Alboran Sea, whereas males predominate in the central North Atlantic: however, the sex ratio is close to 50% in the Mediterranean. These observations suggest that juvenile blue sharks are segregated by sex and age in the Mediterranean Sea and adjacent waters.

Fig. 21.1 A jaw of a tiger shark specimen captured in the Alboran Sea (specimen location: Alborania Museum, Malaga, Spain)

In addition, there are vagrant records of other species. For example, a 4-m tiger shark (*Galeocerdo cuvier*) was caught in front of the beach of "Los Toros" in Manilva (Málaga) in July 1991 (Pinto de la Rosa 1994). This *G. cuvier* record has been challenged (Bradai et al. 2012; CIESM 2018). *Galeocerdo cuvier* teeth are considered to be a taxonomic characteristic (Brandão et al. 2017). The remains of this shark are held in the Alborania Museum (Malaga, Spain), and these clearly correspond to *G. cuvier* (Fig. 21.1). Local abundances of large pelagic sharks could be mediated by climatic oscillation (Báez 2015).

Large pelagic sharks are an essential element of the marine ecosystem and trophic nets (Stevens et al. 2000), but their populations have become depleted worldwide. This process has been particularly marked in the Indo-Pacific Biodiversity Triangle and Mediterranean Sea (Ferretti et al. 2008; Dulvy et al. 2014). Bycatch of large pelagic sharks is the highest in the industrial and artisanal fisheries targeting swordfish and tuna in the Mediterranean Sea (Rey et al. 1987; Buencuerpo et al. 1998; Megalofonou et al. 2005a, b).

Recent estimates suggest a worldwide decline of 90% or more of large shark populations (Heithaus et al. 2008). There is increased evidence of severe drops in the number of large predatory fishes worldwide. According to Ferretti et al. (2008), there are adequate records for analysis for only five of the large shark species present in the Mediterranean: hammerhead sharks (*Sphyrna* spp.), blue sharks, mackerel sharks (i.e. *Isurus oxyrinchus* and *Lamna nasus*), and thresher sharks. The abundance of all these five species has declined by between 96% and 99.99%. According to the International Union for the Conservation of Nature (IUCN) criteria, these species would be considered critically endangered (Ferretti et al. 2008). These pelagic sharks are bycaught in the northern and southern Alboran Sea. The highest rate of bycatch is caused by the use of surface longlines; on rare occasions, they are bycaught by trawlers (Mohammed 2004; Báez et al. 2009). For decades, these species also have been targeted by Spanish and Moroccan driftnet fisheries in the Alboran Sea (Tudela et al. 2005 and references therein).

Unlike the northern Moroccan longline fleet, the longline fleet operating in the north Alboran Sea has lost its pure artisanal character. The most important home-based harbour for the surface longline fleet operating in the Alboran Sea is Carboneras (Almeria), a port situated in the northeastern area of the Alboran Sea. This harbour hosts a large surface longline fleet targeting swordfish (*Xiphias gladius*). The fleet also operates in the western Mediterranean Sea and the Canary Islands. The harbour of Roquetas de Mar (Almeria) also has a large fleet of artisanal surface longliners that operate in the north Alboran Sea. In Morocco, the most important fleet targeting blackspot seabream *Pagellus bogaraveo* are the longliners based at Tangier and the artisanal fleet operating in the area of the Strait of Gibraltar. In recent years, the Moroccan longliner fleet has been more or less stable (around 98 vessels), whereas between 2009 and 2011, there was an increase in the size of the artisanal fleet (CopeMed II 2012). The pelagic waters situated over the submarine canyons near to Motril (Fig. 21.1a) are the most important fishing area in the Alboran Sea for Spanish drifting longliners targeting swordfish. For some months, they also target blue shark. Bycatch by this fishery includes birds, marine mammals, and turtles (Fig. 21.2).

Between 1999 and 2002, the amount of shark caught in the Alboran Sea by the Spanish surface longline fleet was 34.3% of the total weight of the sampled catches. This is the highest percentage of all incidental shark catch in the Mediterranean Sea (Valeiras et al. 2003; Macías et al. 2004; Megalofonou et al. 2005b) and could be related to the location, which is an important migratory channel adjacent to the Atlantic Ocean (Megalofonou et al. 2005b). The higher frequency of sharks in the Alboran Sea could also be due to the higher trophic potential of the western Mediterranean compared to the eastern part. The highest shark catch has been observed in the swordfish longline fishery in the Alboran Sea, where the nominal catch per unit effort (CPUE) was 3.8 sharks/1000 hooks.

Between 2000 and 2012, blue sharks were the most-caught species in the northern Alboran Sea (Fig. 21.3). Between 1999 and 2001, blue shark bycatch by the Spanish surface longline fisheries targeting swordfish was 2% of the total catch. Information collected from onboard observers during 861 fishing sets in 26 longliners operating in the western Mediterranean Sea indicated that the greatest bycatches were taken in the Alboran Sea, representing 75.6% of the total observed bycatch of blue shark. The observed CPUE ranged from 5.5 to 34.1 kg/1000 hooks. The mean length at capture

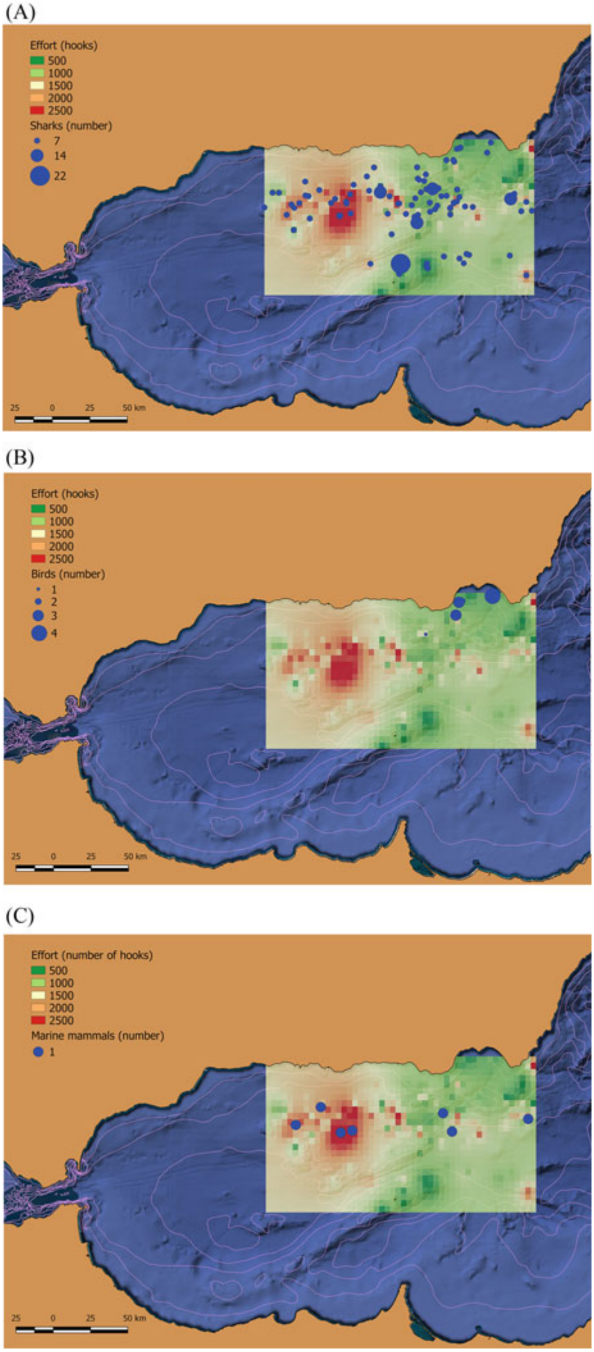

Fig. 21.2 Effort distribution of the southern Spanish surface longline fleet operating in the Alboran Sea (2012–2017). During this period, there were no observations of sea turtle bycatch. Blue dots represent observed bycatch of sharks (**a**), seabirds (**b**), and marine mammals (**c**)

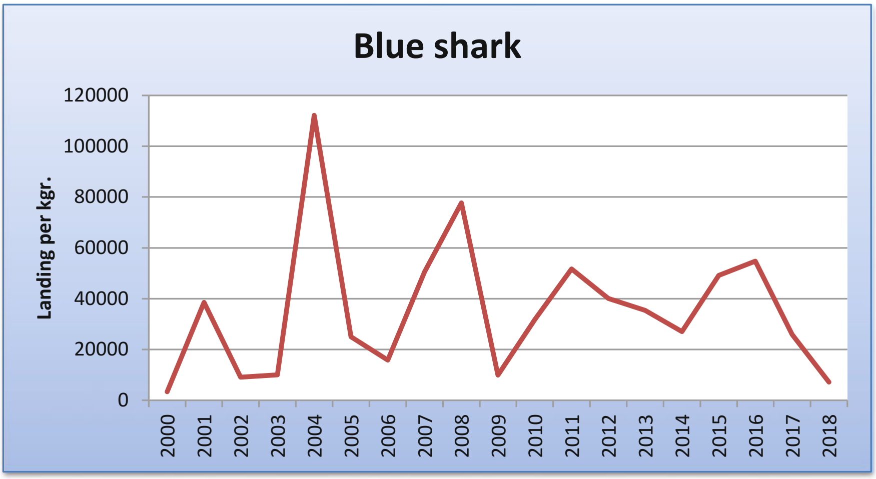

Fig. 21.3 Evolution of landing trends for blue shark from the northern Alboran Sea (2000–2012). An oscillation pattern can be observed

was 141.6 cm (SD = 35.88). The proportion of females to the total was 0.5 (Valeiras and de la Serna 2003). Between 2000 and 2012, the shortfin mako was the second most-caught shark species in the northern Alboran Sea (Macías et al. 2004) (Fig. 21.4). Báez et al. (2009) observed a bycatch per unit effort of sharks in the northern Alboran Sea of 1.41 blue sharks per 1000 hooks, 0.26 shortfin mako per 1000 hooks, and 0.07 bigeye thresher shark (*Alopias superciliosus*) per 1000 hooks (Fig. 21.5).

The Moroccan and Spanish driftnet fisheries are no longer in operation. However, Tudela et al. (2005) reported that the highest catch rates in the Moroccan driftnet fishery were for shortfin mako. In fact, the catch rate per fishing operation for this species was almost three times higher in active shark fishing boats (0.6 Pinto1.9 N/ fishing operation), and the catch per km net was similar (0.06–0.14 N/km). These results (Tudela et al. 2005) are in sharp contrast to the information available on the activity of the former Spanish driftnet fleet in the Alboran Sea. For example, Silvani et al. (1999) reported only anecdotal occurrence of shortfin mako and blue shark in the catch (i.e. 3 shortfin mako and 4 blue shark in 1994 from a total 54 fishing operations monitored). They did not report any capture of thresher shark. These results suggest that sharks are directly targeted in the Alboran Sea.

According to the Junta de Andalucia, the landing data from the Mediterranean Andalusian coast (north Alboran Sea) suggest that blue shark, shortfin mako, and thresher shark are decreasing (Figs. 21.3, 21.4, and 21.5).

Fig. 21.4 Evolution of landing trends for shortfin mako from the northern Alboran Sea (2000–2012). A gradual decline in catches can be observed

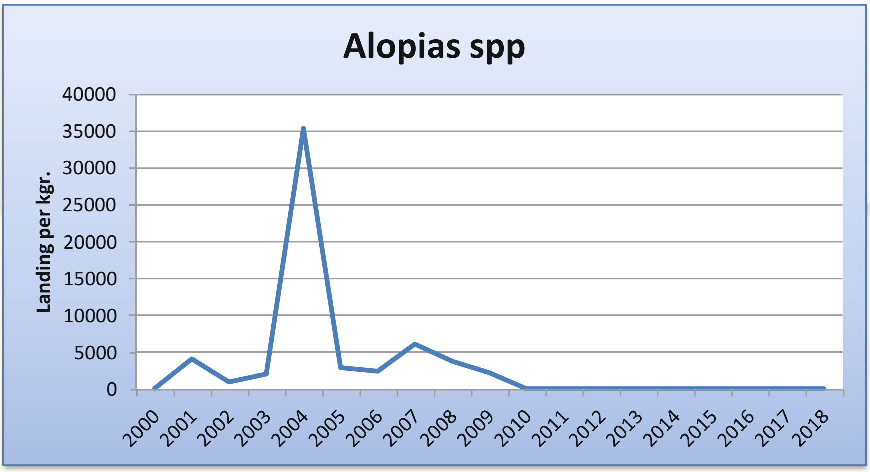

Fig. 21.5 Evolution of landing trends for *Alopias* spp. (2000–2012). A sharp peak followed by a marked decline in catches can be observed

21.3 Sea Turtles

Sea turtles are distributed throughout the Mediterranean Sea (except flatback sea turtle -*Natator depressus*-). The green turtle (*Chelonia mydas*) and the loggerhead turtle (*Caretta caretta*) present nesting beaches in the Eastern Mediterranean Sea (Broderick et al. 2002). Nonetheless, in recent years sporadic nesting of loggerhead are observed around Western Mediterranean. It is a growing phenomenon on the

Spanish coasts of the western Mediterranean (Carreras et al. 2018). It is of interest that the first loggerhead turtle nesting site detected in the Iberian Peninsula was found on the Andalusian coast (Tomás et al. 2008), and recently in Fuengirola (Málaga) (Báez et al. 2020). However, there are not records of such nesting sites on the coast of Morocco (Aksissou M., personal communication; Laurent 1990; Báez and Bellido 2015). Nevertheless, on June 28, 2018, a female was tagged in Valencia and monitored via satellite to a beach in Gouraya (Algeria) on July 7, 2018, (Belda, personal communication) where it probably nested.

Loggerhead is the most abundant sea turtle species in the Alboran Sea (Valeiras and Camiñas 2001; Camiñas 2004). In this area, loggerhead sea turtle specimens come from the Mediterranean, Northeast American, and Cape Verde populations (Margaritoulis et al. 2003; Monzón-Argüello et al. 2010). Adult and juvenile loggerheads are found throughout the year in the Alboran Sea. There is a striking difference in the adult loggerhead sex ratio in this area. Based on strandings, the ratio of males to females is 1:172 (Bellido et al. 2015). Adults were stranded in the Alboran Sea mainly in June and July (Báez et al. 2017). Some studies have suggested bidirectional migration through the Strait of Gibraltar: from the Atlantic area (Gulf of Cádiz) to the Alboran Sea from May to June and a subsequent move from the Alboran Sea to the Balearic Sea from June to July (Camiñas and de la Serna 1995; Báez et al. 2017). The Strait of Gibraltar and the Alboran Sea connect the western Mediterranean Sea and the Atlantic Ocean and therefore have been considered to be relevant corridors for sea turtles (Camiñas and de la Serna 1995; Báez et al. 2017). These migrations could be affected by the North Atlantic Oscillation (NAO) and the Sea Surface Temperature (SST) (Bellido et al. 2008a; Báez et al. 2011). The westerly winds prevailing during positive NAO phases and the subsequent delayed decrease in SST may lead to the accumulation in the Gulf of Cadiz of turtles born in the Atlantic Ocean that are returning to the Atlantic Ocean from the Alboran Sea. On the other hand, a sudden drop in SSTs accompanied by storms increases the number of episodes of cold-stunned turtles in the area (Bellido et al. 2008a; Báez et al. 2011).

Revelles et al. (2007a) suggested that there was an asymmetrical size exchange of loggerhead turtles between the Alboran Sea and the Atlantic Ocean through the Strait of Gibraltar that was due to a physical barrier formed by the flow of surface Atlantic waters entering the Mediterranean through the Strait of Gibraltar. Thus, juvenile loggerheads born in the Atlantic Ocean remain in the Mediterranean until they reach the minimum size to overcome the westward current.

Ocaña et al. (2005) and Benhardouze et al. (2008, 2012a) suggested that loggerhead could use the southern Alboran Sea as a specific foraging area due to the abundance of *Polybius henslowii* (Decapoda, Brachyura). This species is also the main prey of *Caretta* along the southern Portuguese continental coast (Nicolau 2017).

According to genetic analysis, individual green turtles arriving on Spanish coasts come from American or African populations. Carreras et al. (2014) used data on observations of green turtle strandings in Spain. They concluded that the recent results of mitochondrial DNA analysis suggest that the haplotypes of green turtles in

Spanish waters are exclusive to specimens from Atlantic African nesting beaches, whereas no specimens with this haplotype have been found in populations in the eastern Mediterranean (Monzón-Arguello et al. 2011). In 2018, two adult individuals were accidentally entangled in a small tuna trap net close to Ceuta (a Spanish city on the southern Alboran coast) (A. García De los Ríos y los Huertos, Personal Communication). They were subsequently released with a satellite tags. Several months later, one was recorded in the Alboran Sea, and the other was recorded in the Atlantic close to Mauritania. There is a record of one stranding in the Cuevas de Almanzora area (Almeria), which is within the limits of the Alboran Sea.

Leatherback sea turtles (*Dermochelys coriacea*) are regular visitors to the Alboran Sea (Camiñas 1998; Casale et al. 2003). Large specimens, live or dead, have been observed in this area. However, little is known about the biology or migration patterns of leatherbacks on the Andalusia coast due to their low presence in this area (Camiñas 1998). Camiñas and Valeiras (2001) highlighted the Strait of Gibraltar region as a key for loggerheads and leatherbacks. Lalire and Gaspar (2019) recently modelled the distribution of juvenile leatherbacks, finding that those observed in the area of the Strait of Gibraltar mainly came from western Atlantic beaches.

An association has been found between stranding frequency on the Andalusian coast and climatic oscillations (Báez et al. 2012). Between 1997 and 2015, three Kemp's ridley (*Lepidochelys kempii*) sea turtles were stranded on Andalusian coasts adjacent to the Atlantic, but none were stranded on coasts by the Alboran Sea (Bellido et al. 2018a). However, individual specimens of this species have been recorded within the Mediterranean Sea (Tomás et al. 2003; Insacco and Spadola 2010; Carreras et al. 2014). Therefore, it cannot be ruled out that this species sometimes transits the Alboran Sea.

The main threats to sea turtles are collisions with fishing vessels, interactions with fishing activities, and bycatch (Bellido et al. 2018a). Bycatch is the main threat to sea turtles in the Mediterranean Sea and, by extension, in the Alboran Sea (Lewison et al. 2004; Lucchetti and Sala 2010). In the Alboran Sea, sea turtles are bycaught on several types of fishing gear: driftnets (Tudela et al. 2005; Benhardouze et al. 2012b), drifting longlines (Valeiras and Camiñas 2001; Báez et al. 2007), bottom trawling (Báez et al. 2006), trammel nets (Báez et al. 2006; Lozano et al. 2011), and trap nets and another artisanal gear (Báez et al. 2006). There is a lack of reliable information on the relative contribution of each fishing gear to the total bycatch. Báez et al. (2006) suggested that longlines are the greatest source of bycatch in the Alboran Sea. However, changes in fishery strategies, including longline métiers targeting swordfish in deeper waters, have driven a substantial decrease in sea turtle bycatch within the western Mediterranean Sea (Báez et al. 2019).

Báez et al. (2011) showed that sea turtle bycatch in the Alboran Sea is more dependent on distance to the coast distance than to fishing effort or other technological factors. Thus, the probability of bycatching a loggerhead turtle increases as distance to the coast increases. On the other hand, the bycatch frequency and size differentiation of loggerhead turtles are a function of surface longline gear type (Báez et al. 2013).

Another source of threats in the Alboran Sea is the accumulation of heavy metals, such as cadmium, lead, copper, and zinc, which have been detected in loggerhead turtle tissue samples (García-Fernandez et al. 2008). Such heavy metals have also been found in their main prey, *Polybius henslowii*, along the southern Portuguese coast (Nicolau 2017) and in the strait of Gibraltar (Ocaña et al. 2005).

Observations of sea turtles are frequent on the north and south coasts of the Alboran Sea due to the number of specimens that are stranded either alive, dead, or in poor condition in these areas (Bellido et al. 2010a, b; Rojo-Nieto et al. 2011; Benhardouze et al. 2012a). Each year, many injured turtles or their carcasses are found on Andalusian coasts (Camiñas 2002; Bellido et al. 2010a, b). The high frequency and steady rate of turtle strandings per year, as well as mortality/injury rates, suggest that there is a high presence of sea turtles, particularly loggerheads and leatherbacks, along the Andalusian coastline (Bellido et al. 2018a). According to Rojo-Nieto et al. (2011), there are more loggerhead turtle strandings on the northern Alboran coasts, whereas there are more leatherback turtle strandings on southern Alboran coasts.

Regarding strandings for which it is possible determine the cause of death, up to 43% of loggerhead strandings, could be directly attributed to anthropogenic causes such as trauma and interaction with fisheries. According to Bellido et al. (2007, 2018a), longline bycatch is not the main cause of loggerhead strandings on the Alboran coast. Natural causes, such as debilitated turtle syndrome (Vallini et al. 2011), and disease account for the remaining 57% of loggerhead strandings. However, the cause of leatherback strandings is very difficult to determine. In most cases, stranded specimens have been found dead and in an advanced state of decomposition, which makes it difficult to determine the cause of stranding. Nevertheless, in some cases, the presence of net marks on flippers establishes the cause of death as interactions with fisheries (Bellido et al. 2018a).

Regarding natural hazards in the Alboran Sea, sea turtles could be affected by cold stunning (Bellido et al. 2008a), diseases driven by epibionts (Bellido et al. 2010a), and predation by large sharks (Bellido et al. 2018b). Although white sharks rarely prey on loggerhead turtles, the proportion of sea turtles in the white shark diet is the highest in the Mediterranean area (Morey et al. 2003).

21.4 Seabirds

The Gibraltar-Alboran Sea region is one of the most important corridors for seabirds in the Palearctic, because it connects continental Europe and Africa as well as the Atlantic Ocean and Mediterranean Sea (e.g. see Arcos et al. 2009). The numbers of seabird inhabiting in Alboran Sea varies across years and seasons. There are 49 species including resident, migrant, wintering, occasional, and vagrant birds (Table 21.1). Ornithological interest in this biogeographic region arose in the nineteenth century (e.g. Irby 1875; Garrido Sánchez 2017), when naturalists frequently visited the area to collect specimens and eggs and to conduct research on seabirds. Of historical note, the *graellsii* subspecies of the polytypic lesser black-backed gull was described in 1857 by A. E. Brehm based on some specimens captured in the harbour of Malaga (Spain) (Brehm 1857).

Despite the relevance of the region for seabirds, breeding populations are quite small and restricted to a few suitable nesting sites (UNEP-MAP-RAC/SPA 2015). The main breeding sites include wetlands, cliffs, and small islands/archipelagos that offer some degree of protection. For example, the most important breeding sites for Scopoli's shearwater (*Calonectris diomedea*) are the Chafarinas Islands in Spain and the Habibas and Rachgoun Islands in Algeria (Reyes-González and González-Solís 2016), whereas there are only a few breeding pairs of Cory's shearwater (*Calonectris borealis*) in the Chafarinas Islands. It has been suggested that the Almeria-Oran oceanographic front is the actual divide between *C. borealis* and *C. diomedea* (Gómez-Díaz et al. 2006). The Alboran Sea, Chafarinas Islands, and Alhucemas Islands host large colonies of Audouin's gull (Oro et al. 2006; Afán et al. 2010). This species also breeds in other dispersal points on the north African coast and has been observed recently in Ceuta (Guirado and Guirado 2015).

Different wetlands on both sides of the Alboran Sea that have been included in the RAMSAR Convention host large colonies of breeding larids and waterbirds. On the northern shore, these wetlands include the Punta Entinas-Sabinar National Park and the Cabo de Gata salt marshes (Almeria, Spain) (Paracuellos and Nevado 2003; Paracuellos 2006). On the southern shore (Morocco), they include the Sebkha Bou Areg lagoon and the river Moulouya estuary, which is the most significant estuary and floodplain complex of the largest river in the Maghreb. In these sites, emblematic breeding species are the little tern, Auoduin's gull, and the slender-billed gull (Ramsar Convention 2005).

Anthropized environments, such as large cities, are also used as nesting sites by less demanding species such as the yellow-legged gull, which is well adapted to feed on human refuse, discards, and so on (e.g. Sol et al. 1995; García-Barcelona et al. 2018). In fact, the yellow-legged gull is the most abundant breeding seabird species in the Alboran basin with around 15,000 nesting pairs (Molina and Bermejo 2009; Radi et al. 2018). Among wintering species, the Mediterranean gull, the lesser black-backed gull, the northern gannet, and the Balearic shearwater should be mentioned due to their abundance and ecological importance.

Due to high levels of primary productivity in the Alboran Sea, some species, such as the Balearic shearwater, northern gannet, and Mediterranean gull, use this area for feeding and foraging. Although the Balearic shearwater typically inhabits coastal waters on the continental shelf (i.e. mainly the Levantine region of Spain and Balearic Islands) (Louzao et al. 2006), it is also a frequent visitor to the Alboran Sea, where it feeds and forages even during breeding period (Ruiz and Martí 2004; Louzao et al. 2012). Given this behaviour, it has been recommended that countries adjacent to the Alboran Sea should enact transboundary protection measures for this critically endangered species (Louzao et al. 2012).

Three important bird areas have been designated in the Alboran Sea due to its importance for the Balearic shearwater among others species (Arcos et al. 2009). These three areas are Malaga bay, the Maro-Cerro Gordo cliffs, and Almeria bay,

Table 21.1 Breeding status of seabirds present in the Alboran Sea according to Paterson (1997), Garrido Sánchez et al. (2002), and de Juana (2006)

Breeding status	Occurrence	Presence	Common name	Scientific name
Breeder	Abundant	All year	Black-headed gull Yellow-legged gull	*Chroicocephalus ridibundus* *Larus m. michahellis*
	Common	April–November	Scopoli's shearwater	*Calonectris diomedea*
		All year	Audouin's gull Slender-billed gull	*Larus audouinii* *Chroicocephalus genei*
		April–September	Common tern Little tern	*Sterna hirundo* *Sternula albifrons*
	Scarce	All year	Mediterranean gull (abundant in winter) Mediterranean shag	*Larus melanocephalus* *Gulosus aristotelis desmarestii*
		April–September	Cory's shearwater	*Calonectris borealis*
Nonbreeder	Abundant	August–April	Lesser black-backed gull	*Larus fuscus graellsii* *L. f. intermedius*
		September–April	Northern gannet Great cormorant	*Morus bassanus* *Phalacrocorax carbo*
	Common	October–June	Balearic shearwater	*Puffinus mauretanicus*
		March–September	Gull-billed tern	*Gelochelidon nilotica*
		All year	Sandwich tern	*Sterna sandvicensis*
		Post- and pre-breeding migration	Black tern Whiskered tern	*Chlidonias niger* *Chlidonias hybridus*
		November–April	Razorbill Puffin	*Alca torda* *Fratercula arctica*
		September–April	Great skua	*Stercorarius skua*
	Scarce	September-April	Arctic skua Pomarine skua	*Stercorarius parasiticus* *Stercorarius pomarinus*

(continued)

Table 21.1 (continued)

Breeding status	Occurrence	Presence	Common name	Scientific name
		Post- and pre-breeding migration	Caspian tern Lesser-crested tern White-winged tern	*Sterna caspia* *Thalasseus bengalensis* *Chlidonias leucopterus*
	Occasional	Winter	Little, common, herring, great-black-backed, and ring-billed gulls	*Hydrocoleus minutus* *Larus canus* *Larus argentatus* *L. marinus* *L. delawarensis*
		Summer	Wilson's storm petrel Great shearwater	*Oceanites oceanicus* *Puffinus gravis*
		All year	Sooty shearwater European storm petrel	*Puffinus griseus* *Hydrobates pelagicus*
	Vagrant	Winter	Black-legged kittiwake	*Rissa tridactyla*
	Rare	Winter	Caspian gull, Iceland gull, Glaucous gull, laughing gull, Baltic gull, Bulwer's petrel, Manx shearwater, little shearwater, Brown booby, long-tailed skua, Sabine's gull, royal tern, roseate tern, Arctic tern	*Larus cachinnans* *L. glaucoides* *L. hyperboreus* *L. atricilla* *L. fuscus fuscus* *Bulweria bulwerii* *Puffinus puffinus* *Puffinus assimilis* *Sula leucogaster* *Stercorarius longicaudus* *Xema sabini* *Sterna maxima* *Sterna dougallii* *Sterna paradisea*

which act as feeding areas. In addition, the Strait of Gibraltar acts as a migratory corridor for this species. During 2009, more than 17,000 specimens were counted crossing the Strait of Gibraltar (Arcos et al. 2012).

A large population of Mediterranean gulls overwinters in the Alboran Sea, which, after Tarragona (NE Spain), is the second most important wintering area for this gull in the western Mediterranean. The bulk of them overwinter in the north-western area (especially Malaga province). During this period, there are more than 10,000 birds increasing to more than 15,000 during prenuptial migration (Arcos et al. 2012; García-Barcelona 2016). Similar to the situation in Tarragona, in the Malaga Bay area, the Mediterranean gull feeds on fishery discards and on terrestrial sources, such as invertebrates (earthworms, flying ants, other invertebrates), olives, food scraps on beaches, or organic material floating in small river mouths after rain (García-Barcelona 2016). In fact, in the Malaga area, this species is more likely to be observed inland (except in rubbish dumps) than by the sea.

In the Alboran Sea, *L. f. graellsii* is the most abundant of the three subspecies of the polytypic lesser black-backed gull (i.e. *L. f. graellsii*, *L. f. intermedius*, and *L. f. fuscus*). About its origin, the ringed lesser black-backed gulls observed in Malaga were born in the Netherlands (32%), the UK (24%), and Norway (21%) mainly (García-Barcelona 2007). However, the 60% of the lesser black-backed gulls in the north of Spain come from the UK (Álvarez Laó 2005). Carrera (1988) estimated that 4000 to 10,000 lesser black-backed gulls overwintered on the Spanish coast of the Alboran Sea. Between 1984 and 2009, the population increased by more than 400% to around 30,000 (Mouriño 2009). The largest population is in Malaga province. Since the 1990s, there has also been an increase in the European breeding population, particularly in urban environments (e.g. Rock 2002). Between 2007 and 2016, weekly censuses of lesser black-backed gulls in Malaga harbour have shown an increase in the wintering population in this area (Fig. 21.6). Lesser black-backed gulls typically arrive in Malaga in August and begin to return to breeding colonies in February, when gulls from other wintering areas (i.e. the Atlantic and areas adjacent to the Alboran Sea) arrive in Malaga before continuing their migration north (S. García-Barcelona, unpublished data).

The *Larus fuscus fuscus* subspecies is a rarity in the Alboran Sea, Western Europe, and north-western Africa. Sightings of *L. f. fuscus* or the Baltic gull (Fig. 21.7) have been scarce but consistent in Malaga during the last decade, suggesting that the Alboran Sea could be a wintering area for a very small proportion of the global population (García-Barcelona et al. 2017c). This suggestion would be in line with the fact that this subspecies uses a western migration route (Kilpi and Saurola 1984; Marques et al. 2009).

For more than a decade, the Caspian gull population has been expanding towards the northern and western Europe (Klein and Neubauer 2006). A winter Caspian gull was recorded on the coast of the Alboran Sea for the first time in 2014 (S. García-

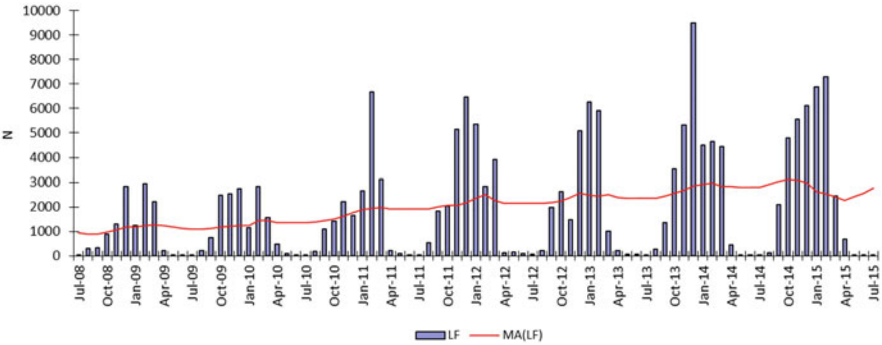

Fig. 21.6 Monthly average frequency of lesser black-backed gulls roosting in Malaga harbour (LF) and seasonally adjusted series (in red) (MA(LF)) using the moving average method (trend)

Fig. 21.7 Left: ringed Baltic gull (white CK0L) near a lesser black-backed gull (subspecies *Larus fuscus graellsii*). This Baltic gull was ringed as a pullus at Mustasaari (Finland) on July 4, 2016, and observed in Malaga on October 15, 2017. Right: unringed adult Baltic gull observed in Malaga on October 31, 2015

Barcelona, unpublished observation). Since then, other isolated winter Caspian gulls have been recorded in the Malaga province (Fig. 21.8) (García-Barcelona 2015, 2017). There has been an inter-annual increase of this wintering species in the Iberian Peninsula (Gil-Velasco et al. 2017).

Due to the geographically strategic position of the Alboran Sea, which has strong westerly winds and sea storms during winter, individual vagrant birds can arrive in the Mediterranean area via the Strait of Gibraltar. This occurred in the case of the black-legged kittiwake (*Rissa tridactyla*) after cyclones Joris and Klaus made landfall in Spain in January 2009 (García-Barcelona and Domínguez Santaella 2009).

The abundance of migratory species differs between the northern and southern coasts of the Alboran sea (Paracuellos and Jerez 2003; García-Barcelona et al. 2015). For example, Balearic shearwaters prefer to use the northern coast to move across the Strait of Gibraltar, whereas Scopoli's shearwaters migrate in much greater numbers along the south coast (Navarrete 2008; Arcos et al. 2012). Several coastal areas by the Alboran Sea are relevant pre-nuptial and post-nuptial migration corridors. The most important area by far is the Strait of Gibraltar (e.g. Programa Migres 2009; Montero et al. 2005).

Other important areas in the Alboran Sea are the transboundary coastal area Oranie and Moulouya (Morocco and Algeria), the Cap des Trois Fourches (Nador, Morocco), and Ceuta (e.g. Arcos et al. 2009; Critical Ecosystem Partnership Foundation 2010; Navarrete 2008).

The time of migration of seabirds in the Alboran area differs according to species. Most migratory seabirds leave the Mediterranean Sea and migrate to the European and African Atlantic coasts during summer after breeding and then fly back in the following spring (March–April) to start a new reproductive cycle. However, some species do not follow this pattern. For example, Balearic shearwaters migrate early (June), remain in the Atlantic for around 3 months, and then return in autumn (October/November), which is when Scopoli's shearwaters start their post-breeding migration. In fact, there is an intensive seasonal dynamic in the western Alboran Sea:

Fig. 21.8 Left: Caspian gull (*Larus cachinnans*) over its first winter observed in Fuengirola harbour on February 22, 2018. Right: a Caspian gull in Malaga harbour observed on January 6, 2014

post-breeding exodus of Balearic shearwaters and Audouin's gulls (June); post-breeding migration of most species and arrival of wintering birds (September); pre-breeding migration of Balearic shearwaters (October); post-breeding exodus of Scopoli's shearwaters (November); start of the exodus of wintering species (February); and arrival of Scopoli's shearwaters and the other breeding populations of seabirds (April).

The only critically endangered species in this area is the Balearic shearwater (BirdLife International 2016). However, in the Alboran Sea, accidental captures on fishing gear, which is the major threat to the species in other areas of the Mediterranean, do not appear to be cause of a decline in their numbers (García-Barcelona et al. 2010a, b; Genovart et al. 2016). The main threats to seabirds in the Alboran Sea and the Strait of Gibraltar can be grouped into terrestrial and marine threats. Terrestrial threats include the presence of invasive species (rats, cats, etc.) in bird colonies and urban development. Marine threats include fishery bycatch (professional and recreational), overfishing, marine pollution, and, to a lesser extent, marine infrastructures (e.g. wind farms) (SEO/BirdLife 2012). The presence of rats in some procellariform colonies (e.g. in the Chafarinas Islands) is a particularly serious problem (Igual et al. 2009). The main seabird bycatch of the Spanish pelagic longline fleet comprises wintering species (i.e. Northern gannets and Great skuas), but yellow-legged gulls are also bycaught (García-Barcelona et al. 2010a, 2016). Little is known about bycatch by demersal longliners. Although this fleet is much smaller than the pelagic longline fleet, it typically fishes close to the Alboran Natural Reserve. Thus, there is a risk of breeding species being bycaught near Alboran Island, which lies within this reserve. However, fishermen claim that seabird bycatches are very rare because they set longlines at night (Skipper Carlos Molina Hernández, personal communication). In the Strait of Gibraltar, artisanal fisheries targeting bluefin tuna (*Thunnus thynnus*) have a low impact on seabirds (i.e. northern gannets, Cory's shearwaters, and gulls) (García-Barcelona et al. 2017b). On the coast, there is increasing concern regarding fishing lines and trolling bait abandoned or lost by recreational fishermen in urban beaches and harbours. Several species of

Fig. 21.9 Left: oystercatcher with fishing line entangled on left leg. Centre: lesser black-backed gull with passerine trap attached to right leg. Right: yellow-legged gull with artificial fishing bait embedded in bill

gulls (i.e. yellow-legged, lesser black-backed, black-headed, Mediterranean, and Audouin's gulls) are permanently affected by this anthropogenic problem, which causes severe injury, loss of legs, and death among large numbers of gulls and even oystercatchers (*Haematopus ostralegus*) (Fig. 21.9) (García-Barcelona et al. 2010b). Finally, three larid species, mainly yellow-legged gulls and lesser black-backed gulls, but also black-headed gulls, are regularly affected by undetermined poisoning that causes paretic syndrome. This syndrome affects hundreds of gulls every year at least in Malaga province and Ceuta (S. García-Barcelona unpublished data). In the worst scenarios, the gulls die, but if they are treated early, they can survive and be released in 2 weeks. This disease has been identified in nearby areas such as the south of Portugal (Soares 2014).

Information on seabirds in the Alboran Sea has been enriched in the last two decades by different monitoring programs, such as the census and monitoring of breeding colonies, coastal monitoring of seabird movements and beached seabirds by volunteers, at-sea monitoring boat-based seabird surveys, and at-sea monitoring seabird tracking, all of which provide very useful information on the ecology of different seabird species (UNEP-MAP-RAC/SPA 2015).

21.5 Marine Mammals

The Alboran Sea is one of the most important areas in the Mediterranean Sea for the conservation of marine mammals (Micheli et al. 2013). The Alboran Sea is also a hotspot for resident marine mammal biodiversity (Coll et al. 2010). In fact, the Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea, and Contiguous Atlantic Area (ACCOBAMS) considers the Alboran Sea to be a Cetacean Critical Habitat (ACCOBAMS 2019). Many authors have underlined the relevance of the Gibraltar-Alboran Sea region for the conservation of cetaceans (Cañadas and Sagarminaga 2000; Boisseau et al. 2010) because it is a natural corridor for species living between the Alboran Sea and the contiguous Atlantic

Ocean (Cañadas and Sagarminaga 2000; Cañadas et al. 2005; de Stephanis et al. 2008a, b). Information on the distribution and relative abundance of cetacean species in the Alboran Sea are obtained from sightings (e.g. the whale watching industry, visual surveys, onboard research vessels, etc.) and stranding data (e.g. see Rojo-Nieto et al. 2011; Bellido et al. 2012; Masski and de Stephanis 2015).

The Spanish Institute of Oceanography (IEO) has recorded opportunistic sightings of eight species of cetaceans. Data recorded between 1991 and 2015 show that 13 cetacean species were stranded on the Alboran coast in this period (Rojo-Nieto et al. 2011; Masski and de Stephanis 2015).

According to Rojo-Nieto et al. (2011), there were differences between the numbers of cetaceans stranded on the northern and southern coasts of the Alboran Sea. Long-finned pilot whales (*Globicephala melas*) were stranded more frequently on the north coast, whereas other delphinid species (mainly *Stenella coeruleoalba* and *Delphinus delphis*) were stranded more frequently on the south coast.

In the Strait of Gibraltar, the most abundant species are the common dolphin (*Delphinus delphis*) and the striped dolphin (*Stenella coeruleoalba*). There have also been many sightings of long-finned pilot whales, sperm whales (*Physeter macrocephalus*) (de Stephanis et al. 2008b), and killer whales (*Orcinus orca*) (Esteban et al. 2013).

The Alboran Sea has the highest dolphin densities in the western Mediterranean Sea. Although the common dolphin has decreased in recent decades in the Western Mediterranean Sea, it remains abundant in the Alboran Sea (Notarbartolo di Sciara 2002; Cañadas and Vázquez 2017), where there have been no changes in population trends (Cañadas and Hammond 2008). Nevertheless, increased SSTs could reduce the amount of habitat suitable for the species (Cañadas and Vázquez 2017; Gambaiani et al. 2008). According to genetic studies and bycatch, common dolphins have higher genetic similarity with populations inhabiting adjacent the Atlantic waters than with dolphin populations in the rest of the Mediterranean (reviewed in Tudela et al. 2003). The most recent abundance estimate for this species in the Alboran Sea is around 19,000 individuals. Abundance increases from east to west (Cañadas and Vázquez 2017), which is the same pattern observed through strandings (Bellido et al. 2012). Giménez et al. (2017) detected spatial segregation between common and striped dolphin in the Alboran Sea.

Long-finned pilot whales have a large breeding and feeding ground in the northeast Alboran Sea (Cañadas and Sagarminaga 2000). There is also a resident long-finned pilot whale community in the Strait of Gibraltar (de Stephanis et al. 2008a). Between 1994 and 2014, the highest number of strandings occurred in 2007 (Torreblanca et al. 2016). In this year and previous years, there was a morbilivirus outbreak that severely affected the population in the Alboran Sea (Wierucka et al. 2014). According to Raga et al. (1991), the abundance of the pilot whale along the Spanish Mediterranean coasts decreases towards the north. The Alboran Sea contains the highest abundance.

In the Mediterranean, the Alboran Sea is the area least frequented by sperm whales (Gannier et al. 2002). The highest densities of sperm whales are found towards the Strait of Gibraltar and south of Almeria (de Stephanis et al. 2013). Despite conservation efforts, the sperm whale population has decreased in the Mediterranean Sea over the last 40 years (Cañadas et al. 2005; Coll et al. 2010). Observations of fin whales in the Strait of Gibraltar suggest a migration pattern from the Mediterranean Sea to the Atlantic Ocean during summer and the reverse in winter (Andrèu et al. 2010). Fin whale population trends in the area remain unknown due to low encounter rates (PNUE/PAM-CAR/ASP 2016).

The Alboran Sea is a key area for another important species, the Cuvier's beaked whale (*Ziphius cavirostris*) (MacLeod and Mitchell 2006), because it hosts one of the highest densities of this species (0.0054 animals/km^2) in the world with an estimated 429 individuals (Cañadas and Vázquez 2014). A "critical area" in the central Alboran Sea has been proposed to protect this species (Cañadas and Vázquez 2014).

According to Bellido et al. (2006), there is no evidence of resident *Phocoena phocoena* populations in the Alboran Sea. However, stranded individuals have occasionally been recorded along the Alboran Sea coast (Rey and Cendrero, 1982; Bellido et al. 2006). In a recent study, Blakeman et al. (2018) suggested that there may be small groups near the Málaga coast.

Dolphins have traditionally been hunted for their meat and for use as bait in pot fishing (unpublished data). At the beginning of the twentieth century, there was a large cetacean fishery in the Alboran Sea near the Straits of Gibraltar with two factories, one in Getares (Algeciras, Spain) (de Buen 1922, 1927) and one in Benzou (Ceuta, Spain). Both factories supported nearby whaling operations mainly targeting fin and sperm whales, although sei whales (*Balaenoptera borealis*) and Bryde's whales (*B. edeni*) were also hunted (Sanpera and Aguilar 1992). In recent years, no cetaceans have been hunted directly in the area, although in the past there was considerable bycatch by driftnet and longline fisheries. The driftnet fishery is currently in disuse in Morocco and Spain. Silvani et al. (1999) and Tudela et al. (2005) reported differential bycatch rates between the north and south Alboran Sea. Bycatch of common and striped dolphin were estimated to be around 327 and 3647 per year in the north and south Alboran Sea, respectively. According to Tudela et al. (2005), the high dolphin mortality rates in Moroccan driftnets were not compatible with maintaining their populations. For this reason, there was a significant flow of individuals from the Atlantic to the Alboran Sea, which has become a sink for the Atlantic common dolphin population. Rissos's dolphin (*Grampus griseus*) is one of the most bycaught cetaceans by longline fisheries in the western Mediterranean Sea (Macías et al. 2012).

The main threats to cetaceans in the Alboran Sea are anthropogenic disturbances, such as bycatch, pollution, and ship strikes (UNEP-MAP-RAC/SPA 2014). Naval exercises pose a further threat. Mass strandings of Cuvier's beaked whales in the Alboran Sea have been demonstrated to be associated with high-intensity underwater noise (Arbelo et al. 2008). Another source of threat is plastic debris; a sperm whale stranded on the coast of Granada contained 17,927 g of this material (de Stephanis et al. 2013). However, specific studies on plastic debris have yet to be conducted in this area.

In the setting of climate change, increased SSTs in the Alboran Sea would reduce the habitat suitable for common dolphins and lead to a progressive decrease in this species from east to west (Cañadas and Vázquez 2017).

The IUCN expert group for marine mammals has designated a set of marine mammal protected areas (MMPAs) in the Alboran Sea (https://www.iucn.org/commissions/world-commission-protected-areas/our-work/marine-mammal-protected-areas) (Fig. 21.10).

Other marine mammal groups in the Alboran Sea include large colonies of monk seals (*Monachus monachus*) on both sides of the sea (González 2007; Mo et al. 2011). Until the 1980s, they were found on the coasts of Almeria (De Juana et al. 1981). In the Chafarinas Islands, there was a small breeding colony that became extinct in 1994 (González 2007). Based on 141 sightings, it is currently believed that there may be a colony between Morocco and Algeria (Mo et al. 2011). Moreover, there are anecdotal records of other stranded seal species, comprising eight hooded seals (*Cystophora cristata*) and one harp seal (*Pagophilus groenlandicus*) (Bellido et al. 2008b, 2009; Torreblanca et al. 2017).

21.6 Studying the Life Traits of Marine Megafauna: An Overview of Tagging Vulnerable and Highly Mobile Species from the Alboran Sea

The existence and magnitude of contacts between Mediterranean and Atlantic marine species populations are key issues regarding regulations on the management of megafauna. To date, little is known about the population size, structure, distribution, and dynamics of megafauna in the western Mediterranean basin. The main issues concern uncertainties in mixing between megafauna stocks, mixing between the North and South Atlantic stocks, the rates and size of North Atlantic-Mediterranean stock mixing, and the possible existence of Mediterranean sub-stocks. It has been shown that there are phylogeographic breaks in gene flow between the Mediterranean Sea and the North Atlantic for several marine species (Patarnello et al. 2007), suggesting that there may be isolated and particularly vulnerable populations in the Mediterranean. The Alboran Sea is an ideal area in which to observe and study the movement of marine animals between the western Mediterranean and the Atlantic Ocean through the Strait of Gibraltar.

In 1982, Lacombe and Richez characterized the hydrodynamics of the Strait of Gibraltar, describing the surface inflow of the Atlantic waters and the deep outflow (between 50 and 200 m) of dense Mediterranean waters. They also described their

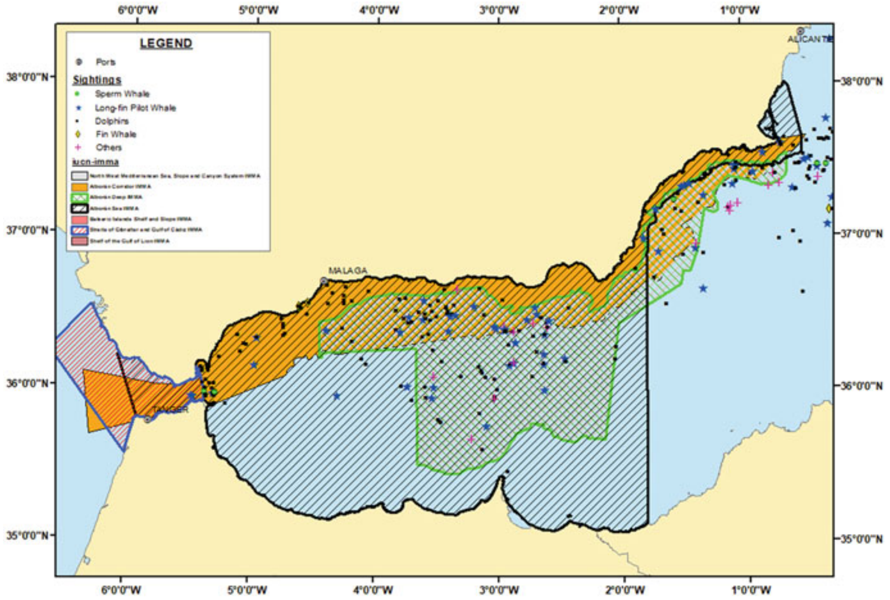

Fig. 21.10 Distribution of opportunistic sightings of marine mammals in MMPAs in the Alboran Sea (source: IEO database)

associated currents, which could be used by species, such as silver eels (*Anguilla anguilla*), to pass through the Gibraltar Strait (Lacombe and Richez 1982).

A critical situation has arisen in the Mediterranean Sea regarding the protection of megafauna from fishing activities due to the lack of effective management interventions by policy makers, Regional Fisheries Management Organizations, the General Fisheries Commission for the Mediterranean (GFCM), and the International Commission for the Conservation of Atlantic Tunas (CICTA). This situation has affected many populations of sharks (Dulvy et al. 2016), marine mammals (Jaume et al. 1999; Panou et al. 1993; Reeves et al. 2001), sea turtles (Clusa et al. 2016; Kasparek et al. 2001), and seabirds (Ancha 2008; Belda and Sánchez 2001).

Anthropic threats to the sustainability of living resources in the Mediterranean Sea are higher than ever, including the presence of chemical elements (D'Ilio et al. 2011), marine debris (Darmon et al. 2017), and collisions in the case of whales (Bentaleb et al. 2011) and sea turtles (Tomás et al. 2008).

Marine vertebrates, such as marine mammals, sea turtles, large pelagic sharks, and seabirds, migrate over long distances crossing many national boundaries and exclusive economic zone (EEZ) waters. They have a widespread distribution and occur in various oceanographic areas that are mainly characterized by their marine productivity. Better knowledge of their spatial ecology is needed in order to protect and manage declining populations and marine ecosystems. Such knowledge would form the basis of the development of successful mitigation and protection measures, as well as aid in the identification of effective marine protected areas (MPAs). The major questions need to be answered to develop realistic fisheries management and conservation strategies. These questions include the following:

Where do animals live and where do they migrate to during various temporal periods (day, season, and year)?

What areas pose the highest risks of interactions with fishing activities or collisions with ships?

Will such interactions occur within protected areas during key life-history events and periods of peak fishing activity?

When do migrations occur, and do species have to pass through major fishing grounds?

How do environmental and physiological variables influence species' habitat use and movements?

How do these behaviours vary among marine species according to their size, sex, and life stage?

Where are the key areas, such as mating, breeding, feeding, or nursery/nesting grounds?

Can we predict the impact of climate change on megafauna movements and distribution?

Tagging technologies can be used to help fill these knowledge gaps. The conventional tagging of sharks (spaghetti tags and Rototags) and sea turtles (flipper tags) and the banding of pinnipeds and seabirds—now replaced by Passive Integrative Transponder (PIT) tags—can provide information on mixing rates between stocks. In the case of sharks, these technologies can be used to validate growth studies, which are usually conducted using hard parts (i.e. vertebrae) to estimate age and accurately convert catch-at-size data to catch-at-age data (provided by growth studies). Tagging studies can be used to estimate critical population parameters such as population size, recruitment, and mortality and survival rates (Kohler et al. 2002). All this information is crucial to the adequate assessment of stocks. However, conventional tagging is limited because it is dependent on fisheries: (a) information can be obtained only if the animal is recaptured; and (b) even in the event of recapture, the route between the tagging and the recapture locations cannot be reconstructed.

In comparison to traditional methods, recent advances in satellite tagging technologies have provided scientists with more detailed information on the behaviour, habitat use, and migration patterns of free-swimming marine top predators. This technology has revealed the key habitats of charismatic species such as white sharks and basking sharks (Boustany et al. 2002; Braun et al. 2018), green turtles (Nishizawa et al. 2018), cetaceans (Balmer et al. 2014; Mate et al. 1998), and seabirds (Burger and Shaffer 2008). Thus, it is now considered to be an essential tool for conservation purposes. Next, we provide a comprehensive review of the use of tagging techniques in ecological studies of marine mammals, sea turtles, sharks, and seabirds in the Alboran Sea.

21.6.1 Marine Mammal Tagging Studies

The number of studies using electronic tags are scarce due to the difficulties involved in safely equipping small cetaceans with such devices (Balmer et al. 2014). Electronic tags are mainly used on large whales (Irvine et al., 2017; Lagerquist et al. 2008). Fin whales (*Balaenoptera physalus*) are the largest marine mammals in the Mediterranean. One study showed that seven fin whales, which were tagged with electronic archival tags off the Provençal coast, remained in the north-western Mediterranean Sea for 9 months (mainly fall and winter) to forage. Of these whales, only one migrated from the Mediterranean Sea to the Atlantic without staying in the Alboran Sea (Bentaleb et al. 2011). To the best of our knowledge, there are no studies using telemetry to track cetaceans in the Alboran Sea.

21.6.2 Sea Turtle Tagging Studies

Sea turtles are tagged to recognise individuals or a cohort for population research purposes. Tag recapture is one of the methods used to estimate abundance in migrating populations. Tagging is also conducted to obtain information on aspects such as reproductive biology, migration, or areas of residence or foraging and to calculate growth rates by age or by population. It is difficult to tag turtles during their marine life-phase, and it is also difficult to gain access to fishing or sports vessels that can catch turtles. Thus, the application of easily identifiable tags from fishing vessels is an area of particular scientific interest.

Conventional flipper tagging and satellite tagging studies have provided information on many aspects related to the behaviour of different marine turtle species, such as the relative importance to loggerhead turtles of neritic zones, as well as other areas on the western Mediterranean Spanish continental shelf (Cardona et al. 2009; Doménech et al. 2015) and by the Balearic Islands (Carreras et al. 2004). A component of homing behaviour is the fidelity of adult loggerhead turtles to breeding sites, which has been demonstrated by the use of genetic data to determine metapopulation structures as well as by direct observations through flipper and satellite tagging (Broderick et al. 2003; Casale et al. 2013; Schofield et al. 2013). Tagging has also revealed the limited exchange of immature loggerheads between regions in the western Mediterranean (Revelles et al. 2008). Loggerhead, green, and leatherback turtles are the main sea turtle species in the Mediterranean. Tagging has provided important insights into their migration (Luschi and Casale 2014) and, in the case of loggerheads, their genetic structuring (Revelles et al. 2007a, b) and distribution (Casale et al. 2007; Revelles et al. 2008).

An external tag is typically fixed to the proximal front flipper, where it does not hinder swimming or flipper movements. A single tag or one tag per flipper can be applied. Two tags are used to check the percentage of tag loss (further information on sea turtle tagging can be found in Balazs (2000)). To reduce possible injury, tags are usually sited on the back edge of the flipper with the closure system facing upward to avoid abrasion to the body of the animal (Camiñas and Valeiras 2008).

The conventional tagging of marine turtles in the Alboran and western Mediterranean Sea has mainly been conducted on loggerheads, after their capture as bycatch on fishing gear or after their recovery from a range of injuries in recovery centres. It is very difficult to estimate the population size of any marine turtle population because only female turtles return to their home beaches for breeding after reaching sexual maturity (males never return to their natal beaches). Researchers mainly use the number of nets or number of females reproducing per year as a proxy of population size (Margaritoulis et al., 2003; Ceriani et al. 2019). This part of the population and its trend are then compared to those of previous years.

Sea turtle tagging began in the IEO Oceanographic Centre of Malaga in the 1980s. Jumbo Rototags were used initially, but these were soon discarded because most of the captured turtles were juvenile and the tags were too large. Subsequently, different metallic tags were used, such as the Monel 400 (Nickel International, USA). These tags were supplied in different sizes with their applicators by the Archie Carr Centre (ACCSTR) (University of Florida, Gainesville, USA). The ACCSTR coordinates a programme for distributing turtle tags, managing tagging data, and facilitating the exchange of tagging information. The tags carry an identification number and the address of the university.

From 1999 to 2001, the same type of metal tag (manufactured in Europe) was used by the IEO to participate in the European Marine Turtle Project (EMTP). Another type of metal tag was donated by the General Directorate of Nature Conservation of the Spanish Ministry of the Environment within the framework of an Agreement between this Ministry, the Spanish Herpetological Association (AHE), and the IEO (Roca 1997; Roca and Camiñas 2000). These tags are smaller than those described and carry a serial number and the inscription “ICONA MINIST, AGRICULT, E-28005 MADRID, SPAIN”. Tagging was conducted on board recreational vessels and fishing boats and in recovery centres.

Some of the turtles tagged within the IEO tagging programme in the western Mediterranean (1986–2018) were recaptured in the following areas: the Algerian and Tunisian coasts, the area south of the Balearic Islands, the Spanish Atlantic and Mediterranean coasts, and the coasts of Cuba, Florida, and Nicaragua.

Most of the tagged turtles were recaptured in the usual fishing zones of the Spanish longline fleet near the southern Balearic Islands in the year following their tagging or in subsequent years. This result is suggestive of an annual reiterative process of trophic migration to the Balearic Sea.

The use of satellite radiometry has led to advances in the study of migration in reptiles and other wild species. The IEO has participated in different projects that have used satellite transmitters. These devices have increased our understanding of the causes of marine turtle migration, the relationship between migration and habitat use by different marine turtle species, and species’ adaptation to different environmental conditions (e.g. temperature, currents, depth, and diurnal eating or resting periods). Currently, all commercially available satellite tags function through the ARGOS system.

The data received from the satellite tags can involve several challenges, such as determining the precise locations of turtles. Accuracy in calculating the most likely position increases as the number of signals received increases. Other challenges involve loss of battery power, damage to the antenna, epibionts on transmitters and antennae, and so on. ARGOS is not a simple system, but it offers a large amount of high-quality information.

The LIFE/NAT/E/8610 Project (2002-2006), in which the IEO participated, tagged 21 loggerhead turtles with satellite transmitters (Eckert et al. 2008). The results obtained indicated movements from the Alboran Sea and the coast of Murcia to the central Mediterranean, as well as the migration of specimens towards the Atlantic that reached the Caribbean coasts. The recapture on the coast of Spain of a loggerhead tagged with a conventional metal tag in the western Atlantic (Moncada et al. 2010) is evidence of western and eastern loggerheads forming part of the same population (i.e. in the current western Atlantic RMU; Wallace et al. 2010) as well as evidence of the transatlantic journey made by many loggerheads to feed in Mediterranean habitats.

In 2008, of the scientific papers on sea turtle satellite tracking worldwide, 11% referred to transmitter deployment in the Mediterranean (Godley et al. 2008). In 2014, a study analysed 195 routes of satellite-tracked turtles published in peer-reviewed articles (Luschi and Casale 2014). Only one study has described telemetry experiments in the Alboran Sea (Eckert et al. 2008). In this study, 19 loggerheads were captured by hand off the Spanish coast and fitted with transmitters. Three subadult loggerhead sea turtles were monitored for up to 363 days as they moved west across the Atlantic Ocean. Large individuals (CCL <57 cm) gradually moved eastward through the Mediterranean Sea after release. Only 14 green turtles have been satellite tracked in the Mediterranean Sea, all of which were in the eastern part of the area. To date, no leatherbacks have been monitored.

The main reason for the limited number of such studies is that sea turtles are typically equipped with satellite tags when they lay their eggs on beaches; however, there are no nesting areas in the Alboran Sea (Laurent et al. 1998). The second reason is that the loggerheads observed in this area are generally too small to be equipped with the satellite tags that are currently available on the market. Loggerheads are the most common sea turtle species in the Mediterranean.

Nevertheless, this situation could change because there have been recent reports of new nesting events in the western Mediterranean Sea, which may be due to a change in sea temperatures (Maffucci et al. 2016). There is a real need to understand the potential impact of climate change in the Alboran Sea, and telemetry could be the appropriate tool to achieve this aim.

21.6.3 Seabird Tagging Studies

Hundreds of thousands of birds are known to migrate between the Mediterranean and the Atlantic above the sea pass through the Strait of Gibraltar (Halpin et al.

2014). The Alboran Sea is a relevant area for three globally threatened species: *Puffinus mauretanicus*, the near-threatened *Larus audouinii*, and the endemic *Calonectris d. diomedea*. Seabird experts have compiled the georeferenced information available to identify crucial areas in Mediterranean open seas (UNEP-MAP-RAC/SPA 2010).

21.6.4 Shark Tagging Studies

In 1962, the US National Marine Fisheries Service (NMFS), in collaboration with recreational anglers and commercial fishers, launched an extensive Cooperative Shark Tagging Program (CSTP) using conventional tags. This programme was designed to study the biology of blue sharks, shortfin makos, and porbeagles (Kohler et al. 2002). The authors summarized the tagging and recapture information collected between 1962 and 2000. Although there no tagging records of shortfin makos and porbeagles, limited movements have been recorded of blue sharks tagged in the Atlantic and recaptured in the Mediterranean. All of the immature males tagged remained in the Mediterranean, whereas one subadult female moved a short distance to the North East Atlantic. Only one adult male tagged in north-western North Atlantic has been recaptured in the Mediterranean Sea. These results have led scientists to consider the Mediterranean stock as separate from the Atlantic stock (Fitzmaurice et al. 2005).

A review of 48 studies published between 1984 and 2010 that used archival satellite tags showed that, during this period, 17 shark species representing 7 families from 4 orders were satellite tagged (Hammerschlag et al. 2011). In general, the studies addressed movement patterns (Shepard et al. 2006), the identification of hibernation seasons and area (Sims et al. 2003), or post-release survival in sharks bycaught on longline or tropical tuna purse seiners (Campana et al. 2009; Moyes et al. 2006). None of these studies were performed in the Mediterranean Sea.

In 2014, a research programme was implemented in collaboration with the fishing sector to investigate the impact of the French bluefin tuna (*Thunnus thynnus*) fishery on megafauna and to provide these fisheries with solutions to reduce interactions and mortality (Poisson et al. 2015). The study aim was to characterize the habitats used by blue sharks, their movements, and the risk of interaction with human activities. In total, 30 blue sharks caught on commercial longliners were equipped with archival satellite tags in the Gulf of Lion (23 individuals) and near Corsica (7 individuals). The Ifremer and the Stellaris Association worked jointly with the IEO of Malaga and a Spanish commercial longliner to deploy 14 archival tags in the Alboran Sea. The ARGOS tracking data of the blue sharks can access on two dedicated websites (http://amop-selpal.com/index.php/suivi-des-especes-marquees and http://www.stellaris-asso.org/suivi-des-requins/).

This was the first time that archival tags have been deployed on this species in the western Mediterranean.

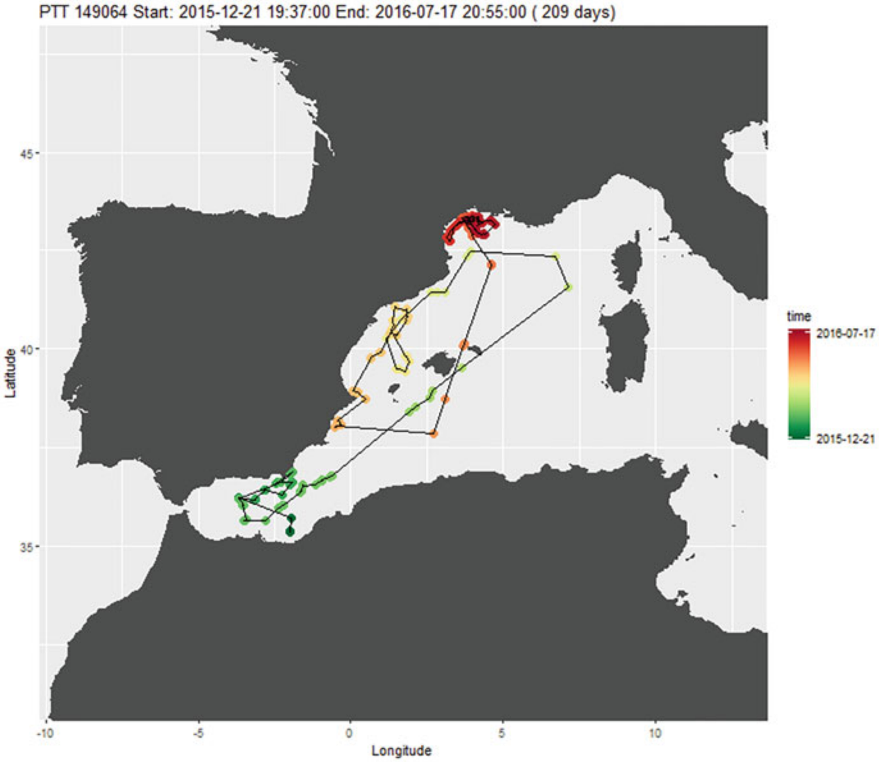

Fig. 21.11 Estimated tracks over 209 days of a small female blue shark (fork length 137 cm) equipped with a SPOT 5 tag in December 2015 in the south of Malaga (Spain) (original data)

The tracking data remains to be published. Nevertheless, the preliminary results show that although some sharks migrated over long distances, mainly along the continental slope, none of the tagged sharks crossed the Strait of Gibraltar or entered the eastern Mediterranean. This result suggests that fishing mortality should be managed at local and regional scales.

Figure 21.11 shows the estimated tracks over 297 days of a small female blue shark (fork length 137 cm) tagged in December 2015. This shark was caught by a commercial Spanish longliner during a routine fishing operation. The shark was equipped with SPOT 5 tag (Wildlife Computers, Redmond, Washington, USA) programmed to communicate every 2 days with ARGOS satellites when the shark's dorsal fin broke surface. The first location was obtained 10 days after tag deployment. This shark stayed in the Alboran Sea until February before migrating to the Balearic Islands for almost 3 months. In May it went to the Gulf of Lion where it

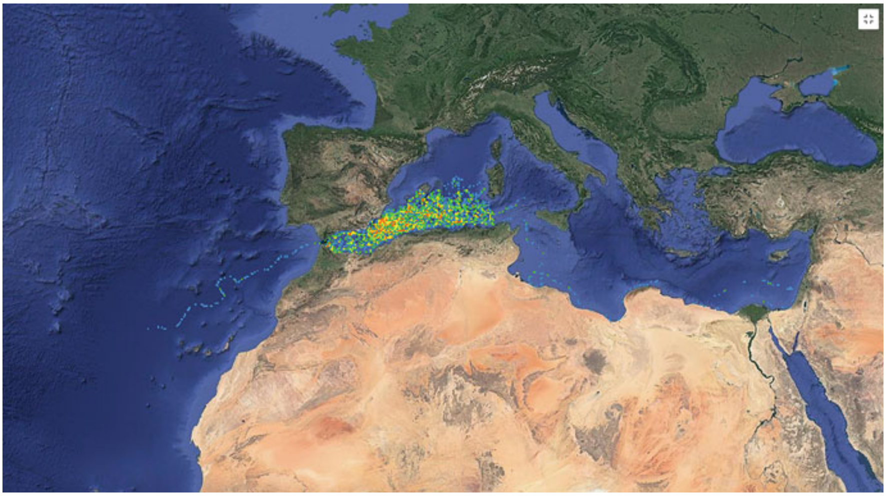

Fig. 21.12 Data from several loggerhead turtle tracking operations extracted from the OBIS-SEAMAP data centre in the study area and displayed on a per species basis. Data available from: http://seamap.env.duke.edu/

stayed until the end of July, after which it returned to the Alboran Sea reaching the Strait of Gibraltar in September.

In addition to the published data presented here, other data are available from dedicated websites that gather telemetry data on highly migratory marine mammals, sea birds, pelagic sharks, and sea turtle species. These websites include OBIS-SEAMAP (Halpin et al. 2009) (Fig. 21.12), Seaturtle.org (Coyne and Godley 2005) and the Seabird Tracking Database of Birdlife International (http://www.seabirdtracking.org/). Using these worldwide information systems, scientists can voluntarily share their data on satellite-tracked animals. Although tag deployment sites are situated on the margins of the Alboran Sea, animals occupy large areas and can be observed in the Alboran Sea itself.

21.7 Conclusion

Most megafauna populations worldwide are considered to be "vulnerable" or "endangered" by the International Union for the Conservation of Nature (IUCN). In this context, the Alboran Sea is a key biodiversity hotspot for marine megafauna. Therefore, it is relevant to improve conservation and protection efforts addressing megafauna species not only in this area but also declining populations in adjacent areas. For example, there is evidence of a population decline of pelagic sharks in the Mediterranean. Several studies have highlighted its potential impact on the trophic cascade (Dulvy et al. 2014; Ferretti et al. 2008).

Mapping distributions, as well as linking movements to oceanographic features, could help identify areas of high conservation importance and offer initial predictions of the effects of climate change.

There are some studies based on satellite telemetry on the habitats and movements of several species, such as fin whales (Panigada et al. 2017), Scopoli's shearwaters (Soriano-Redondo et al. 2016), Balearic shearwaters (Guilford et al. 2012), and sea turtles (Luschi and Casale 2014). Other studies have modelled the preferred habitats of sperm whales (Pirotta et al. 2011) and short-beaked common dolphins (Cañadas and Hammond 2008). Overall, few studies have investigated megafauna movements and habitats in the Mediterranean in general and in the Alboran Sea in particular. A broad analysis of all the sources of data on megafauna species led to the establishment of Specially Protected Areas of Mediterranean Importance (SPAMIs) under the framework of the Barcelona Convention (Halpin et al. 2014; UNEP-MAP-RAC/SPA 2010).

This work represents a relevant contribution to the implementation of conservation measures for megafauna populations. However, beyond these specific cases, additional studies are urgently needed to gather specific spatial ecology data in order to conduct multi-species trophic network analyses. In the face of such urgency, electronic tagging technology could allow the medium-term identification of key ecological foraging hotspots and migratory corridors linking the Mediterranean Sea and the Atlantic.

Satellite tracking data from a number of published and unpublished projects have provided the foundation for launching a massive international Mediterranean-wide multispecies electronic tagging programme in order to develop an ecosystem-based management system (Hooker et al. 2011). This project should be strongly recommended by scientists via regional fishery management organizations. ARGOS telemetry programmes seem expensive at first glance but are relatively affordable compared to the recurrent international scientific trawling and acoustic surveys undertaken in the Mediterranean Sea each year within the EU data collection programme.

A specific budget could fund extensive tagging surveys for a given number of species over a period of several years (e.g., 1–5 years). Because some large pelagic shark species (i.e. shortfin mako) are now very rare, tagging operations should be conducted on a long-run basis. These tagging operations should be conducted systematically. This approach could provide clues for the effective spatial management of large marine ecosystems (Block et al. 2011).

Initiatives have been proposed for the use of aerial sightings, such as the one coordinated by ACCOBAMS (ACCOBAMS 2019). However, these approaches are expensive. In this sense, new technologies, such as unmanned aerial vehicles (UAVs), could also be very useful in research on marine environments because these devices can easily detect marine megafauna on the surface. For example, Kiszka et al. (2016) and Pirotta et al. (2017) used UAVs to obtain information relevant to marine conservation. Nevertheless, new legislation on UAVs is needed.

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Chapter 22
Fisheries Economics and Management Under the Impact of Human and Varying Marine Environmental Conditions in the Alboran Sea

Juan José García-del-Hoyo and David Castilla-Espino

22.1 Introduction

Alboran Sea fisheries play a significant socioeconomic role at regional level in Alboran Sea fishing communities. Clupeids like sardine or anchovy, together with other fish species including red seabream, are of significant socioeconomic importance in this area. However, sustainability of Alboran Sea fisheries is highly dependent on marine environment conditions and fishing industry pattern of exploitation of fish stocks (Fig. 22.1).

There is a general scientific literature and policy-makers consensus around the adoption of an ecosystem approach to fisheries in seas and oceans for sustainability (García and Cochrane 2005; FAO 2009). This is the case of the Alboran Sea in the framework of the Marine Strategy Framework Directive of the European Union (EU).

The so-called ecosystem-based management (EBM) is *an interdisciplinary approach that balances ecological, social and governance principles at appropriate temporal and spatial scales in a distinct geographical area to achieve sustainable resource use. Scientific knowledge and effective monitoring are used to acknowledge the connections, integrity and biodiversity within an ecosystem along with its dynamic nature and associated uncertainties. EBM recognizes coupled social-ecological systems with stakeholders involved in an integrated and adaptive management process where decisions reflect societal choice* (Long et al. 2015: 59).

The adoption of an EBM requires not only the consideration of bioecological and marine environment factors that influence ecosystem life stocks and their interactions but also the identification of the main drivers and pressures of the

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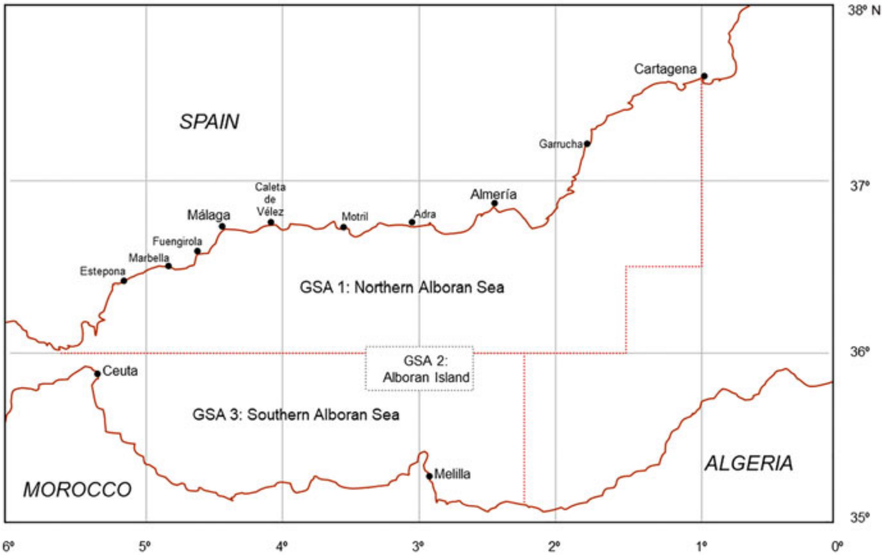

Fig. 22.1 Main fish port areas in General Fisheries Commission for the Mediterranean geographical subarea (GSA) 1

social-ecological system involve in the current state and evolution of them so that appropriate management is posed in place.

According to the Driver-Pressure-State-Impact-Response (DPSIR) framework: *D*rivers consist of a need for social and economic development. They exert *P*ressures through human activities to meet them like emissions from shipping or fishing. As a consequence, the *S*tate of the ecosystem as a whole (particularly fish stocks) changes in terms of variety, quantity, and quality, leading to *I*mpacts on human beings like GDP per capita of coastal communities or ecosystems (decrease or depletion of fish stocks, for instance). The latter may result in a societal *R*esponse that feeds back on the driving forces, state, or impact through adaptation or curative actions (EEA 1999).

More than 90% of cumulative impacts of drivers in Western Mediterranean Sea ecosystem and fish stocks are in order of importance those associated with global warming and fishing industry exploitation of fish stocks (Micheli et al. 2013).

Some other impacts like excess nutrients and hypoxia and shipping are of less importance. Land-based activities that change ecosystem components and biodiversity cause excess nutrients and hypoxia that weaken the demersal/benthic system. There is a decreasing west-east gradient of nutrients in the Mediterranean Sea (Murdoch and Onuf 1972; Caddy 2000), and that main concentration of nutrients takes place in Malaga Bay associated to seasonal upwelling processes caused by wind direction (Macías et al. 2014).

Shipping produces a potential impact on biodiversity through the transport of invasive species or contamination due to oil and fuel spills; however, it is not the most relevant impact in the area despite intensive maritime traffic.

This chapter aims to analyze the socioeconomics of Alboran Sea fisheries as one of the main pressures over fish stocks and insight on fisheries management of the area in the context of an ecosystem-based management approach accounting for marine environment conditions (climate variability and global warming) that influence Alboran Sea ecosystem and, consequently, fisheries. The chapter finishes providing recommendations to improve fisheries management of this area.

The chapter begins describing Alboran Sea fisheries management in Sect. 22.2. Section 22.3 goes through the consideration of the main driving forces that impact Alboran Sea fisheries socioeconomics focusing on Northern Alboran Sea where there is more data availability. Section 22.4 researches on the relation of marine environment variability and Alboran Sea ecosystem. Finally, Section 22.5 provides sound advice to policy-makers to improve the management system of the area.

22.2 Alboran Sea Fisheries Management

Fisheries management is *the integrated process of information gathering, analysis, planning, consultation, decision-making, allocation of resources and formulation and implementation, with enforcement as necessary, of regulations or rules which govern fisheries activities in order to ensure the continued productivity of the resources and accomplishment of other fisheries objectives* (FAO 1997: 7).

Fisheries management involves multiple tasks devoted to accomplish fisheries objectives that must be necessarily set assuming the adoption of an ecosystem approach to fisheries, for succeeding to achieve the sustainability of natural resource use (FAO 2008; Cochrane and García 2009; Long et al. 2015) in the framework defined by the FAO Code of Conduct for Responsible Fisheries (FAO 1995).

Institution plays a relevant role in fisheries. Institutions are the *system of established and prevalent social rules that structure social interactions* (Hodgson 2006). The institutions thus lead fishermen's behavior. The combination of fisheries management and institutions arrangements of fisheries set user's incentives for sustainability (Charles 1992; Yandle 2003).

The evolution and current design of the fisheries management system of Alboran Sea are in the root of this regional sea ecosystem evolution given that its failure can result in the arising of the well-known fisheries problems: overexploitation of the fisheries resources and the dissipation of fishing rent, this is, the biological and socioeconomic unsustainability of fisheries.

This section is aimed at describing and analyzing Alboran Sea fisheries management systems in an attempt to explain its current state. It not only mainly focuses on socioeconomic and technical variables but also accounts for its biological status, related to fisheries as one of the most important goods and services provided by this ecosystem (Millennium Ecosystem Assessment 2003; Beaumont et al. 2007).

Alboran Sea fisheries management is implemented at different geographical levels from international to local arena so that cooperation is guaranteed and specific local/national issues are appropriately met for. The highest geographical level involves three types of regional oceans governance mechanisms: regional sea programs, regional fisheries management organizations (RFMO), and large marine ecosystem mechanisms (Rochette et al. 2015).

The Mediterranean Action Plan (MAP) under the framework of the Convention for the Protection of the Mediterranean Sea Against Pollution in 1976 (Barcelona Convention - UNEP 2019) was the first regional sea program of the United Nations Environment Programme (UNEP) to manage the Mediterranean Sea and consequently the Alboran Sea. The MAP initially included a mandate toward the elimination and prevention of pollution and the conservation of biodiversity, especially through the creation of marine protected areas, of coastal maritime zones of riparian state parties and the areas beyond their jurisdiction.

The MAP has been developed from the beginning within the framework of the Barcelona Convention. The MAP Phase II (1995) was an important milestone toward broader objectives, which are *to ensure the sustainable management of natural marine and land resources and to integrate the environment in social and economic development, and land-use policies; to protect the marine environment and coastal zones, through prevention of pollution, and by reduction and as far as possible, elimination of pollutant inputs whether chronic or accidental; to protect nature, and protect and enhance sites and landscapes of ecological or cultural value; to strengthen solidarity amongst Mediterranean coastal states, in managing their common heritage and resources for the benefit of the present and future generations; and to contribute to the improvement of the quality of life*. Moreover, the adoption of an ecosystem approach has been introduced since 2008.

RFMOs are mechanisms through which states or organizations that are parties work together towards the conservation, management, and/or development of fisheries. RFMOs present in the Alboran Sea are the General Fisheries Commission for the Mediterranean (GFCM, 1952 to the present) under the framework of the United Nations Food and Agriculture Organization (FAO), and the International Commission for the Conservation of Atlantic Tunas (ICCAT, 1967 to the present). They are both RMFOs that can establish legally binding conservation and management measures for contracting parties that include all riparian countries of the Alboran Sea (EU member states, Morocco, and Algeria).

ICCAT aims to maintain the populations of tuna and tuna-like fishes (the Scombriformes with the exception of the families Trichiuridae and Gempylidae and the genus *Scomber*) and such other species of fishes exploited in tuna fishing within the Convention area that are not under investigation by another RFMO. ICCAT permits the maximum sustainable catch for food and other purposes according to the preamble of the Convention. The area covered are international waters of the Atlantic Ocean, including the adjacent seas.

ICCAT has provided a comprehensive compendium of management recommendations and resolutions in force in the Alboran Sea international waters that mainly include the following:

Table 22.1 Main management measures of ICCAT bluefin tuna and swordfish recovery multi-annual plans

Type of management measure	Bluefin tuna (2007–2022)	Swordfish (2017–2031)
Output controls	TAC (T): 28,200 (2018)–32,240 (2019)–36,000 (2020) Individual fishing quota for vessels over 24 m	TAC (T): 10,500 (2017)–10,185 (2018)–9880 (2019)–9583 (2020)
Input controls	– Limited license program for vessels and traps – Annual fishing capacity management plan – Measures for the adjustment of farming capacity – Aerial means prohibited	– Limited license program for vessels – Capacity increasing restrictions – Technical characteristics of long-lines restrictions
	Transshipments at sea operations prohibited	
Technical measures	– Closures (several months) depending on fishing gear – Bluefin tuna weighing less than 30 kg or with fork length less than 115 cm	– Closure (3 months) – Swordfish measuring less than 100 cm LJFL or, in alternative, weighing less than 11.4 kg of round weight or 10.2 kg of gilled and gutted weight

Source: Own elaboration based on recommendations ICCAT/17/07 and ICCAT/16/05

- Monitoring of species included in the agreement in order to provide sound scientific advice for decision-making and evaluating the compliance of resolution and recommendations
- Enforcement measures for the compliance of the agreement
- Management measures designed to reduce bycatch
- A set of management measures, mainly consisting of output limits and fishing effort restrictions for the main species: swordfish, albacore, bluefin tuna, and billfish.

Among other measures, ICCAT is currently implementing two multi-annual (15 years) recovery plans in the Eastern Atlantic and Mediterranean for bluefin tuna (2007–2022) and swordfish (2017–2031) with the goal of achieving the biomass corresponding to the maximum sustainable yield (B_{MSY}) with at least a 60% probability. Table 22.1 shows the main management measures that implement both recovery plans. ICCAT specifies some management measures, and state parties detail further some others. Individual fishing quotas are allocated, in the case of the bluefin tuna fishery, for vessels of more than 24 m; however, the management approach is only partially market-based, and its characteristics are closer to a bureaucratic management following a top-down government mainly focused on blocking fishermen's incentives to maximize capture.[1]

GFCM aims at ensuring the conservation and sustainable use, at the biological, social, economic, and environmental level, of living marine resources, as well as the sustainable development of aquaculture in all the marine zones of the Mediterranean Sea and the Black Sea (Art. 2.2 and 3.1, GFCM Agreement). GFCM focuses on non-tuna species as ICCAT covers them. GFCM provides scientific advice and a framework for the management of Alboran Sea fisheries like small pelagic species, demersal species, and especially sensible fish stocks like blackspot seabream mainly located in the Strait of Gibraltar area (GFCM GSA 1 (Northern Alboran Sea), GSA 2 (Alboran Island), and GSA 3 (Southern Alboran Sea) geographical areas).

GFCM provides recommendations that focus on conservation and management, monitoring, control and surveillance, and data and information reporting. These recommendations are into force 4 months after the date of notification by the GFCM (Article 13.3 of the GFCM Agreement). Contracting parties, particularly the EU, can object to measures adopted within this period. These measures do not bound EU in this case. The other contracting parties are not obliged to implement the contested measure where more than one-third of the contracting parties submit an objection.

Management measures recommendations mainly concern fishing capacity and effort restrictions when specified. Some examples of fishing capacity and effort restrictions are fishing gear restrictions (recommendations GFCM/33/2009/2 or GFCM/22/1997/1), technical measures (recommendations GFCM/40/2016/5 or GFCM/27/2002/1) or area closures like prohibiting the use of towed dredges and trawl nets at depths beyond 1000 m (recommendation GFCM/29/2005/1). GFCM also recommends some other measures to protect ecosystems like preventing bycatch or the creation of fisheries-restricted areas (recommendations GFCM/35/2011/4 or GFCM/41/2017/3).

GFCM has a mandate in progress to develop a management program of the fishing effort concerning demersal trawling fisheries and pelagic trawling and purse seining in Northern and Southern Alboran Sea (GSA 1 and GSA 3) among other fishing areas and a regional plan of action controlling fishing capacity (recommendations GFCM/30/2006/1 and GFCM/34/2010/2).

GFCM also adopted some provisional measures (two-year period) in 2017 until a management plan for blackspot seabream in the Alboran Sea is set in order to monitor fishing capacity of this fishery given that it is overfished and overexploited.

Large marine ecosystem mechanism set in the Mediterranean Sea, and consequently in the Alboran Sea, implements the Strategic Action Programme for the Conservation of Biological Diversity in the Mediterranean region (SAP-BIO) and the Strategic Action Programme for the Mediterranean Sea (SAP-MED) in a

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[1] It is worth noting that state parties can eventually apply measures that are more restrictive in any case and opt for a comprehensive individual fishing quota program.

cooperative government framework that mainly involves the UNEP and the GFCM (Rochette et al. 2015).

Aforementioned regional oceans governance mechanisms present in the Alboran Sea provide a very general framework that needs to be specified in the geographical levels that involve riparian countries of the Alboran Sea (Spain—EU—(GSA 1 and GSA 2), Morocco (GSA 3), and Algeria (GSA 3)).

The management of the Northern Alboran Sea territorial water of Spain is under the umbrella of the Common Fisheries Policy (CFP) (Regulation (EU) No. 1380/2013 of the European Parliament and of the Council of 11 December 2013) and a general framework concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea (Council Regulation (EC) No. 1967/2006 of 21 December 2006). Further progress is being achieved to implement a maritime spatial planning action at the latest by 31 March 2021, considering economic, social, and environmental aspects to support sustainable development and growth in the maritime sector, in particular through an ecosystem-based approach, and promoting the coexistence of relevant activities and uses of seas and oceans (Directive 2014/89/UE of the European Parliament and of the Council of 23 July 2014).

General fisheries management measures of the EU in the Alboran Sea (GSA 1 and GSA 2) are mainly implemented by community-level management plans at a regional scale which mainly focus on fishing effort controls that are later specified by member states involved and the adoption of management plans. These plans are designed for fisheries conducted by trawl nets, boat seines, shore seines, surrounding nets, and dredges within their territorial waters. EU fisheries management is subject to the scientific advice provided by the Scientific, Technical and Economic Committee for Fisheries (STECF).

Fisheries management of the EU in the Alboran Sea also involves a comprehensive set of fishing gear restrictions and technical measures. The latter consists of defining technical minimum size of marine organisms, the protection of certain species and area closures to protect habitats[2], or the creation of marine protected areas (MPA). MPAs currently are those included in the list of *Specially Protected Areas of Mediterranean Importance* (SPAMI), namely, Alboran Island, Natural Park of Cabo de Gata-Nijar, Sea Bottom of the Levante of Almeria, and Maro-Cerro Gordo Cliffs.

There are currently two community-level management plans in force in the Alboran Sea area:

- Measures for the recovery of eel in estuaries and rivers that flow into the Alboran Sea (Council Regulation (EC) No. 1100/2007 of 18 September 2007)

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[2] Fishing above coralligenous bottoms and seagrass beds, especially *Posidonia oceanica* which is present from the Malaga Bay to the limit of the Alboran Sea with relevant concentrations of this seagrass in Almeria coast.

- Recovery plan for bluefin tuna following the mandate of ICCAT (Regulation (EU) No. 2016/1627 of the European Parliament and of the Council of 14 September 2016)

There was an agreement on a proposal of a multi-annual plan for some demersal fish stocks at risk in the Western Mediterranean Sea (COM(2018)115/F1) in 2018 that aims at the sustainability of them in the Northern Alboran Sea. Demersal species included in this proposal are blue and red shrimp (*Aristeus antennatus*), deep-water rose shrimp (*Parapenaeus longirostris*), European hake (*Merluccius merluccius*), and red mullet (*Mullus barbatus*).

The aforementioned proposal set targets, conservation reference points, and safeguards to reach sustainability through effort controls and technical measures. It also provides that the Council shall adopt complementary management measures based on total allowable catches when STECF advice shows that the fishing effort regime is not sufficient to meet management objectives.

As noted before, most of management measures implemented in the Alboran Sea are set at the national level, in the case of Northern Alboran Sea through the adoption of community-level management plans, national management plans, and the specific regulation of MPA. In this sense, it is worth noting that following the EU regulations (Art. 19, Regulation (EU) No. 1380/2013 of the European Parliament and of the Council of 11 December 2013), Spain *may adopt measures for the conservation of fish stocks in Union waters provided that those measures fulfil all of the following requirements:*

- *they apply solely to fishing vessels flying the flag of that Member State or, in the case of fishing activities which are not conducted by a fishing vessel, to persons established in that part of its territory to which the Treaty applies;*
- *they are compatible with the objectives set out in Article 2;*
- *they are at least as stringent as measures under Union law.*

Spain currently implements a comprehensive multi-annual management plan (2013–2019) for purse seiners, bottom trawlers, and passive and other artisanal fishing gears in GSA 1 which set an exploitation rate (total mortality of 0.4 that includes natural and fishing mortality) for small pelagics (i.e., anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*)), a specific management for the aforementioned fleet segments according to the mandate of the EU. Table 22.2 shows the main management measures that are being implemented in the Northern Alboran Sea for the major fleet segments. The most important management measures consist of fishing effort restrictions and technical measures, but in the case of the purse seine fleet, they are combined with vessel catch limits (VCL) per day for anchovy and per week for sardine. The latter combination could be interpreted in certain conditions as a management framework that adjusts fishermen's incentives instead of blocking them like in the case of bottom trawling.

Two other fisheries are subject to specific management frameworks; this is the case of the red seabream fishery (*Pagellus bogaraveo*) of the Strait of Gibraltar and the tow rake and mechanized dredge fleet that target different kind of bivalves in the

Table 22.2 Main management measures for major fleet segments in GSA 1 (Northern Alboran Sea)

<table>
<tr><th>Management measures</th><th>Pulse seine</th><th>Bottom trawling</th><th>Passive and other artisanal fishing gears</th></tr>
<tr><td>Output controls</td><td>VCL: anchovy (5 T/day) and sardine (7 T/week). 2 landings per day (maximum)</td><td>–</td><td>–</td></tr>
<tr><td rowspan="7">Input controls</td><td colspan="3">Limited license program</td></tr>
<tr><td colspan="3">20% fishing effort reduction (vessels and tonnage/engine power)</td></tr>
<tr><td>5 fishing days per week with a rest of 48 hours</td><td>5 fishing days per week with a rest of 48 hours. Fishing trips of up to 12 hours</td><td>5 fishing days per week. Fishing gear operating up to 16 h per day. Fishing gear must not be operating for 41 consecutive hours a week</td></tr>
<tr><td>Technical characteristics of the purse seine (mesh size in range 14–24 mm, 300–450 m in length depending on the fishing area, and 82 m in depth)</td><td>Forbidden of certain types of trawling fishing gear. Technical characteristics of the purse seine (mesh size bigger than 40 mm)</td><td>Tonnage and engine power of vessels cannot increase</td></tr>
<tr><td>Length overall of vessels more than 9 m</td><td>Length between perpendicular of vessels between 12 and 24 m. Engine power up to 500 HP</td><td>Technical characteristics of main fishing gear and the way they are hauled is restricted</td></tr>
<tr><td>Maximum electric power of lights: 12 bulbs (500 W), overall 6000 W, or 100,000 lumens for LEDs</td><td rowspan="2">Length between perpendicular of vessels between 12 and 24 m. Engine power up to 500 HP</td><td rowspan="2">Length overall of vessels more than 5 m but deep longliners (more than 9 m between perpendiculars) tonnage more than 1.5 GT</td></tr>
<tr><td>1 auxiliary boat</td></tr>
<tr><td rowspan="3">Technical measures</td><td colspan="2">Spatial closures (Natura 2000 network, ZEPIM, <i>Posidonia oceanica</i>, and other seagrass beds)</td><td rowspan="3">Seasonal time closures</td></tr>
<tr><td>Fishing forbidden up to 35 or 50 m depth when less than 300 m from the shore. Also forbidden less deep than 70% of net sink</td><td>Fishing forbidden up to 50 m depth</td></tr>
<tr><td>List of authorized fish species</td><td>Seasonal time closures</td></tr>
</table>

Source: Own elaboration based on Spanish regulations

Alboran Sea which is subject to a fisheries management plan (2014–2019). Red seabream fishery has been subject to many changes over time because of successive recovery and management plans (Table 22.3). It is currently managed through effort controls that mainly restrict the number of fishing trips per season and the technical characteristics of the fishing gear.

Table 22.3 Main management measures of red seabream fishery of the Strait of Gibraltar (Northern Alboran Sea)

	Year/period										
Management measures	1999–2002	2003	2004	2005	2006	2007	2008	2009	2010–2011	2012–2015	2016–2018
TAC	–	270 T								–	
Co-management	Monitoring committee				–						
No. of fishing trips	160	150	140		140					180	180
Time closures (months)	2	2½				2½	1½	3	1½	2	–
Max. no. of hydraulic reels	3	–							3	3	3
Fishing gear length	120 m										
Max. no. of fishing gears	30	–				30					
Max. no. of hooks	3000	2800	2600	2400							
Max. hook length	3.55 ± 0.35 cm	3.95 ± 0.39 cm				3.95 c					
Max. hook bend	1.30 ± 0.13 cm	1.40 ± 0.14 cm				1.65 cm					

Source: Own elaboration based on Spanish regulation

The tow rake and mechanized dredge fleet are mainly managed by TACs and daily VCL for certain species (surf clam (*Donax trunculus*), smooth venus (*Callista chione*), Moroccan cockles (*Acanthocardia tuberculata*), and striped venus (*Chamelea gallina*)) and are monitored by means of a satellite-based vessel monitoring system (VMS).

The management of the Alboran Island area is subject to special conditions given that it is a SPAMI/MPA (GSA 2). Fishing is allowed subject to a limited license program in two marine areas surrounding the Alboran Island: a part of the marine reserve that can be exploited using mainly hook artisanal gears and small seiners and the fishing reserve where bottom trawlers between 100 and 1000 m depth, purse seiners, and deep-sea longliners can operate targeting certain fish species. Fishing vessels can carry out fishing trips according to different plans of their choice with a duration of 5 days (plan A) and between 5 and 10 days (plan B).

The management implemented in Southern Alboran Sea (GSA 3) is also mainly based on fishing effort restrictions. This is the case of purse seine fishing fleets where there is a set of restrictions on technical characteristics of fishing gears and a limitation of the number of fishing trips per week. The latter is combined with seasonal closures and areas where fishing is not allowed for a closed list of fish species. The red seabream fishery, where fleet that operates includes more fishing gears than in Northern Alboran Sea (GSA 1), is subject to technical characteristics restrictions combined with the SPAMI/MPA of Al Hoceima National Park and artificial reefs to avoid trawling.

22.3 Socioeconomics of Alboran Sea Fisheries

22.3.1 Study Area

This section analyzes fishing in socioeconomic terms. It focuses on the Northern Alboran Sea (GSA 1 division of GFCM) as an example of the importance and evolution of fishing and its socioeconomics in the whole Alboran Sea.

Ports involved in the exploitation of Northern Alboran Sea (GSA 1) fish stocks are located between 6°W meridian from Gibraltar and 2°W meridian and 36°N parallel and Spanish coast. They are those included in South Mediterranean Spanish region excluding Ceuta and Melilla; ports of Algeciras and La Linea de la Concepción in Spanish South Atlantic region; and ports of Garrucha, Águilas, Mazarrón, and Cartagena, of the Spanish Eastern Mediterranean region (Fig. 22.1).[3]

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[3] GSA 01 includes Spanish maritime districts between Algeciras and Cartagena; however in certain period, we will refer to Spanish South Mediterranean region (Malaga and Almeria) excluding Garrucha in Spanish Eastern Mediterranean region due to data aggregation.

22.3.2 Origins of the Northern Alboran Sea Fishing Fleet

The Northern Alboran Sea has a long fishing tradition. Artisanal beach fishing gears were the most important ones until the beginning of the twentieth century (among them were those locally called *jabegas*, *boliches*, or *sedales*). However, a trawling fleet equipped with steam engines initially located in Malaga, but later in Algeciras or Almeria, expanded from the 1920s by mainly targeting hake (*Merluccius merluccius*) and crustaceans in the north of Moroccan fishing grounds (Rodríguez Santamaría 1923). This fleet segment reached a historical peak of catches in the 1970s and then progressively decreased as the fishing authorities of Morocco restricted the access to their fishing grounds until a full withdrawal in 1999 after the closure of this fishing ground for Spanish trawlers.

The purse seine fishing fleet did not developed until the end of Spanish Civil War (1936–1939), despite some historical references to primitive purse seiners locally called *mamparras* (Bellón and Bono 1950).

The first purse seiners equipped with engine (locally known as *traiñas*) set their port bases mainly in Malaga and to a lesser extent in Almeria, Ceuta, and Melilla, targeting anchovy, sardine, horse mackerel (*Trachurus* spp.), mackerel (*Scomber* spp.), bullet tuna (*Auxis rochei*), and to a lesser extent round sardinella (*Sardinella aurita*). Purse seiners coexist with traditional artisanal fishing gears locally called *jabegas* or *boliches* until the 1980s and *sardinales* that were substituted by purse seiners during the 1950s. The use of *jabegas* was very restricted because of their significant impact on juveniles and immatures in the Bay of Malaga.[4]

Different kinds of tuna traps have also been historically casted in Northern Alboran Sea. The most important ones are *La Atunara* (La Linea de la Concepción, Spain) followed by *Punta Chullera* (Estepona), *Almeria*, *La Azohía* (Mazarrón), and others of less importance, namely, *Águilas*, *Marbella*, or *Cartagena*. Additionally, surface longlines are of relative high importance in the port of Carboneras (Garrucha). The latter fishing gear was also present in Algeciras along with a fleet of deep-sea longliners, locally called *voracera*, that targeted red seabream in the Strait of Gibraltar. Finally, there are some mollusc bivalve fisheries exploited by tow rakes in the ports of Estepona and Fuengirola, together with a significant number of multi-gear fishing boats operating in all Northern Alboran Sea fishing ports.

22.3.3 Northern Alboran Sea Fish Catch Evolution

Because of difficulties to collect historical data on the evolution of catches, fleets, and fishing effort, we need to devote some paragraphs to describe thoroughly the sources compiled and data cleaning up to build time series presented in this section.

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[4] Pérez de Guzmán et al. (1986: 159) noted that there were 165 *jabegas* and *boliches* targeting immature fishes, locally marketed as *chanquetes*, in 1985.

It is possible to get continuous fleet landings since the Spanish Civil War (1936–1939), although there is also data available with some gaps as early back as 1925. This information can be found in the annual publications of the Spanish government: *Estadística Pesquera* for period 1940–1970 and later in *Anuario de Pesca Marítima* for period 1971–1986.

The production of landing statistics stops after the latter period. However, the primary source of data continues being produced by wholesale markets and gillnetters and processed by *FROM* (Spanish acronym for the regulation and organization fund for the fish and sea farm product market) on a monthly frequency. Particularly, the Andalucía regional government collected, cleaned up, and published the monthly series by port in the statistical publication *Producción Pesquera Andaluza* for the period 1985–2006. This time series has been rebuilt since 1999 by means of the first sale information system of Andalusian wholesale markets.

The Spanish Institute of Oceanography (IEO) has been collecting monthly catch and fishing effort data according to its sampling framework. IEO measured fishing effort by number of fishing trips and by port since 1982 for the Northern Alboran Sea, first for a few ports and later for the whole area. It should be noted that there are some discrepancies between the IEO time series and the aforementioned data set because there was not distinction between first and second sales in Malaga and Almeria wholesale markets until 1999 and, to a lesser extent, because of the use of different conversion rate of fishing box weight used in wholesale markets.

Aggregation of time series is an important concern when approaching Northern Alboran Sea catches time series. Data published until 1961 refers to the Spanish South Mediterranean fishing region which coincide with the Northern Alboran Sea but Ceuta and Melilla ports located in the Southern Alboran Sea (GSA 3).[5] Some monthly time series of catches were published in periods 1962–1972 and 1978–1986 per fishing districts, whereas time series of period 1973–1977 are only non-aggregated for Malaga and Almeria districts so that landings of smaller fishing ports can be distinguished. In summary, data on capture up to 1999 should be interpreted cautiously despite the cleaning up process implemented in this chapter.

Figure 22.2 shows the landings of fish, molluscs, and crustaceans by the Northern Alboran Sea (GSA 1) fishing fleets in period 1940–2018. It depicts an increasing trend of landings in tonnes (T) for the period 1940–1960, reaching a global maximum value of 125,000 tonnes in 1985 that represents 15.84% of all Spanish landings. Later on, landings fluctuated due to the high variability of pelagic landings in the range 85,000–110,000 T/year until 1983 when catches started to decrease. Thereafter in the 1990s, landings were hardly greater than 50,000 T and rather decreased sharply after 1999. Nowadays, regional landings fetch around 20,000 T/year and represent only 2% of total Spanish landings. Obviously, the ports of Algeciras, Malaga, or Almeria where the fleets fish on Moroccan grounds are

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[5] IEO built non-aggregated 9 years of catches, fleet, and fishing effort for some wholesale markets and ports in period 1940–1961 (Giráldez and Abad 2000).

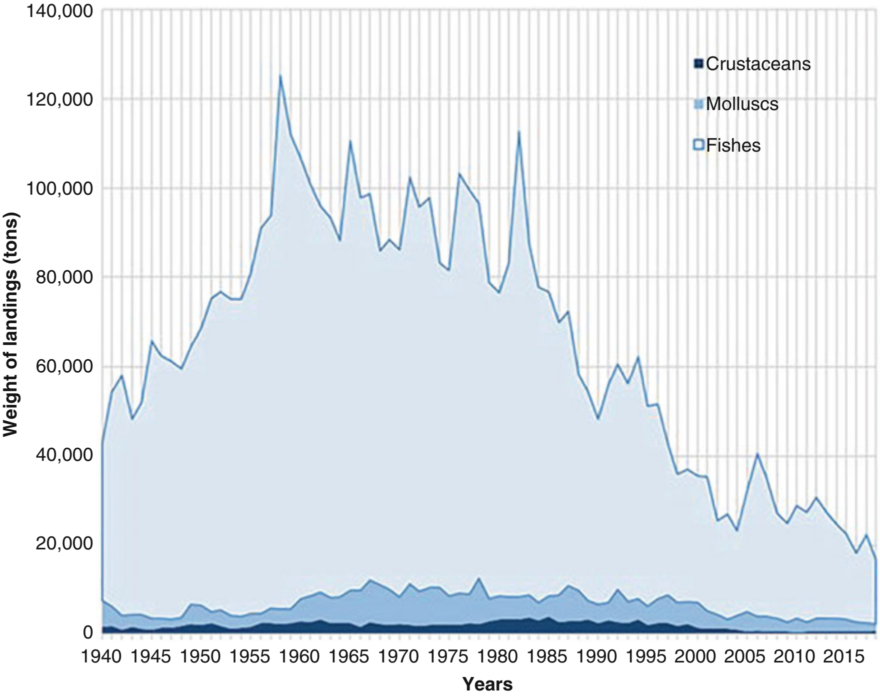

Fig. 22.2 Landings of fishes, molluscs, and crustaceans of Northern Alboran Sea fishing fleets (GSA 1) (1940–2018). Source: *Estadísticas Pesqueras* (1939–1971) and *Anuario de Pesca Marítima* (1972–1986) of the Spanish government, *Producción Pesquera Andaluza* (1985–2018) of the Andalucía regional government, and fishing statistics of the Murcia regional government

those that suffer the highest decrease, while ports where the artisanal fleets are located maintained their captures at a relatively stable level.

A major concern regarding the consistencies of landing time series is that trawlers, purse seiners, and longliners of the Northern Alboran Sea fish in the territorial waters of Spain and Morocco without distinction. This is something expected given that Morocco did not reach independence until 1956. The access of the Spanish fleet to the territorial waters of Morocco became more restricted, especially from 1979, as Spain and Morocco signed the first bilateral agreement in 1999 when the Moroccan fishing grounds were closed to the Spanish fleet. The part of the fleet located in the Northern Alboran Sea that operated from the ports of Adra, Almeria, Malaga, and, to a lesser extent, Motril was relatively big, and it is impossible to distinguish landings from Northern and Southern Alboran Sea until 1978 and only approximated after 1999.

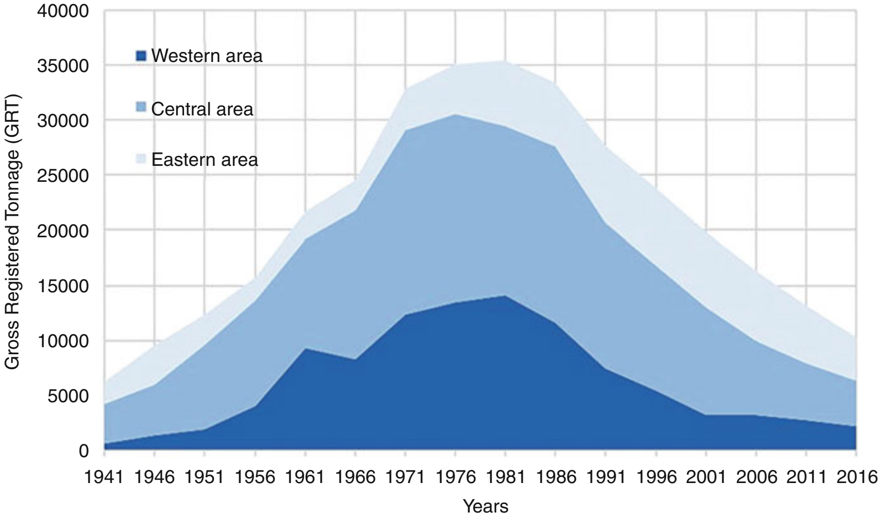

Fig. 22.3 Fishing fleet of the Northern Alboran Sea in GRT (1940–2018). Source: *Estadísticas Pesqueras* (1939–1971), *La Flota Pesquera Española* (1965–1972), *Anuario de Pesca Marítima* (1972–1986), and the Spanish fleet register (1989–2018) of the Spanish government

22.3.4 Northern Alboran Sea Fleet Evolution

Northern Alboran Sea fleet time series are even more problematic and more difficult to produce than capture series. The first time series of fleet and fishing gear began in 1940 even if other partial data was registered prior to this year. This information was attached to the publication of annual fishing statistics *Estadísticas Pesqueras* done by Spanish government for period 1940–1970. Nonetheless, this statistics suffer from important errors given that they do not provide the detail of the fishing gear of vessels but only the typology of propulsion. Moreover, this information refers to the port where boats are registered, and it does not necessarily coincide with the port where they are dispatched when vessels are moving at sea.

The Spanish government began to publish annual statistics of fleet census per fishing gear in *La Flota Pesquera Española* for vessels over 20 GRT in period 1965–1972. These statistics also provided a summary of vessels smaller than 20 GRT. Anuario de Pesca Marítima substituted the latter publication for the period 1973–1986. This statistical source publishes aggregated data per GRT and fishing gear in Spanish territorial waters fishing districts. Spanish fishing fleet register was first published in 1989. Since then, it is possible to build non-aggregated time series of the fleet per port.

Figure 22.3 shows the construction of fleet time series in tonnage (GRT) of Northern Alboran Sea in period 1940–2018 distinguishing the western (Algeciras, La Linea de la Concepción, Estepona, and Marbella), central (Fuengirola, Malaga, Vélez, Motril, Adra, and Almeria), and eastern (Garrucha, Águilas, Mazarrón, and

Table 22.4 Tonnage allocation and evolution per fleet segment in the Northern Alboran Sea (in GRT?)

Fishing port	Trawlers			Purse seiners			Others		
	1976	2016	% change	1976	2016	% change	1976	2016	% change
Western area	9281	388	−95.8%	2079	296	−85.8%	13,372	2215	−83.4%
Central area	10,311	2128	−79.4%	1984	1166	−41.3%	16,899	4050	−76.0%
Eastern area	3206	1320	−58.8%	819	762	−6.9%	4455	4028	−9.6%
Total	22,798	3836	−83.2%	4882	2224	−54.4%	34,726	10,293	−70.4%

Cartagena) areas. There were 1952 fishing vessels of a total tonnage of 6250 GRT employing 13,529 fishermen in 1940. Rowing and sailing vessels represented 82% of the fleet with a total tonnage of 2827 GRT-almost half the tonnage-; however, this fleet segment almost disappeared in the end of the 1970s (1% of the tonnage). The evolution of the fleet in different subareas of Northern Alboran Sea shows a similar pattern. A first phase is characterized by a moderate increase of fishing power until the 1950s. A second expansion phase is characterized by the construction and modernization of new fishing units that strengthen the trawling fleet based in Algeciras, Malaga, and Almeria. These vessels targeted different fish species in the fishing grounds of Morocco. A third sharp decreasing phase that finished with the end of high seas fishing fleet in the 1990s; and finally an adjustment fourth phase of coastal and high seas fishing fleets. Nowadays, it involves 764 fishing vessels for a total tonnage of 10,739 GRT and employs 2605 fishermen.

The fishing industry has experienced drastic changes since the 1970s in the Northern Alboran Sea as can be seen in Table 22.4. The trawling fleet, mainly located in Malaga and Algeciras, decreased by 80% from 442 (22,798 GRT) to 107 (3826 GRT) fishing vessels in period 1976–2016 up to the point that, nowadays, there aren’t trawlers neither in Malaga nor in Algeciras.

The purse seine fleet also experienced a sharp decrease from 264 to 91 vessels (54.4%) in period 1976–2016. Purse seine fleet changes its distribution among Northern Alboran Sea fishing ports in the last four decades. Algeciras and Malaga that represented 52% of the tonnage are now around 5%. All fishing gears follow a similar pattern characterized by a bigger decline of the fishing fleet in the western area and big cities than in the eastern area.

It is obvious that there are relevant differences in the productivity depending on the kind of fishing gear located in each Northern Alboran Sea port excluding landings of frozen fish in other areas (frozen tuna and sardine vessels). Logically, the industrial fishing fleet operating in the high seas was the most productive one, and this caused an important impact on any indicator that we attempt to build. Figure 22.4 shows the productivity evolution of the fishing fleet of Northern Alboran Sea in physical and monetary units related to tonnage and employment for period 1940–2018.

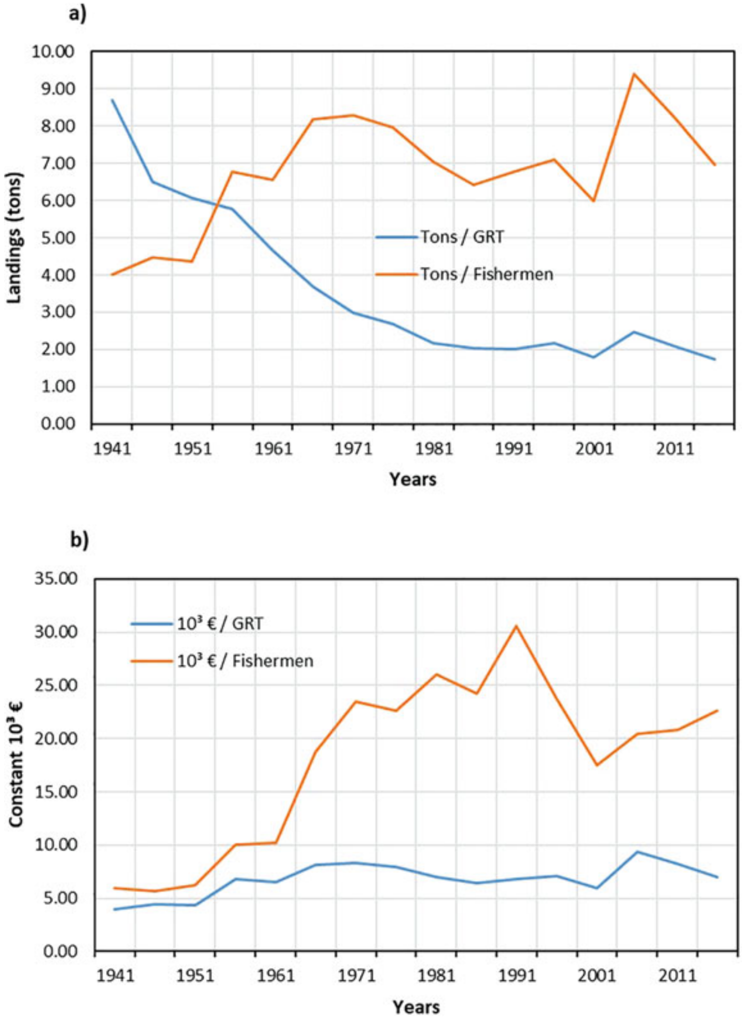

Fig. 22.4 Fleet productivity evolution in physical (**a**) and monetary (constant euros of 2016) (**b**) terms related to tonnage and employment (1940–2018)

Landings per tonnage in the Northern Alboran Sea have decreased during the whole period (from 8.7 T/GRT in 1941 to 2.9 T/GRT in 1976 and 1.7 T/GRT in 2018). In contrast, the decrease in monetary terms has been smaller (56%) partly alleviated by a price increase (a 118% price increase since 1941 due to the reduction of supply) in contrast with an 80% reduction in physical terms.

22.3.5 Northern Alboran Sea Socioeconomic Evolution

The evolution of the labor productivity depicts an increasing trend due to long-term substitution of capital for labor, thus increasing from 4 T/fisherman (1941) to 7.9 T/fisherman (1976) with the expansion of the trawl and purse seine fleets, lessening to 7 T/fisherman in 2016 (i.e., a 73% increase from 1976—Fig. 22.4). The picture changes when considering monetary units as the ratio €/fisherman has increased during the whole period from 6000 €/fisherman (1941) to 22,590 €/fisherman (1976) and 22.650 €/fishermen (2018—278% increase from 1941).

Fishermen's wage is smaller than those of other economic sectors located in coastal areas considering that fishermen's wage represents a 50% share of the gross value added (GVA) net of social security contributions paid for by the ship owner. Note also that the GVA level is small compared to the one attained in other economic activities of the same risk level. The latter explains the significant reduction of the fleet in the Northern Alboran Sea during the last decades turning fishing industry in the area into a secondary testimonial activity.

Additionally, the disappearance of the trawling fleet that operated in the Southern Alboran Sea (GSA 3) resulted in an important loss of landing value in ports like Algeciras (from 27.5% of value in 1996 to 4% in 2018) and Malaga (from 13.6% of value in 1996 to 2.3% in 2018) as shown in Table 22.5. On the contrary, ports like Velez-Malaga, Almeria, Carboneras, or Garrucha increased their relative weight in the region despite the decreasing fleet. Moreover, western ports represented 50.1% of the value of landings in 1986 and hardly 15.4% in 2016, while in contrast, eastern ports represented 9.5% of the value of landings in 1986 and reached 36.5% in 2016.

Table 22.5 Evolution of fishing port weight in value in Northern Alboran Sea in the last four decades

	% value of catches (constant euros of 2016)			
Maritime district	1986	1996	2006	2016
Algeciras	43.67%	27.53%	5.81%	4.00%
La Linea	1.66%	3.80%	1.94%	1.12%
Estepona	3.18%	7.19%	6.25%	6.29%
Marbella	1.57%	1.85%	4.02%	3.94%
Fuengirola	1.58%	2.32%	3.24%	5.36%
Malaga	14.32%	13.55%	3.89%	2.26%
Vélez-Malaga	2.23%	5.36%	12.66%	13.55%
Motril	5.15%	5.25%	9.32%	7.15%
Adra	3.38%	5.01%	4.83%	2.54%
Almeria	13.76%	12.16%	20.48%	17.30%
Garrucha	3.17%	6.51%	13.35%	17.57%
Águilas	2.89%	3.20%	4.92%	3.85%
Mazarrón	1.07%	4.01%	4.29%	8.15%
Cartagena	2.35%	2.25%	5.00%	6.92%

Table 22.6 Evolution of fishing jobs in the GSA 1 region and the degree of dependence on fishing (jobs/total population)

	Fishing employment			Change (%)		Dependency index	
Maritime districts	1941	1961	2016	1941–1961	1961–2016	1961	2016
Algeciras	1625	6829	132	320.2%	−98.1%	10.34%	0.11%
La Linea	807	534	146	−33.8%	−72.7%	0.62%	0.13%
Estepona	1049	835	194	−20.4%	−76.8%	3.60%	0.22%
Marbella	955	642	158	−32.8%	−75.4%	5.28%	0.11%
Fuengirola	536	462	183	−13.8%	−60.4%	2.46%	0.08%
Malaga	3708	6558	70	76.9%	−98.9%	2.17%	0.01%
Vélez-Malaga	1238	1463	354	18.2%	−75.8%	2.70%	0.29%
Motril	1009	1675	154	66.0%	−90.8%	2.58%	0.13%
Adra	2415	1447	160	−40.1%	−88.9%	3.31%	0.12%
Almeria	3506	2059	358	−41.3%	−82.6%	1.94%	0.11%
Garrucha	1179	477	405	−59.5%	−15.1%	1.86%	0.66%
Águilas	810	930	99	14.8%	−89.4%	1.26%	0.08%
Mazarrón	681	342	77	−49.8%	−77.5%	3.47%	0.25%
Cartagena	914	607	257	−33.6%	−57.7%	0.45%	0.11%
Total of the coast	20,432	24,860	2747	21.7%	−89.0%	2.43%	0.11%

Northern Alboran Sea fishing has experienced an important reduction despite aforementioned changes of relative importance in value of different ports. In fact, looking at the long-term evolution of fishing in terms of created employment related to the whole population of each fishing town, the total employment increased from 20,432 land-based and vessel jobs in 1941 to 24,860 jobs in the 1970s and then decreased to 2747 employees in 2016 (Table 22.6).

It is worth noting that the Andalusian coast has experienced a quick increase in population from 852,797 dwellers in 1941 to 2,505,891 in 2016 and that it is one of the most developed touristic areas in Europe and consequently there are many other alternative jobs. For instance, fishing employed 10.34% of the population of Algeciras in 1961, and now, it scarcely employs 0.11%, representing a 98% loss of employment. This pattern has been similar in other coastal districts like Motril (−90.8%), Adra (−88.9%), Águilas (−89.4%), or Malaga (−98.9%), with the exception of Garrucha and Carboneras having a reduction of 15%.

In summary, the fishing activity in Northern Alboran Sea represented 17% of total Spanish landings, against only 2% nowadays, as shown in Fig. 22.5. The current situation is a consequence of the high dependence of some ports on Moroccan fishing grounds, the overexploitation of some fisheries resources, the influence of marine environment conditions on the dynamics of fish stocks, and mainly the low profitability of fishing related to other labor or business alternatives. This is a plausible explanation that fishing has become a testimonial activity in many provinces of the Northern Alboran Sea like Cádiz, Malaga, Granada, Almeria, and Murcia.

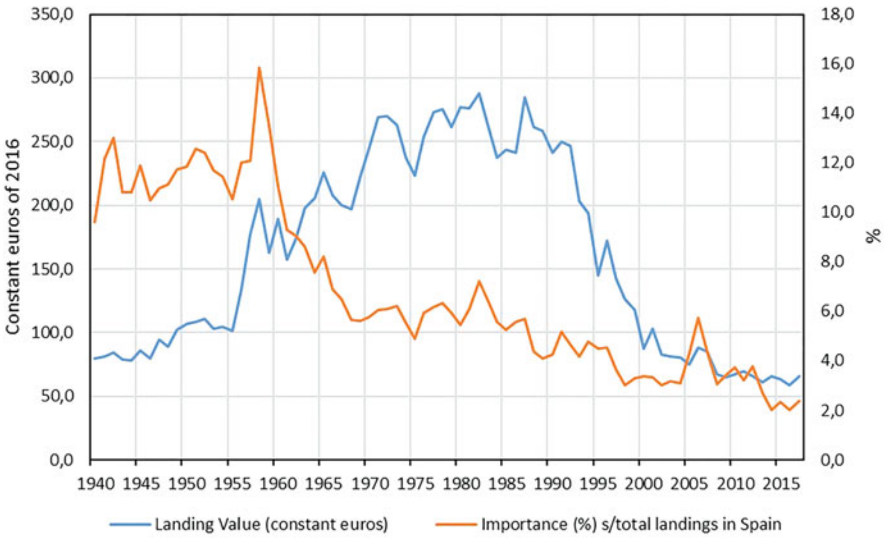

Fig. 22.5 Value of landings in the Northern Alboran Sea in Spain (10^6 constant euros of 2016)

22.4 Marine Environment Conditions and Alboran Sea Fisheries

This section goes through the identification of marine environment factors affecting the evolution of fisheries resources as one of the most important goods and services for food provisions of the seas. The identification of this factor and its interaction in the social-ecological system will allow us to attain the knowledge base necessary for the proper design of the fisheries management system of Alboran Sea fisheries with the aim of sustainability in the framework of an integrated coastal management of it.

This section focuses on climatic drivers and other marine environment factors whose variability influences fisheries, as seen in Sect. 22.3 where technical and socioeconomic drivers were described in the Alboran Sea.

Global warming drivers result in a wide range of impacts on fisheries including changes in fisheries productivity and spatial distribution and consequently on rent and demand (Sumaila et al. 2011). Anthropogenic climatic driving forces are mediated primarily by greenhouse gas (predominantly CO_2) emissions that result in increasing global mean temperature causing a wide range of physical and chemical changes in marine systems (Harley et al. 2006). The increase of sea surface temperature (SST) is the main manifestation of global warming affecting the Alboran Sea fish stocks.

Other drivers like acidification and UV increase are not of the same immediate importance. Acidification, for instance, is due to the CO_2 concentration in the atmosphere in the Mediterranean Sea, especially in the Adriatic Sea and the Gulf of Gabés (Tunisia) (Micheli et al. 2013; Meier et al. 2014). Major acidification impacts are concentrated onto finfish and mollusc species, especially at larval stages. Acidification disrupts the fixation of calcium carbonate ($CaCO_3$) on skeletons or shell frames and affects physiological processes due to hypercapnia (Lacoue-Labarthe et al. 2016).

The scientific community has intensively studied the relationship between marine environmental conditions and fish stocks and especially global warming. Marine environmental conditions are also closely related to climate. Particularly, the evolution of climate affects the evolution of the ecosystem functions that influence the reproduction and growth of commercial fish stocks and other aspects of the biology and habits of these stocks (Sharp 1995). Small pelagic fish stocks, including clupeids such as sardine or anchovy, have been the most strongly affected by these changes over short and long timescales. These stocks have been strongly affected due to their diet based on plankton, their migratory habits, their short reproductive and life cycles, or their ability to cope with these changes (Hunter and Alheit 1997; Klyashtorin 2001), although these relationships are also found in benthopelagic fish species (Lim et al. 2003).

Several articles focused on the Alboran Sea small pelagic fish stocks. Giráldez and Abad (2000) determined the spawning period of anchovy (from April–March to September–October) and showed a high correlation between the gonado-somatic index (GSI) of this fish species and temperatures of the previous month for both sexes. García et al. (2003) detected a higher concentration of larvae at the surface where chlorophyll concentration is also higher, coinciding with a decrease of mean temperatures from 2000 to 2001. They also typified Malaga Bay as nursery area for anchovy, as done before by García et al. (1981) who also showed a high spatial correlation with mesoplankton distribution. Relatively low temperatures increase primary production and consequently induce higher anchovy larval concentration and higher growth rate. The aforementioned causality is supported by the results of acoustic stock assessment campaigns that concluded that anchovy biomass increased from 1716 T to 13,000 T during the period 2000–2001 (García et al. 2003). Agostini and Bakun (2002) looked in the causes of the significant increase of anchovy fish stock in period 2000–2001, stressing the existence of an important upwelling process in the Alboran Sea area during 2001 related to the Atlantic flow through the Strait of Gibraltar to the Mediterranean Sea as noted before by Cano and Gil (1984). This upwelling process caused an increase of primary production in Malaga Bay which resulted in a higher concentration of larvae and individual growth mainly due to climate and marine environment factors (Macías et al. 2014). It has also been demonstrated that kinetic energy levels in the NW Alboran region related to wind regimes favor seasonal upwelling of small pelagic species in the Alboran Sea area (Ruiz et al. 2013).

Mafalda et al. (2008) compared Spanish Institute of Oceanography stock assessments of 1993 and 1994 analyzing the relationship between Atlantic, Mediterranean, and mixed water masses and the existence of larvae of different fish species. These authors showed that the abundance of anchovy larvae was three times higher in 1994 than in 1993. They noted that the increase of fish stocks coincided with SST that was relatively lower in 1994, namely, between 17 °C and 20 °C in 1994 and between

18 °C and 22 °C in 1993, as a consequence of an increasing flow of Atlantic water mass to the deep Mediterranean Sea. This phenomenon was noted before by Arévalo and García (1983).

Palomera and Salat (2003) identified the upwelling areas of the Mediterranean Sea through satellite images of chlorophyll concentration which are the Alboran Sea, Lion Gulf, Adriatic Sea, Black Sea, and in some areas of the Mediterranean Sea coast of Greece, Tunisia, and Egypt. These upwelling areas have primary production levels that are relatively higher than in other areas.

García and Palomera (1996) showed that the period of maximum spawning was in August with SST between 19 °C and 23 °C for periods between March–April and September–October. Moreover, SST lower than 23 °C seems to favor and extend over time the spawning period, while higher SST cut short spawning.

Finally, the mentioned work of Agostini and Bakun (2002) typified the Alboran Sea as one of the most favorable areas for anchovy development due to the Atlantic flow and sea floor orography that favors upwelling along the whole north coast of the Alboran Sea. They consider Malaga Bay a "small-scale example of the most common reproduction habitat of anchovy in Eastern Atlantic Ocean." Moreover, Rubín (1997) stated that upwelling process was not the only phenomenon that takes place in the area, but also concentration of larvae and eggs in the Alboran Sea through transportation processes originated by the Atlantic flow from the Gulf of Cádiz was important for anchovy stock productivity. Apart from Malaga Bay, it can be highlighted that there are other important areas of primary production in Southern Alboran Sea (GSA 3) which are mainly located in the coast surrounding Melilla and Alhucemas in Moroccan waters (García and Palomera 1996; Mafalda et al. 2008).

22.5 Alboran Sea Fishery Management for Sustainability

The fishery management system implemented in the Alboran Sea is a bureaucratic type of fishery management system, with a top-down governance system from international to local level. The participation of stakeholders in the management of the fishery resources is limited to a mere consultation. However, the importance of gillnetters and other fishing industrial forms of associations that organize main stakeholders could make feasible transferring property over fisheries resource or the management responsibilities in certain conditions (Leite and Pita 2016; Hogg et al. 2015).

The absence of appropriated institutional arrangements results in poorly defined property rights over fisheries resource but for some exceptions. Individual quotas are only partly present for certain segments of the fleet like those targeting bluefin tuna. Moreover, co-management is limited to consultation as noted in previous paragraph, so that property rights of the community over the resources are also limited. In this sense, bivalves or octopus fisheries could be interesting candidates to implement Territorial Use Rights for Fisheries (TURFs—Nguyen Thi Quynh et al. 2017).

There are combination of management measures involving VCL in the case of tow rake and mechanized dredges that are far to be considered a second best compared to individual quotas. The latter is because trips do not seem to be restricting fishing activity (Gréboval and Munro 1999), and they are used combined with TACs that might intensify the race to fish in this particular case (OECD 1997).

The adoption of an ecosystem approach to fisheries management is mainly represented by MPAs which include six SPAMI (Alboran Island, Natural Park of Cabo de Gata-Nijar, Sea Bottom of the Levante of Almeria, Maro-Cerro Gordo Cliffs, Al Hoceima National Park, and the Habibas Islands), numerous protected habitats, and large areas where certain fishing gears are forbidden. Additionally, the EU mandate of creating integrated coastal management plans can represent an important step toward the ecosystem approach by 2021. However, the performance of this management approach in Morocco and European countries, in spite of the principle of European Maritime Policy, is small (Pitcher et al. 2009).

Most of Alboran fisheries are multispecies, multi-specific, and artisanal. It is also remarkable to observe the coexistence of multiple uses of the Alboran Sea including tourism, sports, and recreational fishing or shipping, leading to multiple access conflicts that need to be considered. Consequently, it is important to account for the spatial and temporal dynamics of ecosystem services by informing and managing trade-offs among cumulative or competing activities to implement an EBM approach in the area (Miller et al. 2016). MPA also represents an important successful measure in the area of sustainability and responds to the principles of EBM. Regarding highly migratory species of high economic value, further international cooperation together with individual fishing quotas should be put in place. Some fisheries geographically well located like bivalves should be managed using TURFs (Selig et al. 2017).

Alboran sea fisheries are subject to significant marine environmental conditions variability, specially pelagic and semi-pelagic species. This needs to be taken into consideration by fisheries management plans. These conditions are subject to long-term climate change driving forces as noted in previous section so that uncertainty forces policy-makers to follow a precautionary approach in fisheries management so as to guarantee sustainability and to use models that consider environmental variability to forecast future scenarios mixing environmental and human driving forces. Additionally, the human component must be further considered by incorporating into the fishery management system the socioeconomic conditions that generally set reference points mainly based on scientific advice guided by biological considerations.

An adaptive fishery management can be also an approach to promote for an EBM approach in the Alboran Sea. Macías et al. (2014) used, for instance, a simulation modelling tool to account for changing marine conditions, fishing, and socioeconomic conditions to depict future scenarios and to produce sound scientific advice. Other approaches like Ecopath with Ecosim (EwE) could be interesting tools to support fisheries management in the area (Coll et al. 2016; Piroddi et al. 2017).

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Chapter 23
A Historical Approach to Living Resources on the Spanish Coasts from the Alboran Sea Between the Sixteenth and Twentieth Centuries

Juan Pérez-Rubín

23.1 Introduction

“Knowing the past is vital for developing a vision of the future. The oceans and inshore seascapes of the world are rapidly changing, and understanding the human and marine ecosystem forces, trajectories and responses —sometimes over centuries or millennia— is vital for their informed management.” Priority actions needed involve “tracing human interactions with marine ecosystems through deep time” and moving towards a “unifying view of our oceans as networks of social-ecological or coupled human-nature systems” (Ocean Past Initiative 2018).

In order to achieve these objectives, multidisciplinary research efforts have been carried out internationally during the last decades, aimed at improving the knowledge and understanding of the interaction of marine environment between man from the earliest of times and the historical variability in coastal and open sea ecology. Several working groups or programmes such as “History of Marine Animal Populations,” under the Census of Marine Life (Holm et al. 2010; Starkey et al. 2008); “Study Group on the History of Fish and Fisheries” (ICES 2011); “Marine Environmental History” (Holm et al. 2001) and “Marine Historical Ecology” (Lotze and McClenachan 2013) have contributed towards this goal.

Among other needs, the identification of ecosystem components and the recognition of the dynamics between the ecosystem and society are required, along with an extensive review of the literature to identify sociocultural values related to local or regional fisheries (Ignatius and Haapasaari 2018). The intense search for information of the last centuries should include the multiple historical, scientific and technical

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aspects (Lackey 2005), including the evolution of fishery management concepts and old fishery legislations.

The objective of this chapter is to develop these lines of historical-scientific-technical research for the Alboran Sea and the Strait of Gibraltar, from the sixteenth century. The living resources include distribution and abundance of several fish and cetacean species in pelagic and benthos/demersal habitats. Our exposition on human interactions includes mainly fishermen, consumers and fishery management technicians. The subsequent scientific research work accomplished between 1913 and 2014 in the area by the Oceanographic Centre of Malaga has been described in other documents (Pérez-Rubín 2011, 2014a, b; Baro and Camiñas 2014; Camiñas 2018).

Data of regional interrelations between both historical and marine sciences are presented in order to understand the impact of the climate variability and overfishing in human activity. Furthermore, to identify the most important economically, socially and culturally important historical fisheries in the entire area, three clear focal ecosystem components have been established, with the decisive roles of the Strait of Gibraltar (crossroads of currents and fauna from different areas), the quasi-permanent northwestern Alboran Sea upwelling (waters rich in nutrients, with high planktonic productivity and important concentration of sardines, *Sardina pilchardus*, and other pelagic species) and the Bay of Malaga (with anchovy, *Engraulis encrasicolus*, and sardine nursery grounds).

The Strait of Gibraltar and adjacent areas are of utmost importance to marine biodiversity (e.g. Báez et al. in this volume). Both areas (the Ibero-Moroccan Gulf and the Alboran Sea) have common historical aspects for millennia as they share oceanographic and meteorological environments and present particular geological, zoological and botanical characteristics. For that reason, Ramos et al. (2011) proposed the "geohistorical region of the Strait of Gibraltar" as a target study area where human records have existed since the Pleistocene period.

At the beginning of the twentieth century, the relevance of this Atlantic-Mediterranean transitional area was enshrined during the period 1919–1923 from the oceanographic and fisheries point of view. The first two intergovernmental scientific organizations for the study of the Mediterranean (The Mediterranean Science Commission, CIESM) and the North Atlantic (International Council for the Exploration of the Sea, ICES) established the areas of the Strait of Gibraltar and the Gulf of Cadiz as the geographical limits of their respective areas of competence. French researchers showed the oceanographic and fisheries relationship of the Alboran Sea and the northeastern Atlantic for the European hake (*Merluccius merluccius*), a demersal species, with regard to seasonal variations in spawning areas and preferred period for fishing (Le Danois 1920). Unlike for the pelagic sardine, it was proposed that in the region of the Strait of Gibraltar, the two supposed Atlantic breeds were not mixed: to the south the Moroccan and to the north the common for the Gulf of Cadiz and north Alboran Sea (Furnestin 1948).

In addition, the studies carried out during the last decades on the historical fisheries of the Alboran Sea have confirmed the importance of this "border sea" as a transitional area in the Iberian Peninsula, between the waters of the Atlantic and the waters of the northwestern Mediterranean, south of the French border including the waters of Cataluña and Levante (the "Balearic Sea"). Both regional seas (Balearic and Alboran) were the first two great areas identified in the Spanish Mediterranean with well-defined characteristics from the hydrographic and biological point of view (Estrada et al. 1989). Other authors gave more weight to the biogeographical criteria (Bianchi and Morri 2000; Würtz 2010) and found stronger relationships between the Alboran Sea and the eastern Mediterranean (Aegean Sea) in relation to the "ocean triads" hypothesis (Agostini and Bakun 2002).

For all these reasons, the opinion of a Spanish oceanographer of the last century is still useful and is applicable to fishery resources:

> Since the sea, as soon as we drift a few miles offshore, is no longer the heritage of any country and the phenomena that take place there are generally influenced by factors that act over a large surface of the globe, it is absolutely necessary that all countries cooperate in their study by agreeing on common work plans and unifying the methods that must be used (Buen 1931).

23.2 Extraordinary Animals

For centuries, the inhabitants of the area knew about the presence of the Atlantic surface current in the Strait of Gibraltar and the entry of pelagic fishes into the Alboran Sea. These included commercially important fish, as well as lone individuals considered strangers and/or monsters or prodigious due to their large size.

The first records of their presence are from the end of the sixteenth century. A fantastic "tattooed tuna" with drawings on its body was found off the coast of Ceuta in May 1565 and reproduced by the ichthyologist C. Gesner (1670) (Fig. 23.1a). Evidence of the Atlantic current dates back to 1574 when a sperm whale (*Physeter macrocephalus*) was cannoned in the Strait, floated adrift and was stranded on a beach in Valencia (Graells 1889).

In the eighteenth century, additional news mentioned another stranded sperm whale in Ceuta (Fig. 23.1b) and a porcupinefish genus *Diodon* (*D. hystrix* or *D. eydouxii*) presumably caught alive in Tarifa in 1777 (Fig. 23.1d). In the following century, another Diodontidae was described on the beach of Tangier, south of the Strait of Gibraltar (Amor 1859). That Diodontidae family, widely distributed in tropical and temperate marine waters (Leis 2006), was cited by Spanish authors in the nineteenth century in Andalusia and Galicia and by Buen (1926) in the Gulf of Cadiz. A specimen of *Diodon eydouxii*, abundant in the eastern Pacific Ocean, was caught in 1975 west of Tarifa (Zahara de los Atunes) and described by Crespo et al. (1987) together with the tropical African species *Acanthurus monroviae* fished in Marbella in 1981.

Among the Tetraodontidae ("pufferfishes"), *Ephippion guttifer*, a species from Atlantic Africa and the Canary Islands, was caught in Malaga in 1871. A previously caught specimen (Fig. 23.1e) is currently preserved in the museum of a secondary

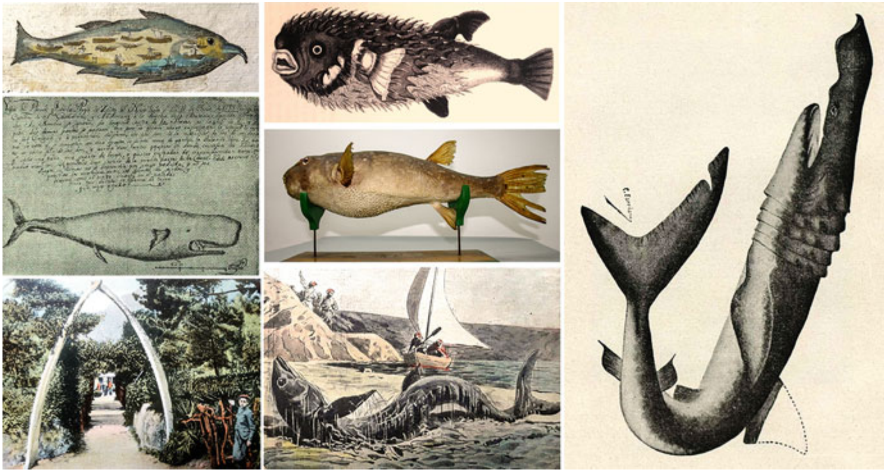

Fig. 23.1 Pelagic "sea monsters" of the Alboran Sea and Strait of Gibraltar (1565–1909). (**a**) Fantastic "tattooed tuna" found in Ceuta in May 1565 (reproduced from Gesner *Fisch-Buch*, 1670). (**b**) Male sperm whale (*Physeter macrocephalus*) stranded in Ceuta in 1753 (reproduced from Barras 1944). (**c**) Whale jawbone arch in a public garden in Gibraltar towards year 1905 (old postcard). (**d**) Porcupinefish genus Diodon (*D. hystrix* or *D. eydouxii*) from Tarifa (reproduced from Brú 1784). (**e**) Pufferfish (*Ephippion guttifer*) caught in Malaga before 1871 and currently preserved in the museum of a secondary school (Photograph by J. Pérez-Rubín). (**f**) Fantastic fish, a mixture of tuna and conger, supposedly beached in Oran in 1906 (reproduced from the French magazine *Le Pélerin*). (**g**) Young specimen of basking shark (*Cetorhinus maximus*) from Melilla (reproduced from Escribano 1909)

school in the town (Garrido 2008). Given this presence in Malaga, the species was included in the Spanish ichthyology by Navarrete (1898).

There are two mentions of "sea monsters" at the beginning of the twentieth century, southeast of the Alboran Sea (African waters). In 1906, a French magazine published the news and illustration of an incredible and fantastic fish that was washed up on a beach of Oran (Fig. 23.1f). Three years later, several Madrid newspapers reported about a "sea monster" found near the coast of Melilla. Then, it was verified that it was a young specimen of basking shark (*Cetorhinus maximus*, Fig. 23.1g) (Escribano 1909). Around 1905, the bones of the lower jaw of a giant whale were used to build an arch in a public garden in Gibraltar (Fig. 23.1c).

23.3 Historical Fisheries and Oceanographic Variability

During the period 1525–1725, we hypothesized that the inhabitants of the Alboran Sea were affected by fluctuations in the abundance of sardines and tuna stocks, as happened in other Spanish Atlantic regions. In fact, during the sixteenth century, the presence of sardine banks in the Galician Rias was highly fluctuating with periods of absence every 20–25 years approximately, resulting in a dramatic sardine crisis during the period 1525–1575 (Juega 2012). On the other hand, according to the raw catch statistics of bluefin tuna (*Thunnus thynnus*) in the traps of Conil and Zahara during 1525–1725 (García and Fernández 1993), we found the appearance of drastic natural fluctuations. In the period 1525–1575, the highest record was observed (average catch 58,600 tuna/year), while during the period 1676–1725 the poorest records were obtained (1760 tuna/year). The interim period 1576–1675 did not show extreme fluctuations, and an average of 15,170 tuna/year was maintained. According to Gancedo et al. (2009), these fluctuations could have been due to the "Maunder minimum" (the so-called the Little Ice Age, years 1640–1715) affecting both abundance and recruitment of tunas in the North Atlantic and the Mediterranean.

For centuries, the harvest of sardine and anchovy has been of crucial importance from a socioeconomic point of view, as their natural and unpredictable fluctuations have resulted in cyclic periods of poverty/wealth in local fishermen populations. On a larger spatial scale (Pérez-Rubín 2008), interrelationships have been found between the abundance of fish stocks and fishermen from Andalusia (the Alboran Sea and Gulf of Cadiz), Galicia and the Balearic Sea (including Levante and Cataluña) during the dramatic crisis of Spanish fisheries in the period 1920–1950. The grave crisis of the sardine industry in Galician waters in 1923–1927 and in 1947–1956 forced the Galician fishing vessels and canning factories to migrate to different ports in Andalusia such as Malaga and Algeciras.

For benthic and demersal fishing, the first two decades of the twentieth century were of great splendour in the Alboran Sea (Miranda 1923). The greatest activity was still centralized in Malaga, with the only steamboat trawlers of the Alboran Sea that were owned by different companies. In the fishing grounds far from the coast, the hegemonic company was "La Pesquera Malagueña" (1903–1927), whose bankruptcy marked the end of a stage of economic growth in the province. It had 20 steamboats using the port of Malaga for its shipyards and refrigerating installations and which directly employed 400 families. It abundantly exported fish and opened its own fish shops in cities in the provinces of Sevilla, Cordoba and Valencia. Around 1925, the northern and southern seabed fishing grounds of the Alboran Sea were overexploited, and a great part of the Spanish bottom trawl fleet fished in the Atlantic waters of Morocco.

In the Alboran Sea, the historical fluctuations of sardine and anchovy between 1945 and 1990 (Giráldez and Abad 1991, 2000) were related to climatic cycles: the sardine predominated in cooler periods and the anchovy in warmer periods (Pérez-Rubín 1996). Comparable changes were demonstrated in the pelagic fish assemblage of the European continental shelf: shifted from cold-water fish species (the 1960s–1980s) to warmer-water assemblages from the 1990s onwards (Montero-Serra et al. 2014) and the collapse of the bluefin tuna fisheries in the Atlantic during the 1960s (Cort and Abaunza 2015).

Several species of small/medium-size pelagic fish are occasionally present in exceptionally high quantities in the Alboran Sea, and they are useful as bioindicators. The boarfish (*Capros aper*) can reflect a greater flow of Atlantic waters which transport significant amounts of their eggs and larvae from the Gulf of Cadiz (Pérez-Rubín and Abad 1994). The respective massive temporal presence of three Clupeiforms (anchovy, sardine and gilt sardine, *Sardinella aurita*) could reflect cyclic episodes of warming/cooling of surface waters (Pérez-Rubín 1996).

23.4 Early Fisheries and First Artisanal Fishing Industries

The Nasrid Kingdom of Granada (1232–1492) was extended across the northern coast of the Alboran Sea, from the Strait to Cabo de Gata, including—until the Reconquest—the current Spanish provinces of Malaga, Granada and Almeria. An influential Genoese colony already trading in salted anchovy from Malaga through its active port would become one of the most important in the Mediterranean (Martín Acosta 2010). The particular fishing wealth is also documented in certain coastal sectors in relation to the populations of Almuñecar, Bezmiliana (with tuna traps), Salobreña (commercial and fishing centre) and Marbella, with an abundance of sardines (Malpica 2009). In the late fifteenth century, the elaboration and commercialization of anchovies and salted sardines in Malaga were the main local industry. An influential Catalan and Valencian commercial colony was established and traded with the handmade, salted anchovy in Malaga, which came to be demanded on a large scale by the eastern Spanish trade (Ruiz Povedano 1987).

The production generated an important maritime export trade and was even transported to distant markets of the Late Middle Ages (López Beltrán 2001). This industry exported thousands of barrels of anchovy and sardines annually, from Malaga and Marbella to different European countries. Sometimes, these provisions travelled to the antipodes, like the 200 barrels of anchovy from Malaga that were shipped in 1519 for the expedition of Ferdinand Magellan to the Moluccas Islands in the Pacific Ocean, along with other Andalusian species of dried fish (Fernández-Navarrete 1964).

In order to repopulate Fuengirola in 1502, 20 families were economically motivated to settle under the protection of the military fortress, and it was recommended that two-thirds of this population should be fishermen and small purse seiner boat owners called "jábegas" (López de Coca 1975). In the current provinces of Granada and Almeria, since the sixteenth century, the presence of towed traps to catch tunas and small species of tuna is documented (Abad 1995–1996). Other historical sources (Malpica 2009) located tuna traps in La Herradura and in the vicinity of the current town of La Mamola (Granada), famous in those days for its abundance of Atlantic bonito (*Sarda sarda*).

In the Malaga ordinances of 1611 (Martín Acosta 2010), a great diversity of fish species that landed on the beaches of Malaga and Granada were still mentioned, pointing out those of greater commercial importance and the variety of fishing techniques used, with four different types of net gears, hooks (longlines) and pots. In these municipal ordinances, 22 species of fish or varieties are mentioned, plus the generic name to refer to very small fish, called "morralla."

On the coast of the current province of Almeria, the fishing village of Balerma was founded and became the most important fishing ground in the area thanks to the protection offered by its fortress against the attack of pirates (García Luján 2002).

For centuries, the greatest source of suffering and mortality for the different populations living on the coast of Andalusia was the continuous pirate and corsair attacks from the north of Africa. They stole the boats and kidnapped the fishermen in order to request a ransom for their freedom. This triggered the depopulation of the coastal zone and the abandonment of fishing and agriculture (Martínez González 1997). On the Almeria coast, given its greater proximity to the Algerian and Tunisian coasts, Berber incursions didn't end until the eighteenth century (Sánchez Picón 1999).

Due to the commercial importance of sharks, they were sold either fresh or air-dried. The first mention about shark fisheries in the Alboran Sea was in the municipal ordinances of Malaga during the period 1489–1501, in relation to the net fisheries. In these ordinances, 10 different species were named, and up to 5 different types of fishing were authorized. Concerning hook fisheries aimed at sharks, the first information comes from the southeastern Alboran Sea in the sixteenth century, where Spanish ordinances (1536–1540) mentioned 4 species of elasmobranch fish that were consumed dried (López Beltrán 1984). In the year 1611 in the municipal ordinance of Malaga, the only shark species named is the "cazón" (*Galeorhinus galeus*), although apparently this term is used as a generic name. In 1789, up to 40 species of elasmobranch are mentioned in Malaga (Martínez-González 1993). During the eighteenth century, the "cazonales" bottom nets were used from Cabo de Gata (Almeria) to Malaga, generally from April to the beginning of July (Sáñez-Reguart 1791–1795). In addition, a decrease in shark catch was observed due to the proliferation of bottom trawl nets. In earlier times, in certain areas, a single vessel could catch on average of around 1700 kg with nets. Using hook handline ("cordel"), it was common to port 10–12 dozen sharks in less than 24 h (Sáñez-Reguart 1791–1795).

23.4.1 The Pelagic Habitat

At the beginning of the sixteenth century, fishing was abundant and varied. In the municipal ordinances of Malaga city council, January 1501, some 30 main species of fish of commercial interest in the area (Mondéjar 2001; Malpica 2009), including 8 cartilaginous species, are mentioned. In a document from Malaga in 1502, 31 fish drying facilities ("percheles") were registered. Foreign trade in the Andalusian Mediterranean was concentrated mainly in the port of Malaga and smaller ones in Marbella, Velez-Malaga, Almuñecar and Almeria. A decade later, in 1512, the entire coastline of the Kingdom of Granada was considered a favourable area for fishing and processing anchovy (Ruiz Povedano 1987).

During the sixteenth and seventeenth centuries, on the coast of Almeria, there was a fishing activity developed with varied techniques, such as pots, gillnets, beach seines, hooks gears (to catch sharks) and two types of tuna traps. One of these, the beach seine trawl modality, was practised in Cabo de Gata from 1566, with intermittent activity until at least the year 1659 and which gave rise to a settlement of fishermen that grew over the years. The first buche's tuna trap ("almadraba de buche") was in Roquetas and leased in 1671 for a 10-year period. At the end of that century, tuna traps were also found in the town of Balerma (Abad 1995–1996).

Throughout the eighteenth century, the greatest fishing force was still concentrated in the capital city of Malaga, and its large industry was intended for salting fish and processing anchovy (Burgos 1994a). Fishing for sardines and anchovies in the northwestern Alboran Sea with "jábegas" was still very important during almost the whole year. In summer, both species started to be salted, as well as tuna and bonitos (Sañez-Reguart 1791–1795). There was a huge number of salting places in several towns on the Malaga coast, where many women and girls worked, exporting production to different Spanish provinces and to France and Italy. The Catalans went to the waters of Manilva and Estepona to fish for sardines, and their salting factories employed around 650 women per campaign (García and Fernández 1993). The activity was equally intense in several locations in the city of Malaga. In countless houses in the fishermen's district, salting anchovy and sardine continued as well as in 16 large anchovy factories. Independently, the Catalans had their own salted fish production on the beaches, where they employed another 100 women and prepared their catches for export, particularly large amounts of dried conger and pickled sea bream (Burgos 1994a).

In the mid-eighteenth century, the port of Malaga had a large number and variety of ships. According to the official register of vessels (Villas 1995), in 1753, there were 112 boats, including 15 large "jábegas" and 20 large longliners (with 7–8 men each). Throughout the north Alboran Sea, a total of 231 fishing boats of different types were registered in the period 1758–1765, plus an additional number of vessels coming annually from the Catalan Sea. The "jábegas" were the most emblematic ones in the province of Malaga. At the end of the century, they used to fish continuously during the daylight hours, and even artificial light was used for fishing at night. These boats caught great quantities of fish, mainly anchovy and sardine (Sáñez-Reguart 1791–1795). The size of these boats and the necessary manpower were increasing so that in some cases, they had 33 men, including the crew and the staff on land. They used an auxiliary boat to take the catches to the selling places (Sáñez-Reguart 1791–1795). The fishing grounds near the Strait were of prime interest and a great rivalry area. Fishermen from Malaga and from the villages of Manilva, Casares and Estepona came to catch mainly tuna. In Spanish Gibraltar, fishing was the only local industry; in the Bay of Algeciras and the rough Levante coast, fishing was very intense. These fish were exported inland and to the ports of Seville and the coast from Malaga to Valencia. At the end of the eighteenth century, Spanish fishermen from Algeciras preferred the "jábegas," whereas in British Gibraltar, the Genoese fishermen preferred the smallest beach trawl nets called "boliches" (Sañez-Reguart 1791–1795).

In the eastern area (the Nerja-Almeria sector) around 1786, the "jábegas", longline and pots were predominant, salting a large quantity of fish which was exported to distant inland populations. In the current province of Almeria, large tunas and small tuna species were temporarily caught with traps (in Vera and Agua Amarga) and with nets called “sedales” (with double the length of the “jábegas”). Fishing was carried out mainly in Balerma and Roquetas (Sañez-Reguart 1791–1795).

Throughout the nineteenth century, the province of Malaga and the northwestern area near the Strait of Gibraltar still maintained the largest fishing catches followed by Almeria, Roquetas and Adra. Around 1817, east of Marbella, bonitos were captured from March to May by obstructing their movements with the “sedal” fishing gear which was installed from offshore to the coastal waters (Burgos and Lacomba 1993). From the beginning of the century, in the Strait, Ceuta had a fish trap to catch small tunas. The trap was set during the summer-autumn months and in the spring with workers from Alicante and Valencia capturing on several occasions as many as 11,000 bonitos that were exported already salted (Madoz 1986a).

In 1814, the previously abundant anchovies and sardines were missing in Malaga. Nevertheless, their production remained an important economic activity in the city until 1824 when a sudden rise in salt prices for fishing purposes caused the decline of the fishing sector (Miravent 1850). A similar situation occurred in Marbella during 1845–1846 because sardines and mackerels (*Scomber scombrus*) entering from the Strait of Gibraltar, which in former times were abundant, decreased substantially (Burgos 1994b).

Mellado (1845) reported that the greatest catches in the Alboran Sea were apparently from the coasts of Estepona, Marbella, Salobreña, Antas, Bédar, Carboneras and Vera. He highlights the coastal “salinas” (solar salterns) of Roquetas (Almeria) and insists on the importance of the Malaga fishing fleet. According to another contemporary description (Marzo 1851) about the fishing activity from Nerja to Estepona, a greater fishing catch from locations near the Strait of Gibraltar is reported. The waters of Manilva were famous for their sardine abundance. Fishermen from Valencia and Alicante fished in the area from the beginning of the century. Madoz (1986b) also reported on the fishing importance in localities in the province of Malaga: Estepona, Marbella, Manilva and, especially, Fuengirola are highlighted. By mid-century, the port of Algeciras became more important (fish of all sorts were abundant and cheap, and in particular cases, sardines were salted). Tarifa annually exported 453,600 kg of tuna, bonito, albacore (*Thunnus alalunga*), mackerel, sardine and anchovy to Valencia (Madoz 1986a).

In the last decades, considerable changes were detected in the abundance and spatial concentration of certain pelagic species on the coast of Malaga. In 1881, sardine catches in Malaga (only with traditional techniques) accounted for 50% of the whole Alboran Sea catches. The only salting factories in the Alboran Sea were in Malaga: three factories and a production of 3,000,000 sardines which consumed 35,000 kg of salt (Lacomba 2006).

During the twentieth century, fishing research was intensified specially for species of great commercial preference. In the year 1920, it included the first reliable statistics on a national scale. The data from the Alboran Sea was detailed, including the Spanish Moroccan Sea (Miranda 1923). The province of Malaga annually landed more than 90% of the total fish catches, and sardine represented nearly 92% (14.3 tons). The local fishing fleet was diversified in multiple modalities and with different types of hooks, gears and nets: longliners, trawlers (with sail and steamboats), large "jábegas" (with as many as 20 oarsmen), fixed gillnets ("trasmallos") and drifting ("sardinales").

On the other hand, the abundance of large cetaceans in the Strait of Gibraltar and adjacent waters boosted the settlement of Spanish whaling factories from the beginning of the twentieth century. According to Aguilar (2013) in the Strait area, with plenty of sharks in the nineteenth century, big shoals of sperm whales (*Physeter macrocephalus*) were discovered. Following this evidence, North American whaling vessels reached the region and hunted whales between 1 and 4 months during the April to September season. In the 1920s, sperm whales were rare, the common whale (*Balaenoptera physalus*) being the most frequent species; that is why some years later more than 700 individuals were caught on the Spanish coasts. Norwegian businessmen maintained the Getares factory (near Algeciras) from 1921 to 1926. During its lifetime, 3610 whales and 352 sperm whales were processed. A new modern factory, which processed 356 whales and 347 sperm whales, was established in the Bay of Benzu (Ceuta) from 1947 to 1954. A businessman from Malaga relaunched the Getares whaling factory in 1950 with less total results during its 10 years of functioning (291 whales and 372 sperm whales). The history of whaling factories in northern Morocco during the 1929–1955 period has been reviewed by other authors (Serrais and Domínguez 2015).

23.4.2 Benthos and Demersal Fish Habitats

In the eighteenth century, in the whole northern area of the Alboran Sea, a variety of deep fishing techniques with hooks were used. Small Catalan longliners (manned by 5–6 sailors) would reach these waters every year from winter to the middle of Lent. They used to operate 23 miles away from the coast with several lines containing hundreds of hooks. Specific hooks existed for bottom fish (both benthic and demersal) which were used to catch conger (*Conger conger*), hake (*Merluccius merluccius*), sparids, groupers, sharks and rays (Sáñez-Reguart 1791–1795). Large catches of sharks were also obtained with specific nets ("cazonales"), mainly in the season April to June. Mule drivers ("arrieros") went particularly to Almeria to buy sharks and took them to the people in the mountains, where they were specifically consumed (Sañez-Reguart 1791–1795).

In the rich waters of the Strait where the currents are stronger, large vessels were needed (manned by 8–12 men). The most used gears of hooks in deep waters were the so-called "cordel" (handline), which could submerge even up to 365 m in depth to capture adult specimens of a variety of species (Sáñez-Reguart 1791–1795).

During the eighteenth and nineteenth centuries, the province of Malaga was the firmest defender of maintaining the most artisanal fishing gear types and untirelessly fought with the new "parejas de bou" of sailing vessels (bottom pair trawl) (Burgos

1996a). For that reason, the exploitation of demersal and benthic species on the seabed of the continental shelf was moderate. These species were caught with simple gear "jábegas" nets (which could fish close to the bottom) and a variety of specific nets for sharks and meagre (*Argyrosomus regius*), as well as pots and hooks aimed at deep-sea fish. The largest volume of demersal fish for exports was composed of hake, cured conger and pickled sparids (*Pagellus* spp.).

Throughout the eighteenth century, bottom trawling was highly controversial in Malaga, until its definitive ban in 1783. In 1702, the first discussion between the fishermen of the city and the foreigners who used primitive bottom trawls (with individual boats, precursor of the trawling pairs or "bous") took place. Initially, the population of Malaga welcomed this new capture technique because it reduced the price of fish for local people and convents (Reder 1991). In the eastern sector of the Alboran Sea, the foreign vessels were mainly incorporated to the towns of Almeria, Roquetas, Dalias, Adra, Albuñol, Almuñecar, Nerja and Velez-Malaga (Fernández and Martínez-Shaw 1984). Among them were the Catalan vessels "laudes," who worked in Almeria, Nerja and Malaga, and after having sold their catch on the nearby beaches, they returned to their places of origin with loads of fish skins (shark hides) or dried fish (Reder 1991). The first three pairs of modern sailboat trawlers from Malaga were conceded in October 1766: two for the supply of the city and the other for the military garrison. These vessels had 10–12 men each and could operate 9 miles away from the coast but needed strong winds to sail. For that reason, the most appropriate seasons to operate were autumn and the beginning of winter. Although they used to catch all types of living animals from the seabed, the most frequent or abundant species were large and small hake, red mullet (*Mullus barbatus*), flat fishes and sparids. Their catches were so abundant that it was calculated that in 6 h, they obtained the same amount of fish as the other techniques (nets, hook gears and pots) which took 48 h to obtain (Fernández and Martínez-Shaw 1984). There is also information about the temporary use of bottom trawl nets on the beaches of Mijas and Fuengirola at least during 1777–1778 (Reder 1991), with high daily catches of hake obtained during winter time in this virgin seabed (60–180 kg per vessel).

At the beginning of the nineteenth century, the king granted the noble Count of Lalaing two pairs of bottom trawlers for Malaga (1801) again, although they did not operate frequently. The number of these trawlers increased to seven pairs in 1814 and continued to rise. Years later, fishermen's associations related to the owners of the "jábega" fishery, protesting against the use of the two granted vessels because their fish was 25% cheaper. They would commit themselves to compensate the heirs of the countess so that these vessels could not fish anymore (Fernández 1866). During the last decades, in certain seasons, part of the Valencian fleet fished in Malaga (Estepona-Sabinillas sector). Other fishing vessels from the Levantine area migrated to the waters near Melilla. In the latter and in the Strait of Gibraltar, a new fishing modality with well-boats (ships with integrated seawater tanks to transport live fish) began (Viruela 1995). In 1895, two steam trawlers, which fished individually, started operating in Malaga.

23.5 Technical Fishery Management: Legislation, Conservation and Statistics

In 1482, the ordinance of the rope makers of Seville (García Cornejo 2001) established the regulations on the mesh size for every piece of the marine fishing nets with their respective lengths. A dozen different types of net gears were mentioned corresponding to two basic categories: the complete “jábegas,” their 6 different sections and the four specific types of nettings to catch sharks and meagre. Those legal regulations were applied later in the Alboran Sea, from the times of the first municipality of the Castilian Malaga during 1489–1495. A valuable fishing regulation, with several provisions for the protection of marine resources, was introduced (García Cornejo 2001). Strict rules regulated the capture, handling and sale of fish, both fresh and salted. A specific place on the coast was arranged for the unloading of the fish coming from all the municipal places, and supply preference was given to residents. As most of the catches from the beach seine trawl (“jábegas”) in the Bay of Malaga were mainly destined to neighbours (for direct consumption or for artisanal processing), only the remaining ones could be exported, fresh or cured. The fish was exported to inland cities as far away as Cordoba and Jaen (about 170–200 km away). The illegal and fraudulent activities of non-resident fishermen and merchants were prosecuted by the municipal authorities. They were obliged to pay the corresponding taxes for foreign trade of fresh or salty fish from the city, by sea or by land (López Beltrán 2001).

According to an ordinance of 1489, the elaboration of anchovies and sardines in Malaga was reserved exclusively for the neighbours, both Spaniards and registered foreigners, the Genoese being the most interested. The salting factories had a large number of workers. Due to hygienic problems and bad odours, the processing of all kinds of fish inside the city was banned, both drying fish outdoors and salting factories. Years later, before the sale to wholesalers, a municipal inspector verified the quality of the preserved fish in the barrels before closing and sealing them (López Beltrán 2001). In addition to this, different measures for the conservation of fishery resources were added. A time-space closure was set to prohibit the use of “jábegas” in determined coastal sectors between April and September with the objective of protecting the immature fish fry of commercially important species. The mesh size of the codends was regulated (the mesh opening cannot be less than the width of the index finger, which was measured by inspectors using a ring) (López Beltrán 2001).

At the southeast end of the Alboran Sea, for several decades after the incorporation of the African city of Bugia to the Crown of Castile, its ordinances from 1536 to 1540 were in force (López Beltrán 1984). They contained information on the local market regulation: rules on fresh fish related to fixed prices for different species and the obligation to sell it publicly in a reserved place. The legislation distinguished among the most valued fish, the species that were caught with the “jábega” and other minor fish that could also be eaten dried (rays and sharks). In the next decade, in the Castilian municipal ordinances of Gibraltar (1555), the great importance that fishing had for the population was clear, both for direct feeding and for exchanging it with another basic foodstuff (Sarriá 1990).

New guidelines were included in the Malaga ordinances of 1611 (Martín Acosta 2010). The diversity of fish species that were unloaded on the beaches of Malaga and Granada was sold both fresh and salty, in both capitals at regulated prices. The municipal control was extended on the beaches with inspectors who measured the lengths of the nets and the size of the meshes of various nets and pots. In order for the post-larval fish and juveniles to escape, a mesh opening of the size of the second finger of a hand was established (verifiable with a mayor's ring). Most species of fish (78%) were selected to specifically supply the city.

In the last decades of the seventeenth century in Spain, there was a decline in fisheries. Its consequences had not been overcome yet in the mid-eighteenth century, when the Spanish fishing fleet and its auxiliary industries continued to decrease, leading to the importation of salted cod from foreign countries. The Bourbon monarchy considered "the advance of fisheries as an inexhaustible treasure of wealth, providing a continuous occupation for the people and a school of sailors" a priority to stimulate better socioeconomic conditions (García and Fernández 1993). A slow process of reconversion of the fishing sector took place by ameliorating the fishing techniques and their abilities, establishing a renewed salting industry and optimizing the fish catch distribution network along the coasts and inland. The price of salt was specifically decreased for the fishing sector, and in different local coastal populations, the Economic Societies of Friends of the Country fostered the establishment of local fisheries (García and Fernández 1993). Within the national fishing grounds regulations, in 1751, there were orders regarding the conservation of different fish species (by prohibiting fishing during spawning seasons and setting mesh size regulations), and in 1753, for the Ensenada Cadastre, the fleet and sailors' inventory for the ports of the province of Malaga was carried out (Villas 1995).

The local fisheries were encouraged by the elimination of municipal taxes on fishery products. Commissioners of the Naval Ministry started to inspect the local fisheries and, consequently, proposed better measures for their regulation. The most prominent and expert of them was A. Sáñez-Reguart and wrote the "Report on the restoration of fishing along the Andalusian coasts." For 15 years, from 1780 to 1795, that naval inspector classified the Spanish fauna captured by the fisheries and published a descriptive five-volume inventory of the varied fishing techniques and skills used in the country (Sáñez-Reguart 1791–1795). The significant inspection in Malaga during 1786 led to the publication of the "Regulatory ordinance for Mediterranean fishing" and of the "Regulation and Order for the Registration of Seamen" (a register of shipowners, skippers, fishermen and sailors) which was published in the city (Burgos 1994a).

Concern about the impact of Catalan bottom trawling on benthic and demersal fauna on the coast of Malaga was constant during this century. Therefore, a conservationist controversy arose against the trawling couples, with important men and local fishermen who reported their harmful effects (Fernández and Martínez-Shaw 1984).

From ancient times, the fishermen of Malaga have been associated to defend their rights before the local authorities (Villas 1984; Burgos 1994a). On many occasions, the “jábega” fishermen in the capital managed to get a limited number of Catalan trawling pairs and the prohibition of pots, arguing that they made their beach seine trawl difficult (Burgos 1996a). The claims of the fishermen with the support of Malaga city council led to the final ban in 1783 for the three local pair trawlers because it was considered that they destroyed the habitats of the adult fish and their juveniles. In 1789, the fishermen kept the privilege of selling from their boats and on the beaches, but if they decided to introduce their catch into the city of Malaga, they would be subject to the police rules, and prices would also be imposed by the city council (Burgos 1994a).

The conflicting situations of the bottom fisheries of Malaga resumed in 1814, when the parliament granted the use of 7 trawl pairs with a reduced period of temporary fishing closure (July and August). In autumn, 4 “parejas” were fishing along the coast of Malaga. The local fishermen provided written documentation on the negative consequences, such as a generalized scarcity of the local catches for the remaining coastal vessels and the need to go fishing beyond 18 miles. The shortage of fish provoked the ruin of some small boat owners and the alarming decrease of the “jábega” catches (85% less) and the longliners and “espineles” (40% less on average). The city council established an inspecting commission to check practical experiences and the effects of bottom trawls on the spot. The commission’s vessel approached the pair trawlers, examined the catches of each haul and wrote an extensive report about it (Fernández 1866).

In the middle of the century, the Naval Ministry recognized the need to restore and promote the national fishing industry. Thanks to the impulse of research in 1847, reports from different ports in the province of Malaga are currently available (Burgos 1994b, 1996b). They include data on the species caught and an inventory of fishermen and vessels during the period between 1842 and 1846.

Great advances were made between 1860 and 1870 in relation to fishing regulations and the protection of living resources (Pérez-Rubín 2006). In Madrid, the Permanent Commission of Fisheries was created by the navy to assess the fishery sector, which was represented by delegations from each part of the national coasts. Time-space closures were established, and the number of vessels destined to fishing was limited. The expansion of the national fisheries was supported by the establishment of fishing agreements between 1860 and 1866 with Morocco, Portugal and Gibraltar. Three basic regulations on priority species were published in 1866: ostreiculture (oyster farming), tuna traps and bottom trawling (beyond 12 miles off the coastline). For the trawlers, in the Strait of Gibraltar and the Alboran Sea, an absolute seasonal closure of 3.5 months (from June to September) was enacted aiming to facilitate the reproduction of the species.

The “Freedom of Fishing Regulations” (1885) prohibited a total of 11 types of destructive fishing gear. Unfortunately, the definitive authorization of the “new bou industry” in 1890 caused the fall of traditional fisheries, provoking much civil unrest (Lacomba 2006). Until then, in twelve coastal towns extending from Marbella to Nerja, 7000 families subsisted on the exploitation of classical fishing gear ("jábegas," "sardinales" and longliners), with 900 small vessel types suffering from an unbalanced competition against the 16 "bou" pairs working intensively (Anonymous 1894). New petitions to ban the "bou" fishing gear on behalf of shipowners and artisanal fishermen achieved the prohibition of fishing less than 6 miles from the coast. In 1895, the spatial limits of each province were delimited on the basis of the greater or lesser extent of the continental shelf. An average depth of 90 metres together with a distance of 5–6 miles from the coast was calculated for the North Alboran Sea. In the year 1895, the first two steam trawlers were registered in Malaga to dedicate them individually to trawl farther than 10 miles offshore. This situation led to the fact that shipowners of sail pairs also joined the protests. In 1898, after a provisional closure of the waters off Malaga (June to August), a new regulation for bottom trawling of all types of vessels was approved (Burgos 1997).

23.5.1 Nineteenth-Century Fisheries Statistics

During the nineteenth century, the navy elaborated the official fishing statistics. Nevertheless, they could have been considered unreliable for many years, with large gaps, and generally, catches were not classified by species. Table 23.1 summarizes the statistical catch information available for our area.

The most important conclusions are summarized. In general for fish catches as a whole and sardine catches in particular, an alternation is confirmed for the maximum values for Galicia, Huelva, Malaga and Atlantic Morocco. In some specific years, fishing catches in Andalusia were much higher than those in Galicia (1883) or similar (1889, 1892) (Viruela 1995).

In the Alboran Sea, the greatest fishing effort and the maximum annual catches were concentrated in the province of Malaga, increasing progressively. The global

Table 23.1 Statistical catch information available in relation to the Alboran Sea and/or Andalusia (1829/1892)

Years	Areas	Authors
1831, 1861	Malaga vs Gulf of Cadiz	Fernández (1866)
1829, 1831–1835, 1845–1847	Alboran Sea vs Gulf of Cadiz	Burgos and Lacomba (1993)
1842–1846	Marbella, Velez-Malaga, Nerja	Burgos (1994b, 1996b)
1831, 1858, 1860, 1861, 1883, 1889, 1892	Andalusia vs Galician	Viruela (1995)
1883	Alboran Sea vs Gulf of Cadiz	Lacomba (2006)
1881 (sardine)	Alboran Sea vs Gulf of Cadiz	Lacomba (2006)
1888	Alboran Sea vs Gulf of Cadiz	García Solá (1888)

catches in this province between 1831 and 1861 multiplied by 12, with 7056 tons and 3415 sailors, compromising 43% of all Andalusia (the Alboran Sea as well as the Gulf of Cadiz). This was caused by the maintenance of the prohibition of the "bou" trawl fishing, and only minor artisanal fishing gear was allowed, thus employing a larger number of vessels and their associated labour workforce (Fernández 1866). The highest percentage was reached in 1883: in the Alboran Sea, 50% of the catches (total species and sardine) and numbers of boats and fishermen were concentrated in the province of Malaga. It was followed by the former maritime provinces of Algeciras and Almeria, which accounted for 21% and 17%, respectively (Lacomba 2006). During 1888, the province of Malaga increased its dominance in the regional fisheries again, which represented 56% of the ships (945 vessels) and gross register tonnage (GTR) and 70% of the manpower (8963 fishermen) (García Solá 1888).

23.6 Summary and Concluding Remarks

From the earliest of times, the study area has been a meeting place for very different civilizations and marine fauna, in both cases coming from distant European, African, Atlantic and Mediterranean coasts. This human confluence, with the exchange of cultures, using their own fishing techniques, has been constant and enriching throughout the centuries. The local marine resources have always been essential for food and economic development of the inhabitants in the area. However, in the cyclical periods of regional fishing crisis, the European-African fishing grounds of the near Atlantic area have been the salvation of the fishing economy. Conversely, in the periods of sardine crisis in the Spanish Atlantic waters, fishermen migrated to different ports in the Algeciras-Malaga sector. This pattern has been repeated throughout centuries with fishermen and their industries moving great distances in order to overcome the fisheries crisis.

In the northern area of the Alboran Sea, African piracy was controlled in the mid-eighteenth century. Since then, fishermen have faced other serious, local and regional fishing crises. Independently, but cyclically, pelagic and seabed fishing was affected. Pelagic fishing was characterized by boom and fall, with the temporary absence of target species. Seabed fishing alternated between the years of prohibition of the trawlers and those of authorization, with serial depletion of the fishing grounds. In both fisheries, the causes of collapse were different (oceanographic variability/overfishing) but had the same negative effect. In the independent cyclical periods of fishing shortages, the majority of both fleets had to migrate to other coasts with more abundant resources. Logically, this process was reflected in the economy: impoverishment on the coasts of origin and enrichment in the new areas of exploitation and processing of the catches.

On the other hand, the advanced technical information collected in relation to the ancient strategies to manage fisheries for sustainability since the fifteenth century is impressive. Those societies were highly dependent on local resources and needed to avoid resource collapse. Initially, the fishing legislation was dictated by municipal authorities. The pioneering laws (ordinances) of the city of Malaga between the years 1489 and 1611 included fishing regulations focussed on protecting the immature fish, regulating on the lengths of the nets, the size of the meshes and the establishment of spatio-temporal closures. These ancient documents cite between 24 and 33 fish species of great commercial interest. Unfortunately, nowadays, the reliable identification of real species with regard to the older common names appears to be a difficult or impossible task to do, also complicated by the high specific richness of the Alboran Sea.

During the eighteenth century, fishing legislation was the responsibility of the navy. Since early times, the fishermen from Malaga were registered in guilds to defend their rights and until the end of the nineteenth century actively fought against the use of seabed trawls. The fishermen's arguments can be described as ecologists, since their detractors tried to prohibit the use of those nets as they were considered destructive for small or immature fish and for the soft seabed ecosystems. By avoiding this local industrial fishing, the greatest fishing effort in Andalusia (in number of boats and fishermen) was centralized in the province of Malaga, owing to the fact that artisanal fishing gear needed more boats and seamen.

Since the mid-nineteenth century, regulations have been improved with the participation of the local fishermen themselves. In the Local Fishing Commission in Malaga, fishermen representing each category of fishing met the commander of the navy and a naturalist advisor periodically. At the end of the century, that naturalist became the natural history professor at a secondary school in the city. He argued and defended the necessary protection of the coastal seabed characterized by the presence of laminarian and coralline algae. Such assumptions are valid in the twenty-first century, because it has been confirmed that both floor types constitute valuable habitats that are necessary to preserve the biodiversity in benthic communities. Likewise, much of the "modern" international fishing management is based on those "ancient" conservationist ideas implemented since the end of the fifteenth century on the coast of Malaga.

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Chapter 24
Sustainable Development and Blue Growth in the Alboran Sea: Enabling Ocean Health and Ecosystem Services Through Ocean Science and Equitable Governance

Luis Valdés, Juan Antonio Camiñas, Juan Luis Suárez-de Vivero, and José Carlos Báez

24.1 Introduction

The Mediterranean Sea is an important route for merchants and travelers since ancient times, allowing for trade and cultural exchange; for instance, it is estimated that the Mediterranean accounts for 15% of the yearly global shipping activity (REMPEC 2008), which makes the Mediterranean a remarkable region for its contribution to global economy and trade. In this context, most of that maritime traffic crosses the Alboran Sea: in 2010, the Spanish Authority on Maritime Rescue reported 112.943 vessels. Considered a large marine ecosystem, its coasts support a high density of inhabitants, and it is one of the top tourist destinations in the world.

With an overall lack of exclusive economic zones (EEZs) and consequently with fish stocks that are often shared among fleets from different countries, the fishery sector and associated commerce have always played an important role in the region. In fact, the annual production of roughly 1.22 million tons offers employment

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opportunities to several hundred thousand people, supplies seafood products for human consumption to local and regional markets, and creates many other indirect benefits, maintaining the social foundation of coastal communities. In addition, fisheries are also an intrinsic part of the cultural landscape, as highlighted by old Roman mosaics and paintings, and the livelihoods of the Mediterranean and Black Sea countries (FAO 2018).

In this framework, the Alboran Sea is a peculiar region connecting the Atlantic Ocean and the Mediterranean Sea, and it represents a natural boundary between Europe and Africa. The Alboran Sea shelters a great variety of natural and human resources and activities including fishing, wildlife, research, transport, and tourism that historically have been exploited by different countries, mainly Spain (from North) and Morocco and Algeria (from South). The Alboran Sea represents a regional Mediterranean space where North and South worlds merge, creating a geopolitical region where marine resources and maritime activities should be managed from both national and international perspectives and also offering and creating opportunities for scientific cooperation.

This chapter presents a step-by-step discussion on the scientific and political changes experienced in the paradigm of the marine ecosystem management in the Alboran Sea (but also valid for other regions). The chapter starts with an analysis of the scientific logic explaining the evolution from a single-species management to an ecosystem-based management. It follows with a discussion on the need of a new socioecological narrative, which have ultimately crystallized in a series of regional policies (leaded by both the United Nations and the European Union) aimed to consolidate the sustainable and responsible use of our resources and ecosystems as an international and common obligation with ourselves and with the future generations. The chapter concludes with a set of recommendations and leverage points aimed to strengthen the scientific cooperation, to enable an equitable management, and to promote fair and effective governance for good environmental stewardship of the Alboran Sea.

24.1.1 Parts and Wholes: The Evolution of Ecosystem Management Paradigm

Within the ecological systems theory, one of the most challenging problems is the management of natural resources. The thinking evolution from a management approach based on single species to an ecosystem-based management (EBM) approach denoted a big theoretical improvement. Even with all the practical difficulties of operationalizing and implementing it, the EBM is nowadays the dominant model in the management of natural resources and marine ecosystems worldwide. And so it is in the Alboran Sea.

The EBM was framed by Christensen et al. (1996), but even earlier, Lubchenco (1994) defined some of the context, language, and goals of EBM, and in 1994, she wrote the following: "In fact, this approach represents a paradigm shift from the

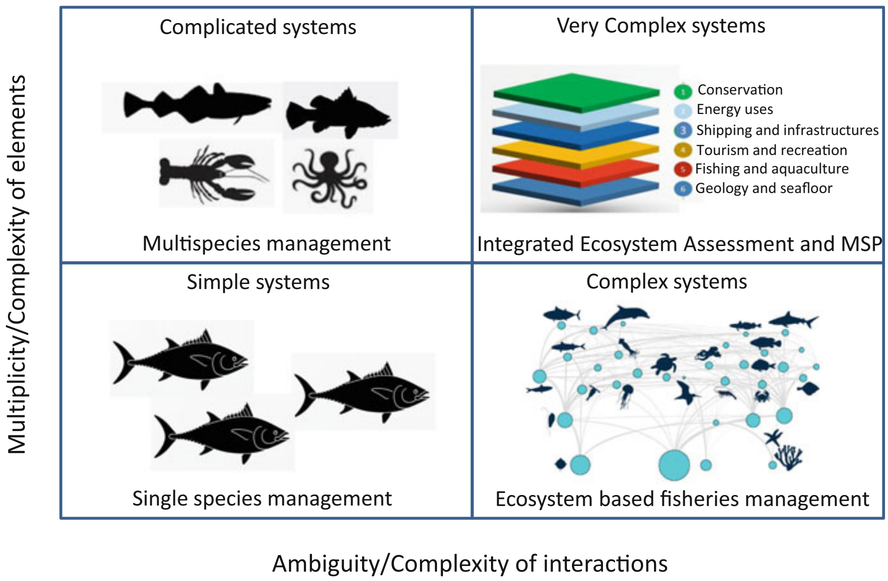

Fig. 24.1 Diagram showing different species and ecosystem management models according to the structural differences between systems complexity of elements and complexity of interactions (the flow diagram model reproduced with permission of Xavier Corrales)

highly focused short-term sector-by-sector resource assessment and management approach in general practice today by natural resource stewardship agencies, to the broader more encompassing ecosystem approach that moves spatially from smaller to larger scales, and from short-term to longer-term management practice."

This change in management practice was not exclusive of fisheries or marine ecosystems. Terrestrial ecosystem-based management (often referred to as ecosystem management) came into its own during the conflicts over endangered species protection and forest and wildlife resources in the United States in the 1990s (Slocombe 1993; Boyce and Haney 1997).

The diagram in Fig. 24.1 is based on a matrix of structural differences between systems complexity of elements and complexity of interactions as formulated by Ulrich and Probst (1988) and shows very visually the transition from the different management stages (from single-species management, to a multispecies management, to the EBM approach). We can distinguish four types of systems dependent on the number of elements and their behavior over time. Understanding these four conceptualizations as different stages along a continuum of resource management models helps to clarify the evolution of different visions of ecosystem management.

The single-species management is the simplest system, and the goal is to obtain the maximum sustainable yield (MSY), which is the largest annual catch that can be taken from a species' stock (lower left panel in Fig. 24.1). Complicated systems are characterized by a large number of elements and in this example correspond to mixed and multiple fish stock, which are harvested together by a common fleet (upper left panel in Fig. 24.1).

But an ecosystem is much more than the mere accumulation of species. It is a network of multiple and complex interactions. That means that it is not only their structure which is complicated, but also their state is constantly changing, and due to the high dynamic, their behavior is not fully predictable. Therefore, the EBM implies the understanding and management of a complexity of interactions (lower right panel in Fig. 24.1), which in this context is defined as the ability of a system to take up a large number of different states over time (Ulrich and Probst 1988). In the diagram, these interactions are represented by the output of an Ecopath with Ecosim (EwE) model in the Eastern Mediterranean Sea (Corrales 2019) (for more information on Ecopath with Ecosim models, see Pauly et al. 2000).

Very complex systems imply the acknowledging of interdependency connections by a large number of elements, including the linkages between marine ecosystems, terrestrial systems and human societies, economies, and institutional systems. These additional elements are represented in the diagram by the marine spatial planning (MSP), which is a process that brings together multiple users of the ocean (e.g., fishing, shipping, energy, conservation, recreation) to make informed and coordinated decisions about how to use marine resources sustainably (upper right panel in Fig. 24.1).

The only appropriate approach, to deal with the cumulative pressures and effects of human uses on marine ecosystems, is for various contributing sectors to set common goals for the protection or management of ecosystems. While some policies may only affect a single sector, others may affect multiple sectors.

Once these concepts were incorporated into the management thinking, projecting this new approach into social science and socioeconomic strategies was only a matter of time, and the “sustainable management” concept to manage ecosystem resources and services was fully assimilated into policy documents, For instance, into the United Nations Sustainable Development Goals (SDG) (UN 2015), into the FAO (2014) Blue Growth Initiative (BGI), and into the European Commission Integrated Marine Policy (EC 2007) and its Blue Growth Strategy (EC 2017).

At a time when humanity is being challenged by many pressures forcing environmental changes at planetary scale, there is no other way than the sustainable management (imbibed into the EBM and MSP) to manage the marine environment in an integral way. The more information we can gather about an ecosystem and all of the interconnected factors which affect it, the more capable we will be of better managing that system. While we are gaining in complexity, we will be rewarded by having healthy oceans and well-being for all of us. At the same time, we will cope with the major achievement of acting with solidarity and equity with both the developing countries and among generations.

In summary, adopting a “sustainability imperative” requires that we do a much better job of managing the natural resources, such as fisheries, while respecting the other sector’s interests and human uses of the ocean; the need for integrative studies has never been more important (Rothschild 2015).

24.1.2 The Emerging Socioecological Narrative

In 1998, Jane Lubchenco published a seminal paper entitled *Entering the Century of the Environment: A New Social Contract for Science*. Among other inspiring thoughts, she wrote: “The false assertion that society must choose between the economy and the environment is often made. In reality, this ‘jobs versus the environment’ choice is a false dichotomy: the real choice is between short-term gain and long-term, sustained prosperity.... A sustainable biosphere is one that is ecologically sound, economically feasible, and socially just.... We can no longer afford to have the environment be accorded marginal status on our agendas. The environment is not a marginal issue, it is the issue of the future, and the future is here now” (Lubchenco 1998).

She concluded that the interfaces between the environment, human health, the economy and social justice are ripe for developing and entraining into the policy arena. In fact, the awareness of humanity about the depletion of natural resources and the compromised sustainability of the lifestyle of western societies have highlighted the relevance of environment science, and the society is demanding more proactive policies to preserve our environment while maintaining sustainable and equitable growth.

Among the intellectual and practical challenges to be achieved at the light of the UN SDG and the 2030 Agenda, we can mention the alleviation of pollution of regional seas and oceans, the rational exploitation of marine resources, the mitigation of global warming and climate alterations, the global cycle of carbon, or the maintenance of biodiversity. Given the complexity and magnitude of these challenges, the demand for marine environmental data from the scientific community and from society is growing, and therefore, oceanography is a science that increasingly attracts the attention of the scientific community and citizens. And, of course, marine science, observation, and data are also fundamental to underpin and deliver scientific advice to the decision-makers and managers, who must do effective the sustainability of the natural and social systems.

In order to achieve a scientifically engaged society, it will be necessary to develop a culture where science is recognized as relevant to everyday life (Pielke 2007). The public must know that science theory is based in facts and associated with objective realities. Also public awareness on the consequences of environmental risks might help to increase pressure on larger organizations to address impacts at larger scales (e.g., to achieve commitments to mitigate risks at the country or international level).

On the other side, marine scientists often find themselves in the position of having relevant information available which they need to share with others outside of the scientific community. Such information should be put into use when designing local and national polices on adaptation and mitigation and when developing strategies to achieve the UN SDGs.

The Alboran Sea marine scientific community must be prepared to use the policy opportunities as a vehicle to reinforce and add value to marine scientific research and to facilitate the transfer of knowledge and technology to third parties (this is a key to ensure cohesion in marine science and development). The active involvement of end users of scientific information, including resource managers, policy-makers, and individual citizens, will enhance the impact and value of our research initiatives and findings. For that, we need to understand, maintain, and extend our relationships to relevant UN agencies, international councils, global programs, and NGOs and participate in alliances and international agreements related, for instance, to ocean governance for a safer, more equitable, cleaner, and prosperous ocean for all.

In summary, to be influential and shape action, we must strengthen the interface between society, policy, and science. Considering that the challenges for society are formidable and will require substantial information, knowledge, wisdom, and energy from the scientific community (Lubchenco 1998), the ability to make marine science understandable to those who make decisions about our future is critical; it should be made clear that the sustainability of tomorrow depends on what we do today.

24.2 International Framework for Sustainability and Maritime Governance in the Alboran Sea

24.2.1 The Balance Between Environmental Research and Decision-Making

Democratic societies have led to a consensus and political commitment toward an environmental sustainability and practices respectful with the environment. The currently happening changes are so vast, so pervasive, and so important that they require our immediate attention (Lubchenco 1998). In consequence, environmental policies have evolved from being much targeted to being more holistic, which implies more knowledge demands, in particular to characterize the added complexities and uncertainties of integrated issues having long-term consequences.

These commitments are embodied in the numerous international conventions which set targets for improving environmental quality supported by specific monitoring programs. Among others, we can mention the Barcelona Convention, International Convention for the Prevention of Pollution from Ships (MARPOL), the IMO regulation and management of ballast water in ocean vessels, the EU Marine Strategy Framework Directive, and many others (major detail in Chap. 2 of this volume).

In addition to the conventions, there are also several international instruments and science-policy interfaces that have been agreed by the member states represented at the United Nations, such as the UN World Ocean Assessment (WOA), the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), and the Intergovernmental Panel on Climate Change (IPCC). These science-policy processes must ensure that updated and accurate science is appropriately reflected in high-level policy discussions (e.g., Conferences of Parties of the

Convention on Biological Diversity (CBD) and United Nations Framework Convention on Climate Change (UNFCCC)).

While setting environmental policies on a global scale as a political goal, the pressure will increase for science to respond more quickly and effectively to the needs of society and participation in the decision-making process and governance. Researchers and scientists should investigate sustainability questions that society defines as important and move beyond a purely technological approach to sustainable development in all dimensions (Schmalzbauer and Visbeck 2016). Underlying the development of policies for sustainable management is the assumption that policy decisions are based on a reasonably certain knowledge base, or the required knowledge can be obtained (Schmalzbauer and Visbeck 2016). However, the interdisciplinary research underpinning the study of sustainable management often lacks this knowledge base, and it can be only achieved if there are investments for more solution-oriented research and for scientific research to improve the knowledge and functioning of the dynamic and changing future.

From all that commented, (i) there is a scientific and social demand to increase our capabilities in oceanographic research in the Alboran Sea, (ii) there is a political consensus on the need to establish environmental sustainability practices, and (iii) there is the technological capacity to improve our data and models, but the paradox is the limitation given mainly by the economic impossibility that a single scientific institution undertakes with charge to its budgets the necessary investments.

Decision-makers must ensure that scientific analysis is articulated in conjunction with other tools such as social impact assessments, and that information is accompanied by a road map, including a timeline with targets and indicators. Because there are other factors affecting environmental decision-making (as the possible irreversible outcomes and the difficulties of balancing short-term gain against long-term uncertain loss), the consequences of the human behavior should be made as clear as possible, e.g., based on scenarios, so that the actors can envision the outcome of their actions. Although necessary, such prioritization is complicated because the priorities may vary for various actors (e.g., business operators, resource managers, NGOs, or governments).

24.2.2 Recent International Developments to Improve Ocean Governance and Sustainability

Seas and ocean international dimension is reflected in its extensive regulatory development. In the Mediterranean Sea (major detail in Chap. 2 of this volume), more than 50 international, general, and regional treaties can be applied, although not all countries are signatories or have ratified them. These treaties cover a wide spectrum of subjects: from fishing to discharges, pollution, biological diversity, or different aspects of navigation and transport. It is essential for management plans that all uses and activities are already regulated. The United Nations Convention on the Law of the Sea (UNCLOS 1982) has special relevance, as it constitutes the legal instrument that defines and regulates the different jurisdictional concepts and the access of states to the sea. Regionally, the Mediterranean Action Plan (1975) and the Barcelona Convention (1976) and its various protocols (among them the Protocol on Biological Diversity and Specially Protected Areas (1995) and the Protocol on Integrated Management of Coastal Zones (2008)) have a special impact on this matter (spatial planning) and in particular with regard to cooperation between coastal states (cross-border dimension of planning plans).

The 2030 Agenda for Sustainable Development, adopted by all United Nations member states in 2015, comprises a collection of 17 global goals set and are envisioned as the blueprint to achieve a better and more sustainable future for all. They address the global challenges we face, including those related to ocean, climate, environmental degradation, clean energy, responsible production and consumption, and international partnerships. The goals are broad and interdependent, yet each has a separate list of targets to achieve. Several nations' governments have begun to incorporate sustainable development in their planning and policy and have found great legitimacy and ownership.

The SDG 14 defined as "Conserve and sustainably use the oceans, seas and marine resources for sustainable development" provides for the first time ever an opportunity to step up action on individual ocean-related issues and expand the profile of the ocean in the development agenda. This standalone SDG for the ocean summarized more than 500 proposals submitted from highly diverse stakeholders, which were framing in a number of targets to preserve and restore life-sustaining functions of the ocean and the role of ocean resources in providing a basis for human and economic development. As the SDGs are intended to pursue transformational change, they include aspirational and intentionally broad elements, and therefore, targets must be viewed not only individually but also in relation to each other SDG (Valdés 2017).

The concept of blue growth came out of Rio+20, and FAO uses this term to emphasize the need for growth particularly in the fisheries and aquaculture sectors. The goals of the BGI are to maximize economic and social benefits while minimizing environmental degradation from these sectors (FAO 2014). These goals are closely aligned with the 2030 Agenda for Sustainable Development. While there are no national obligations and approaches remain flexible for different national and regional realities, the BGI is aligned with other FAO regulations such as the Code of Conduct for Responsible Fisheries to stop illegal, unreported, and unregulated (IUU) fishing (FAO 2001).

The planning of the maritime space and the management and monitoring of the environmental status of the marine environment are reaching further development in the European Union framework and within its integrated maritime policy (IMP) (published by the European Commission in 2007) where maritime spatial planning together with blue growth, marine data and knowledge, integrated maritime surveillance, and watershed strategies constitutes the five main policies that IMP encompasses and coordinates.

The Marine Strategy Framework Directive (Directive 2008/56/EC of June 17, 2008) of the European Parliament and of the Council establishes a framework for community action for marine environment policy, with the main aim of achieving or maintaining a good environmental status of the marine environment no later than 2020. Its transposition into Spanish regulations has been carried out through Law 41/2010 of December 29 on the protection of the marine environment.

The development of maritime space planning plans is regulated by Directive 2014/89/EU, whose transposition into Spanish regulations has been made by RD 363/2017 of April 8.

24.3 The UN Sustainable Development Goals as an Opportunity for Marine Science and Better Ecosystem Management in the Alboran Sea

24.3.1 The Contribution of Science in Implementing the UN SDGs

Achieving the Sustainable Development Goals approved by the UN General Assembly in 2015 (also named Agenda 2030) requires a transformational thinking by the states and the society.

There will be no single straight path toward global sustainability and prosperity. This is where science comes in and takes a holistic approach to identifying and understanding trade-offs between different targets, as well as detecting synergies that can mobilize and boost action. This will require a goal- and solution-oriented scientific approach, and scientists can play an important role by delivering broad and deep understanding of the needs and challenges facing a particular society. Inter- and transdisciplinary science cooperation will be a consequence rather than the founding principle of such an approach (Nilsson et al. 2016; Schmalzbauer and Visbeck 2016).

While SDGs provide a coordinating and synthesizing framework for public (and private) sector decision-making, science can play a pivotal role, for example, (i) in representing sustainability challenges in different contexts (data, analysis, and scenario building), creating models that explore how different targets interact, and tracking progress toward goals (Beisheim et al. 2015; Dasgupta et al. 2015); (ii) in providing the understanding for individuals and institutions to make informed policy and management decisions; (iii) in putting the basis for new technologies (Lubchenco 1998); and (iv) also in advancing methodological approaches to nexus challenges and nexus methods in order to improve policy coherence (Schmalzbauer and Visbeck 2016).

In this regard, new science, innovation, and technology will be required to generate an integrated assessment system (e.g., achieving fisheries management objectives requires fishing activities and other human activities that affect the marine ecosystem, e.g., tourism to be regulated). Both the social and natural sciences will need to contribute to identifying critical interactions between policies aimed at achieving specific SDGs and how possible negative interactions can be mitigated through synergy solutions and possible multipurpose actions.

In addition, it is necessary to make the most of the opportunities that seas and oceans offer to support the development of a blue economy, coordinating the efforts at national level, by defining common priority areas to promote blue growth in order to focus the efforts to tackle cross-sectoral and crosscutting issues, bringing together countries and researchers from different disciplines across boundaries to provide knowledge and conduct the research with the aim of boosting the sustainable growth of the maritime economy (European Commission 2017).

That said, inter- and transdisciplinary science is not the only approach required. Capacity building and institutions and institutional capacities need to be developed to produce integrated assessments. This is necessary in order to bridge the gap between the normative aspirations of the SDGs and the practical needs of those who are implementing the SDGs. Capacity development is a critical challenge for sustainable management in the Alboran Sea.

The proper implementation of an ecosystem-based management (EBM) approach is needed at regional level to ensure the conservation status of the ecosystem and its components. Improving our understanding of how countries can design and implement long-term pathways toward sustainable development is critical. It is necessary to remove barriers in cooperation and governance for it. A clear example of these could be the establishment of marine protected areas beyond the national boundaries for protecting marine diversity in the Alboran Sea. A network of such areas may act as a stepping stone for highly mobile species and ensure connectivity over long distances. Reducing the fishing pressure helps some depleted stocks and ecosystems to recover. On the other hand, the establishment of fisheries-restricted areas may also have some side effects, such as increasing the fishing pressure in the neighboring fishing grounds and destroying ecosystems in good condition. Making the best use of such practices requires therefore sound scientific evaluation, planning, and governance at international level.

New technologies are rapidly changing the classical approach for monitoring fisheries and implementing marine spatial planning. Vessel monitoring systems (VMS), electronic reporting, satellite data, and operational real-time and forecast products of ocean physical and biogeochemical models provide a huge amount of data that can be used and combined to propose new tools for promoting the economic and environmental sustainability of fisheries and help to achieve some of the SDG 14 targets. While geographic information systems (GIS) are becoming a classical mean of developing marine spatial planning, spatially explicit modeling of habitats, marine species distributions and ecosystems, and new methods to explore massive data (e.g., machine learning and, more generally, artificial intelligence) have tremendous potential for new applications and to support the sustainable exploitation of marine resources and the conservation of healthy marine ecosystems.

24.3.2 International Cooperation in Science: A Must to Achieve the SDG 14

The universal nature of science and research and the speed of change and its expansion, favored by the development of new innovative technologies, offer the opportunity to work in cooperation with other countries in large projects or participate in large research infrastructures.

Science is a main pillar for sustainable development and also an instrument for peace (UNESCO 2015). The science dimension of diplomacy has fundamental significance at a time when science has tremendous power to shape the future of humanity and when it is no longer appropriate to design science policy in purely national terms, especially when addressing issues affecting the entire planet such as the sustainable management of the global ocean commons (Valdés and Crago 2017).

Ocean science seeks to understand complex, multi-scale socioecological systems and services, which requires observations and multidisciplinary and collaborative research. Rapid advances in science can best be achieved with an integrated, cross-sectoral, and international engaging scientific agenda that connects upstream fundamental research with solution-oriented research (Schmalzbauer and Visbeck 2016).

Science can make valuable contributions to better understand and identify relevant options for SDG implementation. This requires fragmented knowledge communities to come together in order to provide a synthesis of the current state of scientific knowledge in the context of global sustainability (Schmalzbauer and Visbeck 2016). An international stewardship may help to prioritize SDGs from a local and regional perspective in the areas where they are going to be implemented. As an example of international umbrella in the Mediterranean Sea, the Food and Agriculture Organization of the United Nations (FAO) and its General Fisheries Commission for the Mediterranean (GFCM) have joined forces with a number of partners to further strengthen the role of science in the SDG agenda.

When considering the motivations and benefits of international collaboration in ocean science, the policy and administrative dimensions are important. Ocean science institutions and marine laboratories play a vital role in support of ocean research. There are several institutions and initiatives dealing with ocean issues in the Alboran Sea, at local, national, and regional levels. These existing organizations (such as FAO Mediterranean projects, GFCM, Regional Activity Centre for Specially Protected Areas, United Nations Environment Programme/Mediterranean Action Plan, the Mediterranean Science Commission (CIESM), the IUCN Centre for Mediterranean Cooperation) involved in ocean science and management face challenges in relation to coordination to develop their agendas. Some of these institutions specialize in particular fields and are critical in addressing a variety of scientific questions in collaboration with universities and research institutions such as studies of coastal food webs, ecosystem biodiversity, and human impacts on coastal environments and ecosystems. They also play an important role in training young scientists from the less developed countries on new methodologies and on the formation of researchers and technologists with a range of skills, experience, and knowledge and thereby allow any individual access to skills and knowledge across disciplines. In addition, higher education is becoming increasingly important for ocean science institutions in the Alboran Sea.

There is a tremendous opportunity and need for the scientific community in the Alboran Sea to engage in and develop forward-looking research that has the potential to support new interconnected development pathways, particularly in highly interlinked areas of the SDGs. Strengthen this international collaboration, and governance will result in reducing the level of fragmentation by increasing the coordination and the definition of common agendas, creating critical mass, maximizing efficiency of investments and existing capacities, and creating synergies in marine and maritime research, technology, and innovation fields (Valdés et al. 2017).

The goal is to increase the efficiency and effectiveness of the national investments in research, technology, innovation, related infrastructures, and development of human capacities. To achieve this goal, it’s necessary to improve the transnational cooperation and coordination of actions not only at the Mediterranean but also at pan-European level. This goal should face the societal challenge of having healthy and productive seas and oceans and to contribute to the European and FAO Blue Growth Initiative as well as to the UN SDG.

In line with the need to strengthen the collaboration in the region of Alboran, a recent initiative, the Foro Mar de Alboran (Rueda et al. 2019), was launched as a collaborative process, recognizing the environmental problems and challenges faced by fishermen, administrations, scientists, and society in general to the rational use of the resources of the Alboran Sea. The Foro promotes avoiding fishing discards, bringing together scientists, fishermen, professors of universities, nutritionists, and restaurateurs of recognized prestige from the region to exchange knowledge and seek joint solutions based on science for the future of the Alboran Sea and its people.

24.4 The FAO Blue Growth Initiative for Fisheries and Aquaculture in the Mediterranean

Different regional and international organizations including FAO have reiterated that marine pollution; overexploitation of many fishing target species; illegal, unreported, and unregulated (IUU) fishing; and climate change have become major threats to aquatic species and ecosystems, in addition to other threats such as coastal occupation and degradation, habitats loss, eutrophication, increasing maritime traffic, and invasive alien species (Coll et al. 2010). Consequently, these and other threats (e.g., marine litter and microplastics) affecting the Mediterranean system have negative consequences to the coastal populations.

FAO launched in 2013 the Blue Growth Initiative (BGI), which encompasses capture fisheries, aquaculture, ecosystem services, trade, and social protection. Based on the principles enshrined in the 1995 FAO Code of Conduct for

Responsible Fisheries (CCRF), the BGI is a framework which focuses on "promoting the sustainable use and conservation of aquatic renewable resources in an economically, socially and environmentally responsible manner with the aim of reconciling and balancing priorities between growth and conservation and between industrial and artisanal fisheries and aquaculture, and of ensuring equitable benefits for communities" (FAO 2014).

The BGI is based on previous concepts promoted and adopted within the FAO agenda and then by the international organizations, regional fisheries organization (RFO), and the international community. The BGI became a series of instruments derivate from previous concepts, contemplated and defined as a body of agreements sustained by the law of the sea, aiming to better the sustainable use of the marine system and their resources based on an approach that includes the social, ecological, and economic components.

The BGI of FAO includes both aquaculture and fisheries as main components. In relation to the antecedents of the BGI in relation to fisheries, a revision of how the Ecosystem Approach to Fisheries Management (EAFM) and the Blue Initiative were established in the framework of the FAO General Fisheries Commission for the Mediterranean and Black Sea (GFCM) follows. The 150th session of the FAO Council approved the amended GFCM Agreement, a new framework that not only includes in its preamble a reference to blue growth but also contains a set of modern provisions that underpin the role of fisheries and aquaculture in the Mediterranean and the Black Sea, fully consistent with applicable FAO policies, according the FAO Fisheries DG (FAO 2017).

24.4.1 EBM for Mediterranean Fisheries: From Theory to Practice

As discussed in "Introduction," the management of the fishery resources was first based on single stocks management, or target resources-oriented management (TROM) (the traditional fisheries management) was extended in countries and RFO where fishing activities target mainly one or several species. During the past 50–60 years at least, the dominant fisheries management paradigm has been to maintain the target resource population base through various controls on the species landing size and the fishing activity. This system was based on data series of capture (C) of the target stock, and it associated fishing mortality (F) and the assessment of single stocks using models without environmental considerations. The models simplify the reality but were able to produce a real management of the fishing activity through the control of the effort, establishing total allowable catches (TACs) and quotas, closed season and closed areas as main management tools to improve the stocks status and the economic revenues.

Conceptually, EBM is based on previous TROM. To apply this approach, the ecosystem in which managers must apply decisions should be previously limited and defined, including a set of ecosystem indicators. The models used are complex and data demanding. The main problem is that there are few data series to evaluate the ecosystem variations, although recently in regions as Europe environmental and ecosystems data series are available in some countries and fisheries. EBM includes integrated management of multispecies fisheries and other ocean uses, within a geographic context incorporating a set of ecosystem and conservation objectives that is presently the case for most fisheries management plans.

Initiatives such as the 2001 Reykjavik Conference on Responsible Fisheries in the Ecosystem increased the establishment of new information technology and systems which offer integrated ecosystem assessment. RFO builds on their strengths and successes and begins work on a mutually beneficial framework for cooperation. In the case of the fisheries sector, the objectives would ensure the sustainability of ecosystem features as well as the target species. It is the human activities that are being managed, not the ecosystem.

EBM is relatively a new concept also to the GFCM region. Scientists participating at the meeting of the Subcommittee on the Environment of the Scientific Advisory Committee (SAC) of the GFCM, celebrated in 2002, pointed out that the need to discuss this concept with other international organizations was recommended to create a transversal working group or to organize, jointly with RAC/SPA and Convention on Biological Diversity (CBD) secretariat, a workshop to discuss methodological aspects and scientific initiatives for its introduction in the Mediterranean. Subsequently, Commission (FAO 2002) emphasis was on enhancing the capacity to formulate management advice in conformance with an Ecosystem Approach to Fisheries. In order to implement such mandate, the SAC adopted the organization of an "ad hoc" meeting to analyze the feasibility of the ecosystem-based management approach to fisheries in Mediterranean waters, particularly to examine the existing and applicable ecosystem-based methodologies, to assess and monitor Mediterranean fisheries (mainly those which are shared by two or more countries), and to discuss possible ecosystem-based management tools.

In 2003, FAO advanced in the definition of an Ecosystem Approach to Fisheries (EAF) a step ahead to incorporate definitively the ecosystem in fisheries management. But, what is an Ecosystem Approach to Fisheries Management? FAO explained this concept as follows: "The purpose of an EAF is to plan, develop and manage fisheries in a manner that addresses the multiplicity of societal needs and desires, without jeopardizing the options for future generations to benefit from a full range of goods and services provided by marine ecosystems" (FAO 2003a). This definition and the report of the Reykjavik meeting in 2002 (FAO 2003a) aimed to draft guidelines for an EAF (FAO 2003b) including main principles and concepts.

The interest in the implementation of an EAF has been motivated by heightened awareness of the importance of interactions among fishery resources and with the ecosystems and the advances in science, which highlight knowledge and uncertainties about the functional value of the ecosystems to humans (i.e., the goods and services provided by the ecosystems).

24.4.2 GFCM Midterm Strategy (2017–2020) and BGI

Following the introduction of the GFCM midterm strategy for the Mediterranean and the Black Sea fisheries (GFCM 2016), the region has strong ties with the cultural, social, and economic aspects of fisheries that provide important sources of food and livelihood for riparian countries and sustain the traditions and the way of life of many coastal communities. The recent GFCM report "The state of Mediterranean and Black Sea Fisheries (SoMFi)" (FAO 2018) stated that "About 75 percent of the Mediterranean and Black Sea stocks assessed are currently fished at biological sustainable levels, although the percentage has slightly decreased since 2014 (88%)" and with decreasing catches and shrinking fleets at the regional scale (compared with the average over the 2000–2023 period reported in SoMFi 2016). The report highlighted main fleet segments, areas, and species of interest and stressed on the need to improve the existing information, especially for vulnerable species, in order to have a comprehensive assessment on which to base future management measures. To solve the situation, the GFCM adopted Resolution GFCM/40/2016/2 for a midterm strategy (2017–2020) toward the sustainability of Mediterranean and Black Sea fisheries.

The existing challenges in the Mediterranean and the Black Sea fisheries require the development of tailor-made actions against the backdrop of international commitments toward the sustainability of fisheries as a means to support the livelihood of coastal communities within a blue growth perspective. The midterm strategy is framed around the following five targets:

1. Reverse the declining trend of fish stocks through strengthened scientific advice in support of management.
2. Support livelihoods for coastal communities through sustainable small-scale fisheries.
3. Curb illegal, unreported, and unregulated (IUU) fishing, through a regional plan of action.
4. Minimize and mitigate unwanted interactions between fisheries and marine ecosystems and environment.
5. Enhance capacity building and cooperation.

Concerning the target four of the strategy, GFCM stated that healthy and productive marine ecosystems are an important means to support maximum sustainable yield and to facilitate BGI. It is recognized in this target four that fisheries, as well as other anthropogenic-driven phenomena, such as climate change or the introduction of nonindigenous species, can have potentially negative effects on the marine environment and marine ecosystems.

Target five includes the urgency that contracting and cooperative parties, relevant intergovernmental and nongovernmental organizations and concerned stakeholders, enhance cooperation to promote sustainable development and BG in the Mediterranean and the Black Sea.

The development of all this initiatives related to the BG will offer to the GFCM a prominent position at regional scale to improve the fisheries and aquaculture management under the new paradigm of the BG although it will take some time/years to have a better perspective on the effects and results that this regional initiative will have on fishery resources, aquaculture, the ecosystem, and the several stakeholders' interest in the Mediterranean and the Black Sea issues.

24.4.3 The BGI and the Aquaculture in the Mediterranean Sea

An important conference on "Blue Growth in the Mediterranean and the Black Sea: developing sustainable aquaculture for food security" (FAO 2017) was celebrated in 2014 in Bari (Italy). This was an initiative of the GFCM, the Italian government, and the IUCN Mediterranean, organized in light of emerging economic, social, and environmental issues and taking stock of the progress made in aquaculture research and innovation. One of the objectives of the conference was "build consensus on a regional strategy for achieving BG through aquaculture." The conference acknowledged the key role to be played by this sector in achieving food security, employment, and economic development in the region, under a BG perspective, considering that aquaculture is an activity that plays an important role for coastal communities.

The application of the FAO Code of Conduct to the aquaculture represents a key factor in achieving a sustainable aquaculture sector in the Mediterranean and the Black Sea under the framework of the GFCM. Considering the significant achievements obtained by the aquaculture committee from its inception meeting, the outcomes of the conference were over the expectations of the organizers. Different experts underlined the importance of implementing BG in relation to aquaculture in the Mediterranean and Black Sea region as it is already endorsed by the European Union Maritime Policy (Chapela 2017). Within the conclusions of the conference, it was underlined that "aquaculture constitutes therefore a strategic sector for future development, in particular from the perspective of blue growth."

24.5 EU Main Policy Instruments for Marine Environmental Management

24.5.1 Relevance and Scope of the Marine Strategy Framework Directive (MSFD)

In the framework of the thematic strategy for the marine environment of the Sixth Environmental Action Programme of the European Community, on July 15, 2008, Directive 2008/56/EC came into force establishing a framework for community action in the field of marine environmental policy or Marine Strategy Framework Directive (called "MSFD" or "Directive" hereinafter) (Bellas 2014). The main objectives of this Directive into others are to protect and preserve the marine environment. The MSFD in Spain is under the umbrella of Law 41/2010 for the protection of the marine environment (LPME). The LPME, in addition, includes the regulation of spatial planning (Bellas 2014). This maritime spatial planning is delimited, with the aim of facilitating the implementation of marine strategies, five subdivisions denominated "demarcations."

The Atlantic region includes three demarcations: the North Atlantic (NOR, Spanish north coast), the South Atlantic (SUD, Spanish coast of the Gulf of Cádiz), and the Canary Islands (CAN, the Canary Islands). The Mediterranean region comprises two demarcations: the Levantine-Balearic (LEBA, east coast of Spain and Balearic Islands) and the Strait of Gibraltar and Alboran Sea (ESAL). The demarcations were delimited according it biogeography and oceanographic and hydrological characteristics.

Therefore, the Alboran Sea is within the ESAL demarcation of the MSFD. Within the regional coordination, in a first step, regional expert work groups were established for the generation of a report that includes the baseline and environment status from each descriptor previously detailed (MITECO 2020).

In general, ESAL shows a good environment status in function of its biodiversity, marine fisheries resources, and habitats. However, multiple sources of impact and threats have been identified among which are listed: extraction of solids (i.e., exploitation of underwater deposits and port dredges), extractions of sands for the creation and regeneration of beaches, discharges of dredged material, regeneration of beaches and creation of artificial beaches, offshore wind farms, alteration of hydrodynamic conditions and modification of sedimentation, retention of river flow in reservoirs and other regulatory infrastructures, extraction of fishing species of commercial interest through trawling, boat anchoring, human pressures for the use of recreational coastal water and seawater (diving, noise, tourism, etc.), marine litter and other wastes, desalination plants, accidental and/or uncontrolled discharges, introduction of microbial pathogens, invasive species, ballast water discharge, and aquaculture.

Next step is the performance of the monitoring program, which they will be addressed to implement seawater strategies for the development of the continuous assessment of the state of the marine environment and will be used to estimate the resistance between the environment state of the demarcation, based on the elements listed in the Annex III of the MSFD. This second cycle is currently in progress.

24.5.2 The Challenge of Maritime Spatial Planning (MSP) in the Alboran Sea

The Alboran Sea maritime management, as in the rest of the Mediterranean Sea, does not yet have approved plans, including the northern shore where the European Directive that regulates them (Directive 2014/89/EU) already has several years. However, the regulation with spatial impact of different uses and maritime activities already has a long tradition, with perhaps fishing being the most illustrative example.

Nevertheless, due to the particular characteristic of the Alboran basin, that is, the concentration of maritime traffic within the Alboran Sea and the presence of two large ports such as Algeciras and Tangier Med, in a geo-economic context where the most important development gap is between North and South, an MSP is necessary. Around 80% of the basin are waters and seabed under national jurisdiction and, consequently, theoretically subject to the control of the coastal states. Each of these three countries, Spain, Morocco, and Algeria, can develop their own maritime space planning plans over which they exercise sovereignty and jurisdictional rights, being the state with the greatest territorial responsibility.

The Directive 2014/89/EU is the European standard that legally supports the administrative practice that has set in motion the development of the so-called maritime spatial planning plans and that in Spain has been incorporated by RD 363/2017 of April 8. This norm is only one component of a broad system—which we call here the “institutional framework”—made up of a series of legal, political elements and principles that conclude or substantiate as mandatory rules, guidelines, or recommendations.

The preparation and application of maritime spatial planning plans must take into account other mandatory rules approved by the European Parliament, in particular the directives on habitats (1992), waters (2000), evaluation of plans and programs (2001), spatial information infrastructures (2007), marine strategies (2008), and renewable energies (2009). Of particular relevance is Directive 2008/56/EC (marine strategies) as it is the basis on which, especially in Spain, maritime spatial planning plans are being developed (RD 363/2017), interpreted as an extension and prolongation of said strategies (Law 41/2010 on the protection of the marine environment).

In addition, there is an initiative that aims to support the development of MSP plans. The European Union and IOC-UNESCO have launched the so-called MSP global initiative, which includes a project in the western Mediterranean with the aim of training experts in Algeria, Spain, France, Malta, Morocco, and Tunisia.

MSP global also aims to develop methodological guides on transboundary marine spatial planning. It is precisely the cross-border dimension of the plans that is one of the strategic decisions of marine planning in the EU context, so the level of regional cooperation is a key factor in areas such as the Alboran Sea. In this sense, Spain, Morocco, and Algeria have created a platform (Exploring the Potential of Maritime Spatial Planning in the Mediterranean Sea) to deal more specifically with issues related to conservation, sustainable development, and relations between users and participants in the maritime sector, an initiative that although meritorious still lacks the strength to advance consistently and effectively in the development of this type of plan.

24.6 Policy Implications and Leverage Points

In spite of the richness of the data presented in the previous chapters of this volume, there are still many gaps in our understanding of the ecosystem functioning in the Alboran Sea in order to produce and deliver the most efficient advice based in robust scientific knowledge. In addition, as discussed in this chapter, the Alboran Sea is facing management and governance challenges that need special attention to ensure the sustainability of the many human activities and the delivery of services provided by this ecosystem and to effectively contribute to the success of the UN SDG (Agenda 2030), the FAO BGI, the EU MSFD, and MSP directives and other international policies.

In this context, more research is needed to understand the ecosystem functioning and its resilience to environmental and human disturbances. Obtaining data with a better spatial and temporal resolution is a crucial and necessary step to take the pulse of the Mediterranean Sea and the whole Alboran Sea and then keep it under permanent review to permit the taking of management options and to revert unwanted human-induced disturbances and other undesirable environmental situations. In addition, more basic and interdisciplinary science must be boosted to increase the knowledge base needed for the most efficient and coherent advice for sustainable development.

Moreover, it is necessary to reinforce the existing national and regional collaborative systems and international frameworks to share common management policies of the marine environment. In country, bilateral North-South and South-South collaboration among universities and research institutions needs to be reinforced. As proposed during the first meeting of Alboran universities organized under the framework of the 1st Alboran Sea Forum, the common work between universities and researchers should result in reinforcing the existing collaboration between professors and research groups within the universities of the Sea of Alboran; analyze the relevance of their work (teaching, research, advice) to be useful and relevant in relation to the priorities and purposes of the international organizations competent in marine environment, fisheries, and conservation; and promote the participation of the academic sector in the conservation of the environment and marine biodiversity of the Alboran Sea.

Establish new platforms for free and open data sharing with transparent metadata accessible to all stakeholders when and where necessary, which could be also used as the basis for creating ecosystem and performance/trends joint indicators. In this context, establish pan-regional universities-science-policy interfaces (e.g., the Foro Mar de Alboran) that could help to perform a better multidisciplinary knowledge to ensure that the best scientific knowledge is available and conveyed in due time to all decision-makers in the different states as well as to the stakeholders and the society in general.

Only with a good and proper management at ecosystem scale (e.g., ecosystem-based management, marine spatial planning) the Alboran Sea can be preserved in good health for now and for the future and have an equitable and sustainable future for all. The existing experiences of international cooperation in the subregion are time fixed or focus on partial aspects of the marine system, as the FAO-CopeMed project (http://www.faocopemed.org/) aiming to improve the cooperation, capacity building, and data sharing to evaluate shares stocks, but not other important aspects of the environment. In this regard, there is a need for an international framework of cooperation for the Alboran Sea; this can be extended to scientific research, governance, and capacity building.

The immediate target related to management and governance is to ensure that 10% of this territory is effectively protected, as indicated by the Convention on Biological Diversity and the EU Strategy of Biodiversity. Thus, there is a need to build upon a network of MPAs and marine reserves and its corresponding data collection systems to ensure that ecologically important areas are protected and that these pristine portions of the Alboran Sea regions serve as reservoirs for marine biodiversity, heritage, and culture.

Regarding the aims of management actions, this should include regional strategies for (i) implementation of marine spatial planning approaches for management, (ii) development of sustainable fisheries management plans, (iii) actions to revert the effect of climate change in the region, (iv) action to reduce the risks of entrance of new alien species, and (v) action to preserve the marine biodiversity.

As in other oceans and seas worldwide, the governance of the Alboran Sea is fragmented (fishing, shipping, offshore gas, offshore renewable energy, etc.) as if we were managing separate entities. This inequality in governance and the cost of inaction jeopardize the sustainability of ecosystem services in the Alboran Sea, and therefore, creating an integrated ocean governance framework in the Alboran Sea is a must.

There is a special urgency in applying the international regulations and measures to combat illegal, unreported, and unregulated fishing as promoted by GFCM and ICCAT and also to stop the use of flags of convenience by fishing vessels. The success of international legal instruments (e.g., international conventions), which contain commitments to reduce the human impact on the ocean and marine ecosystems (e.g., ballast water, oil spills, protected species), depends heavily on the decision of governments and states bordering the Alboran Sea, including the implementation and continuous use of national systems of control and surveillance; in this regard, there is a lack of commitment of the states in the Alboran Sea to regulate and implement such corpus of environmental legislation together.

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Chapter 25
Marine Protected Areas and Key Biodiversity Areas of the Alboran Sea and Adjacent Areas

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25.1 Introduction and Historical Background of Marine and Coastal Conservation in the Alboran Sea

Biodiversity conservation probably represents one of the biggest challenges for humans in the twenty-first century, especially considering the continuing human impacts on most of the ecosystems at different scales (Rands et al. 2010). Effective conservation of biodiversity is essential for human survival and for maintenance of ecosystem processes and services. Despite some conservation successes (especially at local scales) and increases of the public and government interest in living sustainably, habitats and species are still declining at an unprecedented rate (Ichii et al. 2019). Moreover, this rate is expected to rise in the future due to human population growth, depletion and inefficient management of natural resources and unsustainable practices affecting the ecosystems, among other causes (Ichii et al. 2019). Marine species and habitats are experiencing a similar decline if compared to terrestrial ones; however, knowledge for the marine environment is more limited, and marine conservation has always lagged behind terrestrial conservation in most coastal countries (Maxwell et al. 2015). At the end of the twentieth century, the concept of protecting certain marine areas was widely accepted, and since then, this idea has been consolidated with hundreds of Marine Protected Areas (MPAs) established around the world. As their numbers have grown rapidly, so have their diversity and complexity; MPAs vary dramatically in concept, size, design, purpose, focus, name and effectiveness (Norse 1993). This same process recognized in other seas and countries has followed a similar trend in the Alboran Sea. In this way, MPAs have been defined by International Union for Conservation of Nature (IUCN) as “any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment” (Kelleher 1999). MPAs represent a traditional way for preserving species, habitats

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and ecological-geological-oceanographical processes and currently are an important central axis of marine conservation efforts (Kelleher 1999; Kuempel et al. 2019). The benefits of establishing well-designed and enforced fully protected MPAs are well-documented (Giakoumi et al. 2018). Scientific evidence indicates that MPAs can produce ecological, economic and social benefits under appropriate design and management conditions (Ban et al. 2012, 2017).

According to the IUCN (2016), Key Biodiversity Areas (KBAs) are sites that contribute significantly to the global persistence of biodiversity. The identification of a site as a KBA simply implies that the site should be managed in ways that ensure the persistence of the biodiversity elements for which it was considered important. Nevertheless, some KBAs may sometimes not have in itself any character of protection. In this sense, several KBAs can also overlap wholly or partly with existing MPAs, including sites designated under international, national and local levels. Thereby, it is expected that some MPAs overlap with KBAs; however, this is not always the case, because MPAs are sometimes established locally by different criteria and opportunities. IUCN (2016) established global standard criteria for the identification of KBAs worldwide. The main criteria are based on the presence of threatened species/habitats for which site-scale conservation is appropriate, including the importance of such site in the biology, ecology and preservation of these species and habitats (Butchart et al. 2012; IUCN 2016). Other criteria are that the KBA can host a significant number of endemic/rare species and/or has a highly pristine status. Therefore, MPAs and KBAs designation are useful steps for conservation of global biodiversity, for identification of key sites for elements of biodiversity and for provision of resources to decision-makers that are essential for guiding decisions on the conservation and sustainable management of a particular region.

25.1.1 International Agreements for Marine and Coastal Conservation of the Alboran Sea

MPAs and KBAs have been identified as potentially multifunctional areas which could provide ecosystem and socio-economic services useful for conservation management in the Alboran Sea (Robles 2010; IUCN 2012a). These MPAs and KBAs (without IMMAS) cover ca. 7% of the world's ocean (UNEP-WCMC and IUCN 2017), whereas in the Alboran Sea, these areas represent ca. 10%. The political scenario of the Alboran Sea region is characterized by a clear division between the north and south sectors, and national interests predominate both north and south in terms of the maritime map, with a resulting mosaic of jurisdictions that facilitates neither bilateral nor multilateral agreements (Talamo and Riera 2019). The north-south asymmetry of the Alboran Sea can also be seen in the existence of two distinct and greatly differing socio-economic and cultural models. The north has high or very high human development indicators, whereas the south has average human development indicators.

International agreements have been helpful in the designation of some of the MPAs and KBAs of the Alboran Sea. Some of the most widely known KBAs focussing on vertebrates are the Important Bird and Biodiversity Areas (IBAs) adopted by Birdlife International and the Birds Directive (2009/147/EC) (only in countries of the European Union) and Important Marine Mammal Areas (IMMAs) adopted by IUCN (2016). The biosphere reserves (e.g. Cabo de Gata-Níjar, Intercontinental of the Mediterranean) recognized by the UNESCO Man and the Biosphere Programme are areas made up of terrestrial, marine and coastal ecosystems. The objectives of this UNESCO programme are to promote solutions to reconcile the conservation of biodiversity with its sustainable use, economic development, research and education. Global Geoparks, also recognized by the UNESCO (e.g. Cabo de Gata-Níjar), are single, unified geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development. Their bottom-up approach of combining conservation with sustainable development while involving local communities is becoming increasingly popular. The Ramsar Convention aims for the conservation and wise use of all wetlands through local and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world. In the Alboran Sea, this convention has recognized three Ramsar sites in Spain (Cabo de Gata-Níjar, Punta Entinas-Sabinar, Albufera de Adra) and another three in Morocco (Cape Trois Fourches, Sebkha Bou Areg, mouth of river Moulouya). Another figure is the Specially Protected Areas of Mediterranean Importance (SPAMI) that are areas declared under the Protocol concerning Specially Protected Areas and Biological Diversity in the Mediterranean (SPA/BD 1995) under the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (also known as Barcelona Convention 1995). These SPAMIs guarantee the survival of the biological values and resources of the Mediterranean Sea, since they contain typical ecosystems of the Mediterranean area or habitats of endangered species, which have a special scientific, aesthetic or cultural interest. It is also important to highlight the ecologically or biologically significant marine areas (EBSAs) recognized by the Convention on Biological Diversity (CBD). In 2009, the ninth meeting of the CBD COP9 adopted different scientific criteria for identifying ecologically or biologically significant marine areas in need of protection in open-ocean waters and deep-sea habitats (Malcolm et al. 2014). The Regional Workshop of the Mediterranean region agreed on the description of 17 areas meeting EBSA criteria, among them the Strait of Gibraltar, Alboran Sea and connected Spanish, Moroccan, and Algerian areas. In 2014, despite the positive results of this workshop, the COP12 of CBD governments has not reached an agreement in the same direction; therefore, to date, it appears that the creation of an EBSA area in the Alboran Sea is not feasible. Talamo and Riera (2019) aimed to renew and underline the importance and value added in creating an EBSA to support more and better cooperation in the policies of conservation and sustainable development of the Mediterranean Sea. A recent concept is the Peace Park which is defined as "transboundary protected areas that are formally dedicated to the protection and maintenance of biological diversity and of natural and associated cultural resources, and to the promotion of peace and cooperation" (Sandwith et al. 2001). In 2010, during the Commission Internationale pour l'Exploration Scientifique de la mer Méditerranée (CIESM) workshop in Siracusa (Italy), eight

Peace Parks were proposed for the Mediterranean Sea, the Near Atlantic Marine Peace Park (Ibero-Moroccan Gulf, Straits of Gibraltar and the Alboran Sea) being the first one of them (Aguilar et al. 2010). An integrated governance framework as set out in process may offer appropriate horizontal tools to help policymakers and economic and environmental actors to join up their policies, interlink their activities and optimize the use of marine and coastal space in an environmentally sustainable manner.

Another international tool for preservation of marine life has been through the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Its aim is to ensure that international trade of specimens of wild animals and plants does not threat their survival. Roughly 5800 species of animals and 30,000 species of plants are protected by CITES against over-exploitation through international trade, and some of them are present in the Alboran Sea (e.g. black corals). These species are listed in the three CITES Appendices according to how threatened they are regarding international trade.

25.1.2 Marine and Coastal Conservation in the Spanish Sector of the Alboran Sea

The Spanish legislative framework regulating the figure of MPA, focused on maintaining the sustainability of the marine environment and biological diversity, is referred to the Law on Natural Heritage and Biodiversity (Law 42/2007 of December 13) that identifies the MPA concept for the first time and contemplates the creation of a network of MPAs. This law thus incorporated into the Spanish legal system the possibility of creating MPAs and also established different protection figures: Natural and National Parks (Parques Naturales, Parques Nacionales), Natural Reserves (Reservas Naturales), MPAs, Natural Monuments (Monumentos Naturales) and Protected Landscapes (Paisajes Protegidos) (Fig. 25.1) (Mateo-Ramírez et al. 2020a), depending on the assets and values to be protected as well as the management objectives to be met. Later on, the Marine Environment Protection Act (March 12, 2010; BOCG 121/000059) addressed new aspects of marine environment protection and management, with three key elements: (1) marine strategies as a planning instrument, (2) the creation of a network of MPAs and (3) the incorporation of environmental criteria in the uses of the marine environment. Previously, the Law 1/2002, of April 4, regulated the management, promotion and control of marine fishing, shell fishing and marine aquaculture (BOE 106/2002 of May 3, 2002, p. 16189; BOJA 45/2002 of April 4, 2002). Legislation at the autonomous level of Andalusia has also created different regulations for the protection of marine natural areas and their resources. In 1989 (Law 2/1989 of July 18, BOJA 60 of July 27), the inventory of the Protected Natural Areas of Andalusia was approved. Currently, more than 30 years later, the Network of Protected Natural Areas of Andalusia (Red de Espacios Naturales Protegidos de Andalucía, RENPA)

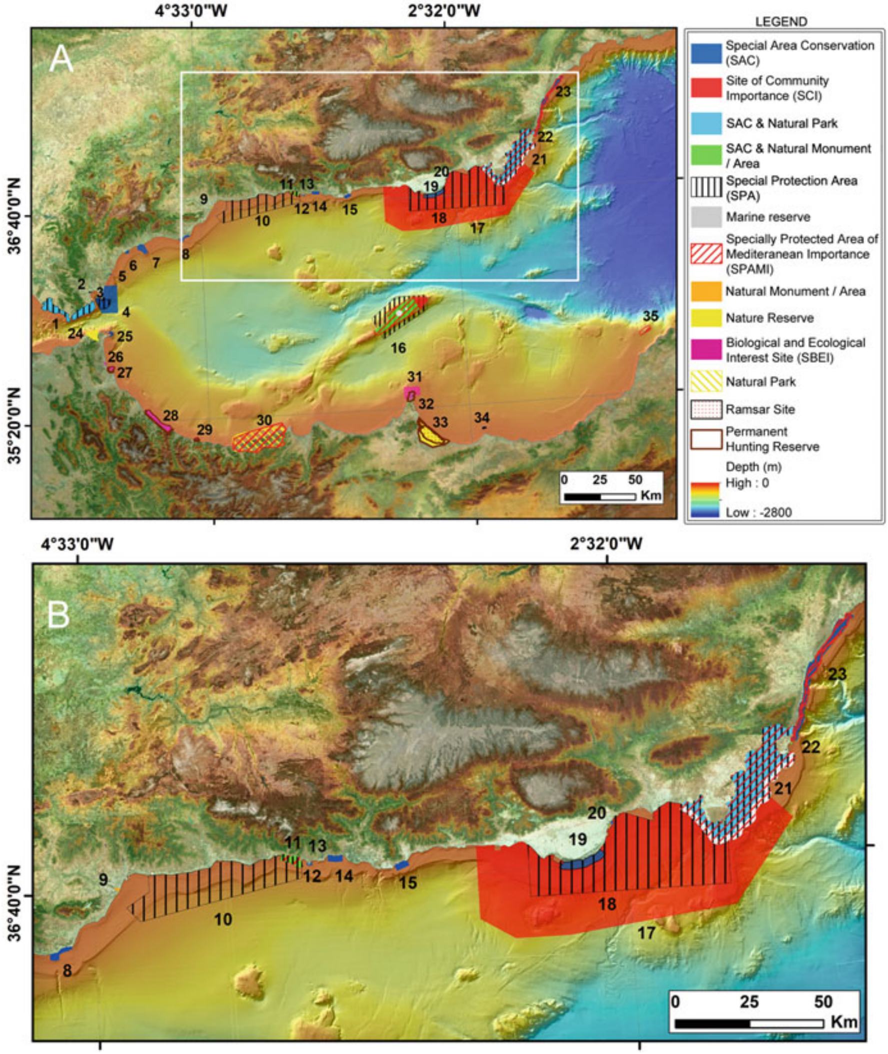

Fig. 25.1 (**a**) Marine Protected Areas and Key Biodiversity Areas established in the Alboran Sea and adjacent areas, with a close-up of the northern sector of the Alboran Sea (**b**). (1) Parque Natural del Estrecho; (2) Paraje Natural de Marismas del Río Palmones SAC—Fondos Marinos Marismas del Río Palmones SAC; (3) Southern Waters of Gibraltar SAC; (4) Estrecho Oriental SAC; (5) Estuario del río Guadiaro SAC and Fondos Marinos Estuario del Río Guadiaro SAC; (6) Fondos Marinos de la Bahía de Estepona SAC; (7) El Saladillo-Punta de Baños SAC; (8) Calahonda SAC; (9) Paraje Natural Desembocadura del río Guadalhorce; (10) Bahía de Málaga-Cerro Gordo SPA; (11) Maro-Cerro Gordo Cliffs SPAMI and collateral figures of protection; (12) Acantilados y fondos marinos de la Punta de La Mona SAC; (13) Peñones de San Cristobal Natural Monument; (14) Acantilados y Fondos Marinos Tesorillo-Salobreña SAC; (15) Acantilados y fondos marinos de Calahonda-Castell de Ferro SAC; (16) Alboran Island SPAMI and collateral figures of protection; (17) Sur de Almería-Seco de los Olivos SCI; (18) Bahía de Almería SPA; (19) Fondos Marinos de Punta Entinas-Sabinar SAC; (20) Arrecife barrera de *Posidonia* Natural Monument and Arrecifes de Roquetas de Mar SAC; (21) Natural Park of Cabo de Gata-Níjar SPAMI and Parque

is composed of 249 protected areas, with ca. 20 of them being marine. This network includes, among others, the following national and regional protection figures (only those with marine spaces are mentioned): Natural Park (Parque Natural), Natural Area (Paraje Natural) and Natural Monument (Monumento Natural) (Fig. 25.1). In the context of the Alboran Sea, it should be noted that the Cabo de Gata-Níjar Natural Park (maritime-terrestrial), declared in 1988, is considered the first MPA sensu stricto (in this case mixed), declared in the Spanish State (Ortiz García 2002).

Spain is an EU member and, therefore, has to fulfil with community policies regarding the environment. Considering that other protection figures have been developed at European level, under the framework of the Natura 2000 network, such as Site of Community Importance (SCI) (previous step without management plan) and Special Areas of Conservation (SAC) (once a SCI has approved a management plan) (Council Directive 92/43/EEC of May 1992—Habitats Directive) and Special Protection Areas for Birds (SPA) (Council Directive 79/409/EEC of April 1979—Birds Directive—actually Directive 2009/147/EEC). It is interesting to clarify that, currently, some MPAs of the Andalusian coast included in the Natura 2000 network are managed by the Spanish government and others by the Andalusian government (Fig. 25.1). The Habitat Directive (HD) on the conservation of natural habitats and of wild fauna and flora aims to promote the maintenance of biodiversity, taking account of economic, social, cultural and regional requirements. It forms the cornerstone of Europe's nature conservation policy, together with the Birds Directive (BD), and establishes the wide EU Natura 2000 ecological network of protected areas, safeguarded against potentially damaging developments. Over 1000 animal and plant species, as well as 200 habitat types, listed in the HB annexes are protected in various ways. The BD is one of the oldest piece of EU legislation for environmental conservation and one of its cornerstones. Amended in 2009, it became the Directive 2009/147/EC, and it places great emphasis on the protection of habitats for endangered and migratory birds. It establishes a network of SPAs including all the most suitable territories for these species. Since 1994, all SPAs are included in the Natura 2000 ecological network, set up under the HD. The ca. 500 wild bird species naturally occurring in the European Union are protected in various ways under the annexes of the BD.

Another tool for the conservation of wild flora and fauna in Spain is provided by the National Catalogue of Threatened Species (Catálogo Nacional de Especies

Fig. 25.1 (continued) Natural del Cabo de Gata-Níjar; (22) Isla de San Andrés Natural Monument and SAC; (23) Fondos Marinos del Levante Almeriense and Terreros and Negra Islands Natural Monument; (24) Jbel Moussa Nature Reserve, Site d'Intérêt Biologique et Écologique (SIBE) and Réserve de Chasse Permanente (RCP); (25) Zona marítimo-terrestre del Monte Hacho SAC; (26) Lagune de Smir SIBE and collateral figures of protection; (27) Koudiet Taifour SIBE and RCP; (28) Cote Rhomara SIBE and RCP; (29) Cirqued'El-Jebha SIBE and RCP; (30) Al Hoceima National Park SPAMI and collateral figures; (31) Cap des trois Fourches SIBE and collateral protection figures; (32) Zona marítimo terrestre de los acantilados de Aguadú SAC; (33) Sebkha Bou Areg SIBE and collateral figures of protection; (34) Islas Chafarinas National Refuge of Hunting and SAC; (35) Les îles Habibas SPAMI and collateral figures

Amenazadas), regulated by the Royal Decree 439/1990, under the List of Wild Species under Special Protection Regime (Listado de Especies Silvestres en Régimen de Protección Especial, LESRPE). Both the Catalogue and the List have been later on updated in 2011, 2012, 2015, 2016, 2019 and 2020. In that list, the species are categorized according to their degree of threat for their persistence and in accordance to some specific measures for the recovery of their populations. Likewise, and following a similar approach, the Andalusian Catalogue of Endangered Species (Catálogo Andaluz de Especies Amenazadas) has been elaborated under the framework of the Andalusian List of Wild Species under Special Protection Regime (Listado Andaluz de Especies Silvestres en Régimen de Protección Especial, LAESRPE) (Decree 104/1994 of May 10). Both the List and Catalogue were also updated in 2003 and 2012.

25.1.3 Marine and Coastal Conservation in the Moroccan Sector of the Alboran Sea

In Morocco, several institutions are involved in the conservation and management of its marine biodiversity, including various coordination, management, monitoring and control institutions. The Moroccan Fourth National Report on Biodiversity (2009) contains the Moroccan strategy for the conservation and sustainable use of its biodiversity. Morocco has made great strides in creating an institutional and legislative framework for the conservation and management of biodiversity. One of the first steps was done with the legal regulation on maritime fishing of November 23, 1973, and its revisions, which aimed to guarantee the sustainable management of fishery resources. In this law, it is important to highlight the laws on maritime fisheries code and on the preservation of marine ecosystems and of the coastline. The Law 11/2003 represented another step towards conservation, focussing on the enhancement of the environment in which “Specially Protected Areas” are defined as those “terrestrial or marine spaces with a particular natural and cultural value within which measures must be taken for the protection and environmental management.” A new law on protected areas was adopted in July 2010, and it defines the roles and responsibilities of the different administrations and the possibility of delegating the management of these spaces. Regarding the law, the figures of protected spaces are grouped into the categories of National Park (Parc National), Natural Park (Parc Naturel), Biological Reserve (Réserve Biologique), Natural Reserve (Réserve Naturelle) and Natural Site (Site Naturel) (Fig. 25.1) (Mateo-Ramírez et al. 2020a).

Regarding conservation sites, Morocco has developed an initiative to identify sensitive areas in relation to their ecological functions, such as feeding and/or breeding sites for the main demersal species, and their richness in biodiversity, including fauna and flora species that are sometimes unique at the regional level. These areas, under the responsibility of the Water and Forest Administration, are declared as Sites of Biological and Ecological Interest (Site d’intérêt Biologique et

Écologique, SIBE, Fig. 25.1) of Priority 1, 2 or 3, according to the following definition: Priority 1 SIBE, areas that must be declared under some protection status (such as the Nature Reserve) for a period of 5 years; Priority 2 SIBE, areas that must receive a protection status for 10 years; and Priority 3 SIBE, areas where any human activity is excluded and must enjoy a protection status for a period of 10 years.

25.1.4 Marine and Coastal Conservation in the Algerian Sector of the Alboran Sea

In Algeria, the legislation on marine and coastal areas has adopted during the last decades regional and international legal instruments to which the country is signatory (Boubekri and Djebar 2016). The development of protected areas through the National Framework of Land Management (Schéma National d'Aménagement du Territoire) constitutes the cornerstone of in situ conservation of biological diversity in Algeria. As part of its environmental strategy, an important effort is being carried out aimed at the knowledge and protection of coastal marine areas of relevance to biodiversity, as well as complementary actions for the development of a management plan in a series of preselected areas (e.g. the Habibas Islands). According to this strategy, measures related to the protection and conservation of the coastal heritage will be applied in the future. Changes in national legislation to adapt the country to the international legal background include a law on land use (2001), relative to the organization and sustainable development of the territory, together with Coastal Law 02-02 (2002), followed by enactment of coastal area management programmes in 2003 and creation of the National Commission for the Littoral (Commissariat National du Littoral) in 2004 to coordinate the management of marine nature reserves in Algeria. According to Boubekri and Djebar (2016), the interest in the establishment of MPAs in Algeria started in the 1980s. At that time, there was a lack of legislative structures for their designation, and only one location (Banc des Kabyles) was declared a Marine Reserve as part of Taza National Park. Later on 2002, Law 02-02 on the protection and valorization of the coast encouraged the creation of a second MPA, which was subsequently established at the Habibas Islands in 2003 under Decree No. 03.147. The purpose of that law is the elaboration and application of a specific national policy for the management and protection of the coast. The Law 11-02 of February 2011 defined the functions and responsibilities of the different administrations and the possibility of delegating the management of protected areas. According to this law, the following categories were established: National Park (Parc National), Natural Park (Parc Naturel), Integral Nature Reserve (Réserve Naturelle Intégrale) and Nature Reserve (Réserve Naturelle), among others (Fig. 25.1) (Mateo-Ramírez et al. 2020a). For this, the law institutes a National Commission of Protected Areas that will be in charge of evaluating the proposal and categorization of each proposed area. The management of each proclaimed area falls also on the institution that prepares the proposal.

25.2 Important Marine Mammal Areas and Other Cetacean Critical Areas Within the Alboran Sea

The IUCN expert group for marine mammals has identified a set of KBAs known as Important Marine Mammal Areas (IMMAs), which are defined as "discrete portions of habitat, important to marine mammal species, that have the potential to be delineated and managed for conservation" (Corrigan et al. 2014; Hoyt 2015). Currently, the IMMAs have no status, and their proposal as protected areas has to be made by the coastal countries that have the authority to implement it. Some IMMAs described in different basins (IMMA group 2020) overlap, and the Alboran Sea represents an example regarding this, since the entire basin and its adjacent areas (e.g. Strait of Gibraltar) host four different IMMAs (Fig. 25.2) known as Alboran Corridor IMMA, Alboran Deep IMMA, Alboran Sea IMMA and Strait of Gibraltar and Gulf of Cádiz IMMA. Thus, within the Alboran Sea, IMMA areas cover a large proportion of the Alboran Sea, overlapping. Table 25.1 shows the area covered by each IMMA and the main marine mammals for which each IMMA has been delineated. For more details on the biology of those cetaceans, and of the main threats within the Alboran Sea, please consult Báez et al. (see Chap. 21 of this book).

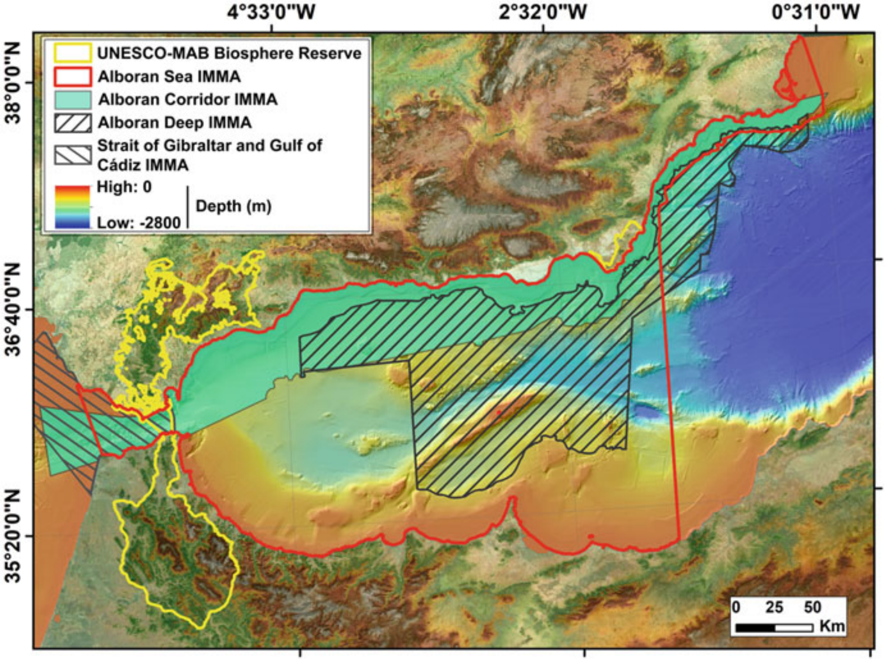

Fig. 25.2 Location of the four Important Marine Mammal Areas from the Alboran Sea and adjacent areas: Alboran Corridor IMMA, Alboran Deep IMMA, Alboran Sea IMMA and Strait of Gibraltar and Gulf of Cádiz IMMA (Source: IUCN MMPATF Important Marine Mammal Area)

Table 25.1 Surface area (km^2) and main marine mammals of each IMMA declared in the Alboran Sea

IMMA name	Surface area (km^2)	Main species present (Marine Mammal Habitat 2020)
Alboran Corridor IMMA	20,208	Sperm whale (*Physeter macrocephalus*), fin whale (*Balaenoptera physalus*)
Alboran Deep IMMA	22,638	Long-finned pilot hale (*Globicephala melas*), sperm whale, Risso's dolphin (*Grampus griseus*), Cuvier's beaked whale (*Ziphius cavirostris*)
Alboran Sea IMMA	55,906	Common dolphin (*Delphinus delphis*), bottle-nosed dolphin (*Tursiops truncatus*)
Strait of Gibraltar and Gulf of Cádiz IMMA	4538	Orca (*Orcinus orca*), striped dolphin (*Stenella coeruleoalba*), long-finned pilot hale, common dolphin, Risso's dolphin, sperm whale, fin whale

A recent study based on opportunistic sightings assessed the suitability of IMMAs for cetacean conservation in the Western Mediterranean Sea. In this same study, Báez et al. (2019) demonstrated the higher abundance of cetaceans in IMMAs of the Alboran Sea compared to those in other Mediterranean IMMAs.

25.3 Important Bird and Biodiversity Areas

The Important Bird and Biodiversity Areas (IBAs) are sites of international importance for bird conservation on land and sea, which have worldwide recognition as practical conservation and management tools (Donald et al. 2018). The concept of IBA has been applied during the last decades, and a big effort has been made to agree on a robust and simple criterion to be applied consistently worldwide. The selection of these important areas has been completed through the use of quantitative ornithological data and considering up-to-date knowledge of the sizes and trends of bird populations. In this way, it is ensured that all selected IBAs are of high interest for bird conservation at the international levelling terms of the presence and abundance of species that occur there seasonally or all year-round (Heath et al. 2000).

At present, 1873 out of 13,599 existing worldwide IBAs are exclusively marine IBAs (www.birdlife.org/datazone/site, accessed April 3, 2020). Spain and Portugal were pioneers in the design of marine IBAs in the open sea, where these important areas for birds typically coincide with areas of interest for other organisms, such as cetaceans or marine turtles (Arcos et al. 2009). The Alboran Sea hosts nine marine IBAs, which cover an area of 718,766 km^2 and include representatives of "areas of high-intensity use at sea," "seaward extensions of breeding colonies" and "migration hotspots." Furthermore, there are six IBAs in the Alboran Sea occupying inshore (coastal) waters (see Table 25.2).

The Strait of Gibraltar, in the western limit of the Alboran Sea, is the only connection between the Atlantic Ocean and the Mediterranean Sea and represents

Table 25.2 Important Bird and Biodiversity Areas (IBA) in the Alboran Sea and adjacent areas

IBA name	Code	Country	Area (km^2)	IBA type	Main species of interest
Strait of Gibraltar	ES404	Spain	2572.85	MH	Balearic shearwater, Audouin's gull, Cory's shearwater, Sandwich tern, northern gannet and great skua
Bay of Málaga—Cerro Gordo	ES405	Spain	712.22	HIU	Mediterranean gull and Balearic shearwater
Bay of Almería	ES406	Spain	1338.77	HIU, SEBC	Balearic shearwater, Audouin's gull, slender-billed gull and little tern
Tabarca—Cabo de Palos	ES407	Spain	1495.15	HIU, SEBC	Audouin's gull, European storm petrel, slender-billed gull, Balearic shearwater, common tern and little tern
Littoral islets of Murcia and Almería	ES170	Spain	134	SEBC	Scopoli's and Cory's shearwaters and European storm petrel
Chafarinas Islands	ES220	Spain	271.1	SEBC	Scopoli's and Cory's shearwaters and Audouin's gull
Alboran Island	ES221	Spain	662.2	SEBC	Audouin's gull
Mountain range and saltpans at Cabo de Gata	ES216	Spain	461	ICI	White-headed duck, Audouin's gull, greater flamingo, little tern
Wetlands of western Almería	ES219	Spain	30	ICI	White-headed duck, marbled teal, slender-billed gull, Audouin's gull and Kentish plover
Habibas Islands	DZ030	Algeria	0.4	SEBC	Audouin's gull and Eleonora's falcon
Rachgoune Island	DZ031	Algeria	0.27	SEBC	Audouin's gull
Sebkha Bou Areg	MA006	Morocco	180	ICI	Audouin's gull, greater flamingo, Kentish plover
Embouchure Oued Moulouya	MA007	Morocco	27	ICI	Audouin's gull and marbled teal
Jbel Moussa	MA001	Morocco	40	ICI	Soaring migratory birds (raptors and storks)

IBA types: Migration hotspots (MH), high-intensity use at sea (HIU), seaward extensions of breeding colonies (SEBC), inshore-coastal IBA (ICI)

a clear example of a bottleneck for seabirds, with migrants being constrained from both sides into a narrow front of 14.4 km at the nearest point between the European and African coasts. It concentrates the majority of seabird populations entering and leaving the Mediterranean Sea, being especially remarkable the cases of three Mediterranean endemic species, the Balearic and Scopoli's shearwaters and Audouin's gull, as well as the Mediterranean gull and the northern gannet. Tarifa

Island is a strategically located point from where populations of some species can be estimated through coast-based counts (Arroyo et al. 2016). From this point to the east, the Alboran Sea as a whole could be considered a migration corridor, with certain areas of special interest where seabirds occur in high numbers for foraging purposes, as the bays of Málaga and Almería, and several locations that host important breeding colonies of species listed in Annex I of EC Birds Directive, as Audouin's gull or Scopoli's shearwater (see Table 25.2).

Seabirds are one of the most threatened groups of birds at global level, mostly due to human activities at sea and on land, especially in their colonies (Croxall et al. 2012). As the identification and designation of IBAs do not guarantee full legal protection, conservation initiatives should be implemented to ensure the protection of the most interesting enclaves and areas, including the open sea. The regular monitoring of the IBAs, together with the identification and assessment of the main threats affecting the species all year-round, would be important tools to guide and design effective conservation and management initiatives. This is particularly important because most of the seabirds inhabiting the Alboran Sea are highly mobile species (González-Solís et al. 2007; Bécares et al. 2016; Pérez-Roda et al. 2017).

25.4 SPAMIs and Other Overlapping-Connected Marine Protected Areas

The Specially Protected Areas of Mediterranean Importance (SPAMIs) are marine and coastal sites for conserving "the components of biological diversity in the Mediterranean, ecosystems specific to the Mediterranean area or the habitats of endangered species, which are of special interest at the scientific, aesthetic, cultural or educational levels". These SPAMIs were created under the Protocol concerning Specially Protected Areas and Biological Diversity in the Mediterranean (SPA/BD 1995) and the contracting parties to the Barcelona Convention (BC). The SPA/BD Protocol was adopted in 1995 and called for the creation of SPAMIs and, however, entered into force in 1999. Nowadays, there are 35 SPAMIs in the Mediterranean Sea, with six of them located in the Alboran Sea and its adjacent areas (http://www.rac-spa.org/spami); new SPAMIs could be included in the future as this is an ongoing process. The SPAMIs have to follow the criteria listed in the Annex I of the SPA/BD Protocol: (a) uniqueness, (b) natural representativeness, (c) diversity, (d) naturalness, (e) presence of habitats that are critical to become endangered or threatened or to harbour endemic species and (f) cultural representativeness. In addition, they have to follow the procedure and the stages to be included as SPAMI in the List. SPAMIs are one of the most important networks of MPAs recognized by all Mediterranean country signatories to the BC. Each SPAMI needs a management plan, and all the parties of the SPA/BD protocol are committed to respect the protection and conservation measures defined in the proposal for inclusion.

The main SPAMIs located in the Alboran Sea are presented from West to East direction and from North to South order. In some cases, these SPAMIs also overlap with other figures of protection, which has also been indicated and explained.

25.4.1 Maro-Cerro Gordo Cliffs SPAMI and Collateral Figures of Protection (Spain)

The Maro-Cerro Gordo Cliffs (Acantilados de Maro-Cerro Gordo) are located on the northern part of the Alboran Sea, between Nerja (Málaga) and Almuñécar (Granada). It includes a narrow strip of 12 km along the coast, from Maro beach to Cerro Gordo Cliff, which contains a series of small beaches, coves and cliffs (Fig. 25.3). The total extension of this maritime—terrestrial site—is 19.13 km^2, of which 3.84 km^2 are terrestrial and 15.29 km^2 are marine (one nautical mile from the coastline) with a depth range from the coast of ca. 70 m in front of Cerro Gordo Cliff. In these cliffs, the outcrop of various units of the Alpujárride Complex occurs where the age of the rocks and their degree of metamorphism increase generally towards the east, consisting of Middle-Upper Triassic carbonates or marbles, together with mica schists and quartzites of low metamorphic grade and Lower-Middle Triassic age, graphite schist of middle to high metamorphic grade and locally migmatitic gneiss both of Palaeozoic age.

This MPA was firstly declared as Natural Area (Paraje Natural) by the Andalusian government (Junta de Andalucía) in July 1988, and it represents one of the few MPAs within the RENPA that is also a SPAMI. In October 2002, this MPA was classified as Special Protection Area (SPA, ES6170002) according to the Birds Directive (BD), but due to its relevance in the Mediterranean basin, it was also declared as SPAMI in 2003. Later on, the SPAMI was also confirmed as a Site of Community Importance (SCI) (Acantilados de Maro-Cerro Gordo, ES6170002) in July 2006 and designated as a Special Area of Conservation (SAC) in January 2015, in compliance with the Habitats Directive (HD).

The confluence of Atlantic and the Mediterranean waters, the occurrence of upwellings and the presence of soft (with variable grain sizes) and rocky bottoms, cliffs and underwater seawalls and submerged caves makes this a privileged location where several types of marine habitats and a high biodiversity have been described (Rueda and Marina 2009). Around 16 types of natural habitats included in Annex I of the HD are present, four of which are strictly marine: sandbanks which are slightly covered by seawater all the time (Habitat 1110), reefs (1170), submerged or partially submerged sea caves (8330) and the priority habitat *Posidonia* beds (1120) (Mateo-Ramírez et al. 2020b). The most representative structure for the habitat 8830 is the Cerro Gordo cave, which has ca. 100 m length and that

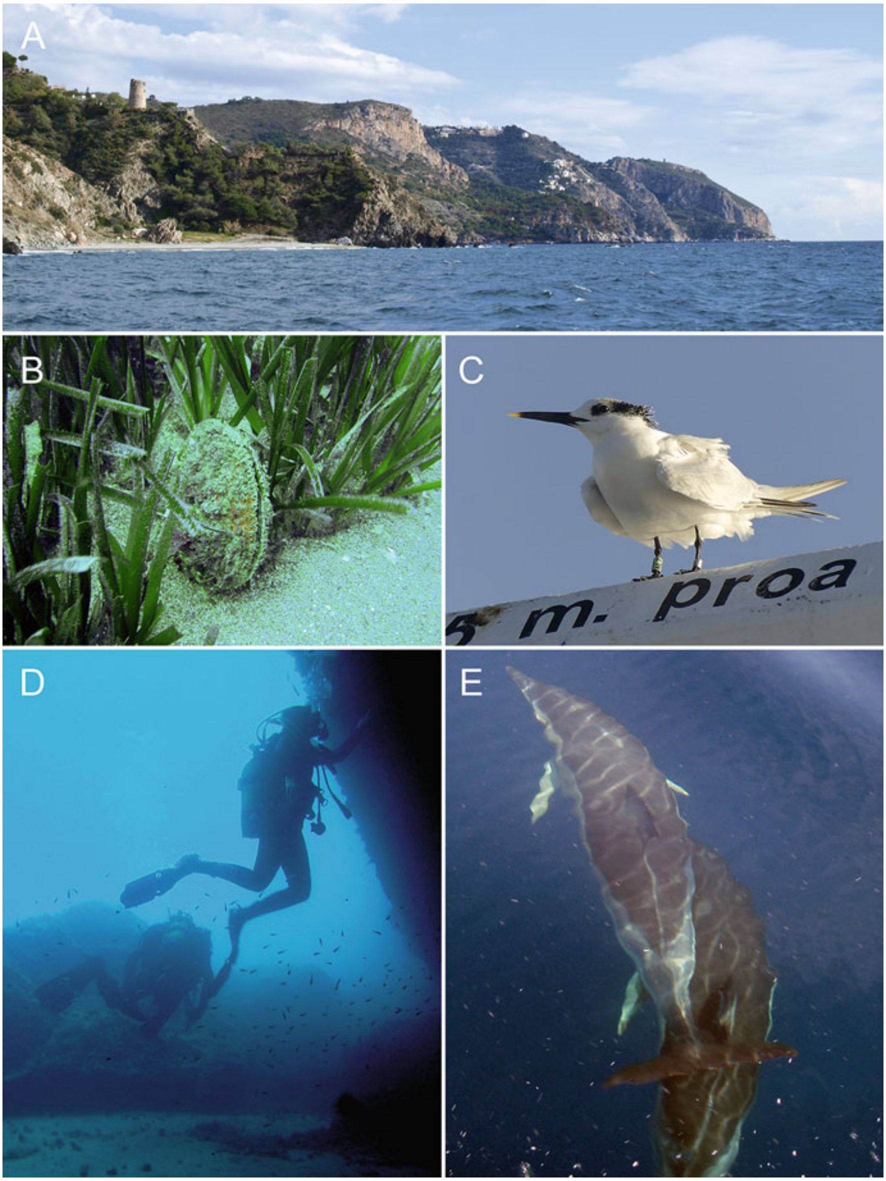

Fig. 25.3 Maro-Cerro Gordo Cliffs SPAMI and collateral figures of protection. (**a**) Partial view of the cliffs and caves of the Marine Protected Area (MPA); (**b**) the noble pen shell (*Pinna nobilis*) among the shoots of a *Posidonia oceanica* meadow; (**c**) a sandwich tern; (**d**) scuba divers exploring the submerged seawalls of this MPA; (**e**) striped dolphins (*Stenella coeruleoalba*) swimming in the MPA (**a**, **b**, **d**, **e** Pablo Marina; **c** Juan Ramírez)

presents a diverse fauna assemblages that change towards the end of the cave (https://litoraldegranada.ugr.es/).

Moreover, some vertebrates included in Annex II of the HD have also been detected such as the striped dolphin (*Stenella coeruleoalba*) (Fig. 25.3) or the loggerhead turtle (*Caretta caretta*) as well as birds species such as the Mediterranean gull (*Larus melanocephalus*), Audouin's gull (*Larus audouinii*), the sandwich tern (*Sterna sandvicensis*) (Fig. 25.3) and the osprey (*Pandion haliaetus*) during migration and winter; Cory's and Scopoli's shearwaters (*Calonectris borealis* and *C. diomedea*, respectively) during migration and summer; and the peregrine falcon (*Falco peregrinus*) breeding in coastal cliffs, all included in Annex I of the Birds Directive (2009/147/EC) (Mateo-Ramírez et al. 2021).

A wide variety of fish species occur in this MPA, such as the sunfish (*Mola mola*), the ornate wrasse (*Thalassoma pavo*), the African striped grunt (*Parapristipoma octolineatum*), the pearly razorfish (*Xyrichtys novacula*) or *Opeatogenys gracilis*, a small cryptic fish that inhabits the seagrass meadows (Rueda and Marina 2009). In the rocky reefs, it is still possible to spot some dusky grouper (*Epinephelus marginatus*) and shoals of the grey triggerfish (*Balistes capriscus*), being the only member of the Balistidae family in the Mediterranean Sea. The invertebrates in this MPA are also of importance, with some of them included in different conventions, the HD or the Listado de Especies Silvestres en Régimen de Protección Especial (LESRPE) from the Spanish government, such as the hatpin urchin (*Centrostephanus longispinus*), the chalice coral (*Astroides calycularis*), the knobbed triton (*Charonia lampas*) and the vermetid *Dendropoma lebeche* (previously known as *Dendropoma petraeum*; Templado et al. 2016) classified as "Vulnerable" (Vulnerable) or the endangered ribbed Mediterranean limpet (*Patella ferruginea*) as "En Peligro de Extinción" (In Extinction Risk) in the Catálogo Español de Especies Amenazadas (CEEA) and the scarce and beautiful brown cowry (*Luria lurida*) (Endangered Species in the BC) and the noble pen shell (or fan mussel) (*Pinna nobilis*) (included in the Annex IV of the HD and in Annex II of the SPA/BD Protocol) (Fig. 25.3). The noble pen shell has practically disappeared since 2016 due to the cryptogenic parasite *Haplosporidium pinnae* that caused an extensive mass mortality of this large and endemic bivalve in the Mediterranean Sea (Catanese et al. 2018; Templado et al. 2021, Chap. 10 of this book). In the underwater caves and hard bottoms, different gorgonians (*Eunicella verrucosa*, *Paramuricea clavata*, *Leptogorgia sarmentosa*), some of them listed as Vulnerable in the Libro Rojo de los Invertebrados de Andalucía, occur. Biological communities of some seagrass beds of this MPA (e.g. *Zostera marina*, *Posidonia oceanica*) have been studied and displayed a high diversity of fauna, but unfortunately, they have experienced a strong decline in the last years (Rueda et al. 2021, see Chap. 9 of this book).

Agriculture and fisheries (mainly artisanal purse seining, gillnetting and longlining) have historically sustained human settlements around the MPA, but the increasing tourism and recreational activity offered by its natural environment have nowadays taken on enormous importance. Nevertheless, this represents one of the main impacts on this MPA, especially during summer when tourist affluence increases. Unauthorized activities such as free camping, transit and anchoring of motor boats; recreational fishing or scuba-diving; and urban solid waste and untreated sewage from nearby villages (e.g. Nerja) are the main threats. In the same way, agriculture greenhouses have proliferated in recent years in the western part of the MPA (e.g. Maro village), generating a high visual impact and a large amount of solid (plastic) and liquid (pesticides, fertilizers, etc.) waste, which can negatively affect the long-term stability of habitats that are sensitive to coastal water quality such as seagrass beds. This together with some illegal bottom trawling was postulated among the potential drivers that led *Z. marina* beds to their local extinction (Rueda et al. 2009).

25.4.2 Alboran Island SPAMI and Collateral Figures of Protection (Spain)

The Alboran Island is a small and flat island, 642 m long and 265 m wide, located in the centre of the Alboran Sea from which it received its name. It belongs administratively to the Almería province, distance ca. 85 km, and is situated ca. 55 km away from Morocco.

The island is of volcanic origin and represents the top of the Alboran Ridge, an elongated submarine seamount that is one of the main structural highs of the Alboran Basin. This island is flat (not exceeding 15 m in height) with an irregular morphology, as well as the surrounding insular platform, due to the abrasive marine erosion. It corresponds to an outcrop of volcanic breccias and tuff of the cal-calkaline series that varies from pyroxene andesites to basalt-andesites, of Upper Tortonian age (IGME 1983; Aparicio et al. 1991). This outcrop is abraded by several levels of quaternary marine terraces with detrital limestone deposits, which provide a characteristic tabular relief to the island, and covered by a deposit of Holocene eolic sands (IGME 1983).

The island is located on a linear NE-SW elongated platform that is ca. 45 km long and 10 km wide and is disconnected from the nearest continental areas (Bárcenas et al. 2004). The platform is located in the NE sector of the Alboran Ridge, an elevation of ca. 200 km in length which controls the physiography of the southern part of the Alboran Sea. This structure is made up of a series of tight anticlinal-syncline folds generated since the Upper Tortonian to the present and is located over a main thrust (Vázquez et al. 2015a) according to the convergence of the Nubian plate towards the northwest (see Vázquez et al. 2021, Chap. 5 of this book). This elevation is dotted with volcanic outcrops, highlighting the trapezoidal building that corresponds to the basal Alboran Island edifice (Vázquez et al. 2000).

The insular platform is connected to a high slope flank that extends down to 1000–2000 m (Vázquez et al. 2015a). The morphology and sediments spatial distribution indicates the existence of two different hydrodynamic areas on the Alboran Ridge (Bárcenas et al. 2018): (a) the northern area with energetic

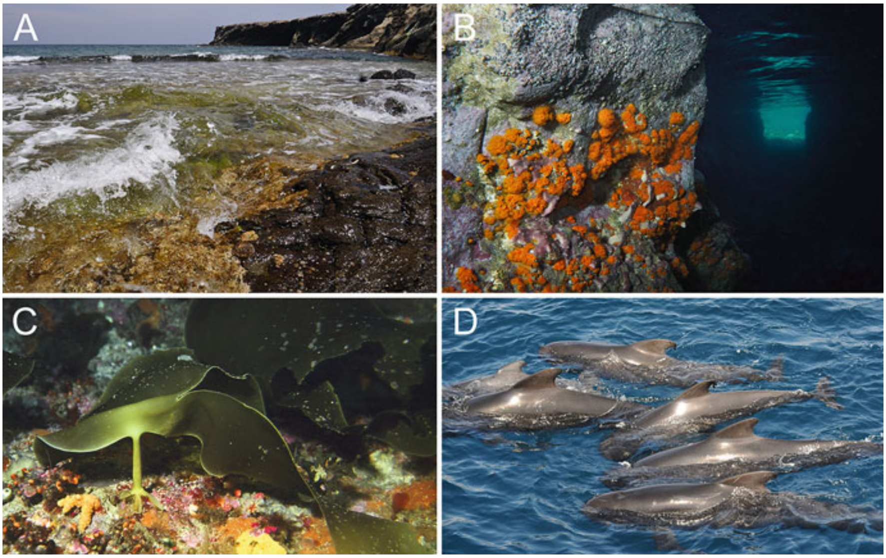

Fig. 25.4 Alboran Island SPAMI and collateral figures of protection. (**a**) West coast with a specimen of the limpet *Patella ferruginea* in the first place located right in the lower part of the intertidal; (**b**) cave with colonies of the chalice coral (*Astroides calycularis*); (**c**) Coralligenous bottoms with a juvenile of the kelp *Laminaria ochroleu*ca. (**d**) Family of long-finned pilot whales (*Globicephala melas*) (Diego Moreno/Sustainable Marine Environment Management Program/ Junta de Andalucía)

hydrodynamics and a predominance of erosive processes together with the presence of kelp beds (Fig. 25.4), which have been found in very specific areas of the Mediterranean subjected to Atlantic influence (Templado et al. 2006), and (b) the southern area with less energetic hydrodynamics conditions, mostly harbouring muddy sediments, but with a high biotic productivity associated with upwelling currents, as occurs off the Málaga coast. These could be responsible for the formation of rhodoliths and higher concentration of biogenic gravel and carbonates.

The first two protection figures of the area surrounding the island, a Marine Reserve (4.29 km^2) and a Fishing Reserve (ca. 490 km^2), were declared in 1997 by the Spanish Ministry of Agriculture, Fisheries and Food (MAPA). The fisheries regulations in the Marine Reserve were revised in 2018, with a ban of bottom trawling between 0 and 100 m and below 1000 m. In 2001, the Alboran Island, with its underwater platform, was declared SPAMI, according to the Barcelona Convention. In 2003, the Andalusian government declared the island and its platform (ca. 264.56 km^2) a Natural Area (Paraje Natural), and the management plan for this and the associated SPAMI was approved in 2005. In 2003, the terrestrial part (ca. 0.8 km^2) was also declared a SPA (SPA ES0000336). In 2006, a SCI (SCI ES6110015), coincident with the marine part of the Natural Area (ca. 263 km^2), was approved for the Alboran Island platform. In 2014, just after the LIFE+ INDEMARES project, a new SCI proposal was adopted and named as Espacio

Marino de Alboran (Marine Space of Alboran) (ESZZ16005), which expanded the extension of the previous SCI (an additional 108.9 km^2). The objectives of the LIFE + INDEMARES project were to characterize and identify the main habitats and biocoenoses of this offshore area, to evaluate their conservation status and possible threats and to propose management measures in order to include this site in the Natura 2000 network. The LIFE+ INDEMARES studies covered an area of 2753.46 km^2, which corresponded to the platform surrounding the Island of Alboran down to a depth of 200 m. Finally, a new SPA (ES0000505) named Espacio Marino de la Isla de Alboran (Marine Space of the Island of Alboran) (ca. 661 km^2) was declared in 2014. Albeit the Andalusian government declared in 2015 a SAC (ES6110015) for the Alboran Island (BOJA 2015/153) with associated management measures (BOJA 2015/193), alleging an ecological continuity between the terrestrial and the marine adjacent area, the High Court of Justice of Andalusia cancelled both orders in 2017 (Order of December 18, 2017, in BOJA 244/2017). The main reason for that was that the ecological continuity between the land and the adjacent marine area could not be credited. Therefore, the competence for declaring and managing both SCIs (ES6110015 and ESZZ16005) corresponds nowadays to the Spanish government. This judgement does not affect the Natural Area and its management plan which remains in force under competence of the Andalusian government.

The terrestrial part of the MPA is the home of interesting endemic plants such as *Diplotaxis siettiana* and *Senecio alboranicus* (Mota et al. 2006), as well as of few invertebrates (Paracuellos et al. 2006). Nowadays, the colony of Audouin's gull of the Alboran Island is the main one for the Alboran Sea, and it has had an increase of its population, up to 800 breeding pairs reported in 2019 (Paracuellos and Nevado 1995, Paracuellos and Nevado 2003, 2010; SEO CEUTA 2019). Several cetaceans display important populations in the waters around the island (Fig. 25.4), such as Cuvier's beaked whale (*Ziphius cavirostris*) (Annex IV of the HD, among other conservation lists) (Mateo-Ramírez et al. 2021) and Risso's dolphin (*Grampus griseus*) (Annex V of the HD, among others) (Cañadas et al. 2005; Junta de Andalucía 2008–2019; Mateo-Ramírez et al. 2021).

The Alboran Sea has been considered a hotspot of marine biodiversity within the Mediterranean Sea (see Chaps. 9 and 10 of this book), hosting most of the Andalusian threatened marine species (Barea-Azcón et al. 2008). The marine biodiversity of the Alboran platform is very rich. The macroalgae, with 220 known species, are very abundant in the sublittoral zone, including extraordinary forests of the kelp *Laminaria ochroleuca* that surrounds the Alboran Island between depth of 30 and 60 m (Fig. 25.4). Nevertheless, seagrass meadows which otherwise characterize most of the coastal protected areas of the Alboran Sea are completely absent around the island (Moreno 2006). Thirteen benthic communities have been identified in the sublittoral bottoms of the Alboran Island and its platform during the LIFE+ INDEMARES project (Gofas et al. 2014). From these, the rhodolith beds (related to Habitat 1110 of the HD), which extend from depth of 20 to 100 m should be highlighted (Mateo-Ramírez et al. 2020b). More than 300 species of invertebrates have been identified in this habitat; some of them shared with coralligenous and coarse bioclastic bottoms. Two different communities are found on circalittoral rocky bottoms (Habitat 1170 of the HD) surrounding the Alboran platform. A shallower occurring one (coralligenous), between depth of 30 and 100 m, is very heterogeneous and rich in species. In this habitat, the most conspicuous are the gorgonians (*E. verrucosa*, *P. clavata* or *L. sarmentosa*). Some colonies of the red coral (*Corallium rubrum*) (Annex V of the HD between other conservation lists) (Mateo-Ramírez et al. 2021) can be present from depth of 50 to 150 m, under overhangs of the rock. Some species of echinoderms, such as the sea urchins *Sphaerechinus granularis*, *Gracilechinus acutus* and the hatpin urchin (C*entrostephanus longispinus*) (Annex IV of HD between others) (Mateo-Ramírez et al. 2021) as well as the ophiuroid *Astrospartus mediterraneus* are frequent, the latter usually attached on the gorgonians. On deeper rocky bottoms, from depth of 100 to 200 m, there are different species of gorgonians, such as *Viminella flagellum*, *Acanthogorgia hirsuta*, *Eunicella filiformis* and *Callogorgia verticillata*. The latter is characteristic of the bathyal, but it reaches the edge of the platform in the Alboran Island. Some deep rocky bottoms harbour the so-called sponge gardens with some interesting species, such as *Phakellia robusta*, *P. ventilabrum* and the "lollipop" sponge *Crella pyrula* or the Atlantic *Asconema setubalense*. One of the most extended habitats is the coarse bioclastic bottoms that are present mostly below 100 m and at the edge of the platform (Gofas et al. 2014), replacing the rhodolith beds. This is one of the most species-rich communities of the Alboran platform, with 415 species of invertebrates identified during the INDEMARES project (Gofas et al. 2014). The sea pens are particularly conspicuous and include the species *Veretillum cynomorium*, *Pennatula rubra* and *Virgularia mirabilis*. Other species present in this habitat are the sea cucumber *Parastichopus regalis*; the sea stars *Anseropoda placenta*, *Chaetaster longipes* and *Marginaster capreensis*; and the small sea urchin *Genocidaris maculata*. The bioclastic bottoms are rich in crustaceans, with *Galathea intermedia*, *Inachus dorsettensis* and *Munida speciosa* as dominant species.

Among the studied marine fauna (Templado et al. 1986, 1993, 2006; Templado and Luque 1986; García Raso 1989), one of the best known groups is the molluscs (Salas and Luque 1986; Peñas et al. 2006) with more than 650 species listed for the Alboran Island, including some endemic species. The ribbed Mediterranean limpet (*Patella ferruginea*), catalogued as "In Extinction Risk" in the CEEA, has in this MPA one of its best populations, with ca. 950 individuals (Paracuellos et al. 2003; Moreno and Arroyo 2008; Arroyo et al. 2011; Junta de Andalucía 2008–2019) (Fig. 25.4). The sponges and cnidarians are also noteworthy, with more than 198 (Gofas et al. 2014; Sitjà and Maldonado 2014) and 76 species (of which 36 are anthozoans), respectively (César Megina and Pablo López, pers. com.). Among the cnidarians, in addition to the great diversity of gorgonians, important elements are the chalice coral (Vulnerable in CEEA) (Fig. 25.4); the red coral, which was exploited for many years (Templado et al. 2006; Moreno 2008); or the rare and giant whip gorgonian (*Ellisella paraplexauroides*) (LESRPE) (Mateo-Ramírez et al. 2021), a unique Mediterranean relic from the Mauritanian-Senegalese Pleistocene interglacial expansion (Maldonado et al. 2013). Altogether, about 1500 species have been reported around the Alboran Island (an exhaustive catalogue can be found in

Templado et al. 2006), making the marine space of Alboran a biodiversity hotspot for the Alboran Sea and, therefore, the Mediterranean Sea (Barea-Azcón et al. 2008; Gofas et al. 2014).

In the Marine Reserve, outside the integral reserve, professional fishing is only permitted with the gears and equipment traditionally used such as bottom longline, trolling, fishing rods with live bait and purse seine for small pelagics, as well as recreational trolling. Bottom trawling is only allowed in the Fishing Reserve, and it represents the most important fisheries targeting deepwater species such as the blue and red shrimp (*Aristeus antennatus*). The number of authorized bottom trawling boats is currently 51 with Almería being the main base port. One of the main threats of this MPA is the contamination derived from maritime traffic and possible oil spills. Although the emerged part of the island is guarded by a service of military forces, the MPA is very large, and the limits are far from the coast, so illegal fishing is also a threat. Competences shared by regional and national governments should not affect the good management and conservation goals of the MPA.

25.4.3 Natural Park of Cabo de Gata-Níjar SPAMI and Parque Natural del Cabo de Gata-Níjar (Spain)

The Cabo de Gata (Gata Cape) and its surroundings (mountains, salt pans and seabeds) are located in the Almería province (south-eastern Spain), and they were declared as Natural Park (Parque Natural), with the name “Cabo de Gata-Níjar” by the Andalusian government in 1987 (published in January 1988). It included more than 50 km of coastline and 120 km^2 of marine area, constituting the first maritime-terrestrial protected area of Andalusia and of the northern Alboran Sea. The marine area spans one nautical mile from the coast along the 50 km of coastline, with maximum depths of ca. 90 m and six zones of maximum protection: Cabo de Gata, Los Genoveses, Punta de la Loma Pelada, Punta de la Polacra, Punta Javana and Mesa Roldán. The first management plan was published in 1994 (with an extension of the terrestrial part to the current 375 km^2), and it was later on updated in 2008. This Natural Park is provided with management and scientific team, offices and equipment, and it has been a pioneer in many conservation activities of its rich natural heritage. For example, it has the only artificial conservation reef in Andalusia, installed between 1993 and 1994 to protect the integral reserve in front of Cabo de Gata (Guirado et al. 1997b). In 1989, the salt pans area (Salinas) was included in the Ramsar Convention and together with the adjacent mountains was classified as IBA (ES216), and the entire MPA was then proposed as SPA in 1992. In 1995, it was declared a Marine Reserve (only the external waters) by the Spanish Ministry of Agriculture, Fisheries and Food and Biosphere Reserve by the UNESCO in 1997. In 2001, it was catalogued as a Geopark, entering in the European Geoparks Network in 2006 and in the UNESCO Global Geoparks Network in 2015. Moreover, it was declared SPAMI in 2001, following the BC. At the same time, this MPA was

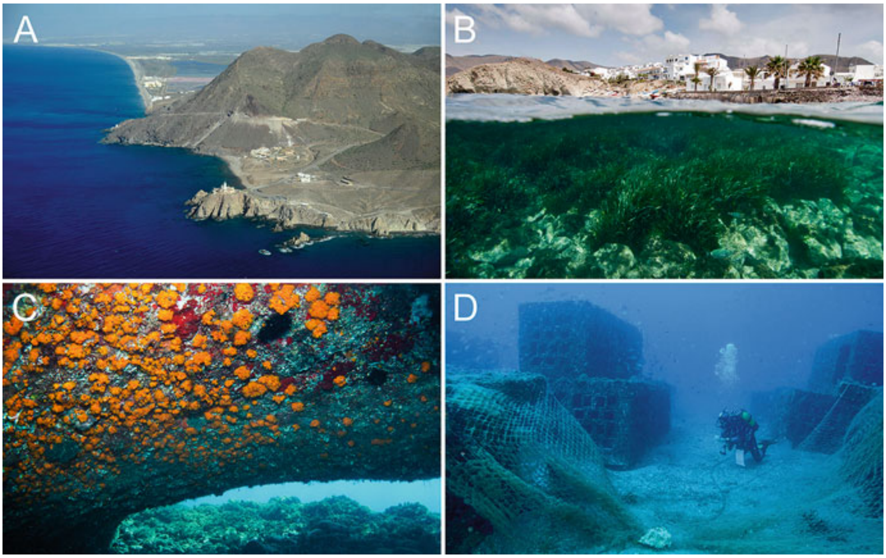

Fig. 25.5 Cabo de Gata-Níjar SPAMI and collateral protection figures. (**a**) Gata Cape (Cabo de Gata), the lighthouse, the mountains and the salt pans within the Bay of Almería; (**b**) the small fishing village of La Isleta del Moro with its *Posidonia oceanica* meadows; (**c**) submarine cave near San José, with the chalice coral (*Astroides calycularis*); (**d**) artificial reef with concentration modules and anti-trawling blocks with several nets hooked in 2015. (**a**–**c** Diego Moreno/Sustainable Marine Environment Management Program/Junta de Andalucía; **d** Agustín Barrajón Domenech/Sustainable Marine Environment Management Program/Junta de Andalucía)

designated as SCI (Cabo de Gata-Níjar**,** ES0000046) in 2001, which was further ratified in 2006 and 2009, and finally designated as SAC (ES0000046) in 2012. Regarding that, this MPA is one of the most recognized coastal areas in Spain, and it contains a significant number of protection figures.

This MPA nowadays spans over ca. 500 km^2, including the Gata Cape (Cabo de Gata) that is a first-order geographical accident (Fig. 25.5). The promontory “Charidemo,” as named by the ancients, is where the volcanic mountains of Cabo de Gata end, and it is characterized by an extensive outcrop of volcanic rocks mainly from the cal-calkaline series. They are constituted by a dominance of andesites and dacites Miocene in age (between 14 and 7.5 Ma) (Fernández Soler 1996). On the volcanic structures, especially at the north-eastern zone, there are important Messinian reef limestone deposits (Villalobos 2003) from a period in which the Mediterranean Sea was warmer than today. The volcanic complex of Cabo de Gata is the largest in the SE of the Iberian Peninsula and is characterized by its diversity (Villalobos 2003).

In addition to the mountain and the succession of cliffs, the native vegetation includes numerous endemic species (Mota et al. 1997, 2011). This MPA has also extensive sandy beaches in the Bay of Almería, with dune areas and large shrub vegetation dominated by species of African origin such as *Ziziphus lotus* (Tirado

2009). Middle Pleistocene fossil beaches, with *Strombus* shells, also occur in specific areas (e.g. mouth of the seasonal river of the Amoladeras) (IGME 1983). The salt pans located close to Gata Cape, on an old natural coastal lagoon that was transformed by humans, are still of importance for the salt industry. They house a high biodiversity of birds (Castro 1993), including the black-winged stilt (*Himantopus himantopus*), pied avocet (*Recurvirostra avosetta*), Kentish plover (*Charadrius alexandrinus*) and the greater flamingo (*Phoenicopterus roseus*), all included in Annex I of the BD.

A wide variety of habitats occur in this MPA, with sedimentary bottoms (Habitat 1110 of the HD), hard bottoms (1170), seagrass meadows, mostly of *P. oceanica* (1120) and some marine caves (8330) (Fig. 25.5), among others. Regarding fauna, several cetaceans included in directives (Annexes II–V of HD) and catalogues inhabit the waters of this MPA (e.g. the fin whale (*Balaenoptera physalus*), the common dolphin (*Delphinus delphis*), the bottle-nosed dolphin (*Tursiops truncatus*)). Some threatened invertebrates are the vermetid *Dendropoma lebeche* (Vulnerable), *Patella ferruginea* (Endangered), *Astroides calycularis* (Vulnerable) (Fig. 25.5), *Charonia lampas* (Vulnerable) and *Pinna nobilis* (Critically Endangered) (Moreno and Barrajón Domenech 2008a; Moreno and De la Rosa 2008; Mateo-Ramírez et al. 2021). The latter, as already mentioned by Templado et al., (Chap. 11 of this book), suffered a mass mortality event in 2016 (Vázquez-Luis et al. 2017), and no live specimens have been currently detected here and in the northern Alboran Sea (Junta de Andalucía 2008–2019).

Regarding seagrass meadows, the most extensive ones are those of *P. oceanica* (Fig. 25.5), especially in the northern zone, with some meadows on hard bottoms in the southern zone (García Raso et al. 1992). *Cymodocea nodosa* meadows are also well represented in the MPA, and there are specific sites with presence of *Zostera noltei* (Luque and Templado 2004). In the mesolittoral rock, ribbed Mediterranean limpet is nowadays scarce, but it was probably more abundant in the past as witnessed by the archaeological sites in the mountains (Moreno 1992; Moreno and Arroyo 2008, Arroyo et al. 2011). One of the most characteristic formations of this MPA is the vermetid reefs of *D. lebeche* which are the most important ones in the northern Alboran Sea (García Raso et al. 1992; Moreno 2008; Junta de Andalucía 2008–2019). In shallow rocky bottoms, there is great diversity of photophilous algae, including different species of *Cystoseira* (e.g. *C. mediterranea*, *C. tamariscifolia*) as well as *Padina pavonica*, *Halopteris scoparia* and *Acetabularia acetabulum* (Ballesteros and Catalán 1984). Some zooxanthellate scleractinians, such as the pillow coral (*Cladocora caespitosa*) (Moreno et al. 2008a; Junta de Andalucía 2008–2019) and *Oculina patagonica* (Zibrowius and Ramos 1983; Moreno 2010; Junta de Andalucía 2008–2019) as well as the rough pen shell (*Pinna rudis*) (Moreno and Barrajón Domenech 2008b), also inhabit these shallow rocky bottoms. In the sciaphilous rock walls, there is a wide diversity of macroalgae (*Peyssonnelia* spp., *Flabellia petiolata*, *Codium bursa*, *Cystoseira zosteroides* and *Dictyopteris polypodioides*), bryozoans (e.g. *Myriapora truncata*) and tunicates (e.g. *Clavelina dellavallei*), among other invertebrates (García Raso et al. 1992; Ballesteros and Pinedo, 2004). Important precoralligenous habitats also occur in shallow areas (down to depth of 6 m) with the presence of chalice coral colonies (García Raso et al. 1992), a species that has its main Spanish populations in the Alboran Sea westwards of Gata Cape (Moreno et al. 2008b), and the purple sea star (*Ophidiaster ophidianus*) (Moreno and Pérez-Ruzafa 2008). Interesting rhodolith beds occur in the MPA (Luque and Templado 2004), but coralligenous communities are not well developed and are characterized by some hardy gorgonians and small kelp such as *Phyllariopsis purpurascens*, which is just occasional in some years (Moreno et al. 2005). There is a good knowledge on the marine flora and fauna of this MPA, at least regarding mega- and macrofauna, and it can be considered a biodiversity hotspot for the Mediterranean Sea (Barea-Azcón et al. 2008). García Raso et al. (1992) listed more than 1400 species, later on updated and increased by Luque et al. (1999) and Moreno (2003). In summary, ca. 265 species of macroalgae (168 red algal species), more than 50 sponges, 60 cnidarians, 5 ctenophores, ca. 175 polychaete annelids, ca. 375 molluscs, 120 crustaceans, 17 lophophorians, 32 echinoderms, 46 tunicates, more than 150 fish, 2 marine turtles, ca. 30 seabirds (Guirado et al. 1997a) and at least 8 cetaceans have been recorded so far in this MPA. Unfortunately, the monk seal (*Monachus monachus*) has not been detected since the mid-twentieth century when it was considered very rare. Nevertheless, it certainly lived in the area because several places were named in relation to the monk seals (e.g. Arrecife de las sirenas (Sirens reef), Torre y Colina de los Lobos—hill and tower of the Wolves).

The ichthyofauna of the artificial reefs installed in the integral reserve has been monitored for more than 20 years in summer and winter. An increase of 72 fish species has been detected, as well as an evolution of the typical soft bottom fish assemblages (dominating *Pagellus acarne* and *Mullus surmuletus*) to more stable and typical hard bottom fish assemblages with large predators (e.g. dusky grouper and goldblotch grouper (*Epinephelus costae*)) and some pelagic species (e.g. *Seriola dumerili*) that benefit from the reef environment (Moreno et al. 2006). Several fishing nets hooked on the reefs were removed during monitoring, confirming the effectiveness of this passive method against bottom trawling (Junta de Andalucía 2008–2019) (Fig. 25.5). Similar monitoring was carried out for shallow rocky bottoms inside and outside the maximum protection areas for testing the "reserve effect" in coordination with other MPAs of south-eastern Spain (Moreno 1995; García-Charton et al. 2004). In all these MPAs, the dusky grouper was more abundant within maximum protection areas than outside them, and smaller serranids than this grouper (e.g. goldblotch grouper, *Serranus cabrilla*, *Serranus scriba*) were more abundant in Cabo de Gata-Níjar than in other MPAs (García-Charton et al. 2004).

The Andalusian administration has also done big efforts in increasing the knowledge and conservation of seagrass meadows of this MPA, with projects for mapping *P. oceanica* meadows of the coasts along Almería (the largest meadows in the Andalusian coasts) in 1995–1996 by the Universidad Autónoma de Madrid (Luque et al. 2004). Recently, further mapping was carried out with the EU LIFE+ *Posidonia* Andalucía project between 2011 and 2016 (Mendoza et al. 2014; Arroyo et al. 2015). The project also carried out numerous divulgation actions and promoted the definitive establishment of a monitoring network for *P. oceanica* (POSIMED) with five fixed sampling stations (three of them for demographic studies) in this MPA (Junta de Andalucía 2008–2019). Recently, the LIFE Blue Natura project is studying the CO_2 stock of *P. oceanica* meadows, with one station in Agua Amarga. Here, a corer of more than one metre was retrieved in the deep meadows (-18 m) and resulted in ages of more than 3000 years BP (Mateo et al. 2018).

The socio-economic importance of this MPA is mainly related to the appreciation of its natural values by tourism, sport and recreational activities (e.g. sunbathing beaches, swimming, scuba-diving). In addition to the natural and landscape values, the MPA contains interesting and diverse historical (Roman salting factories, watch-towers and castles, etc.) and cultural heritages (cottages, waterwheels, abandoned mines, etc.), as well as numerous artisanal activities, such as traditional crops, fisheries and salt extraction in the salt pans (Villalobos et al. 2004). Regarding fisheries, there is a fleet of 30 artisanal vessels and 15 purse seine boats. The main artisanal gears used are gillnets targeting cuttlefish (*Sepia officinalis*) or mullets (*Mullus* sp.); “moruna” that is similar to a small “almadraba” targeting small tunas such as greater amberjack (*Seriola dumerili*), Atlantic bonito (*Sarda sarda*) or little tunny (*Euthynnus alletteratus*); and pots targeting common octopus (*Octopus vulgaris*) and soldier striped shrimps (*Plesionika edwardsii*). Recreational fishing from the coast or using a boat is subjected to different restrictions. The authorized recreational modalities from the boat are “chambel” or “volantín” to be used outside the limit of the *P. oceanica* meadows and surface trolling, being subject to a series of restrictions (e.g. number of gears per fisherman, catch limits), and some species are prohibited with this modality such as dusky and goldblotch groupers, shi drum (*Umbrina cirrosa*), meagres (*Sciaena umbra*/*Argyrosomus regius*), all types of commercial crustaceans and molluscs except the common squid (*Loligo vulgaris*). Bottom trawling and spearfishing are not allowed in the entire MPA.

The semi-arid climate of Almería, one of the most arid ones in Europe (200 mm of annual rainfall) (Guirado et al. 1994), probably has not allowed important human settlements. In addition to the oceanographical conditions, this may have favoured the transparency of the seawater and the good status of its seabeds. Among the notable threats, it is possible to highlight the maritime traffic that passes very close to the Gata Cape, the increasing tourism, the arrival of invasive alien species (*Caulerpa cylindracea* in 2012; Junta de Andalucía 2008–2019) and poaching. A greater coordination between national, regional and local administrations is desirable for improving the management of this MPA.

25.4.4 Sea Bottoms of the Levante of Almería SPAMI and Terreros and Negra Islands Natural Monument (Spain)

This MPA is located between Almería and Murcia provinces (adjacent area to the north-eastern Alboran Sea). It was proposed as SIC in 1997 and approved in 2006 with the name “Fondos Marinos del Levante Almeriense” (Sea bottoms of the

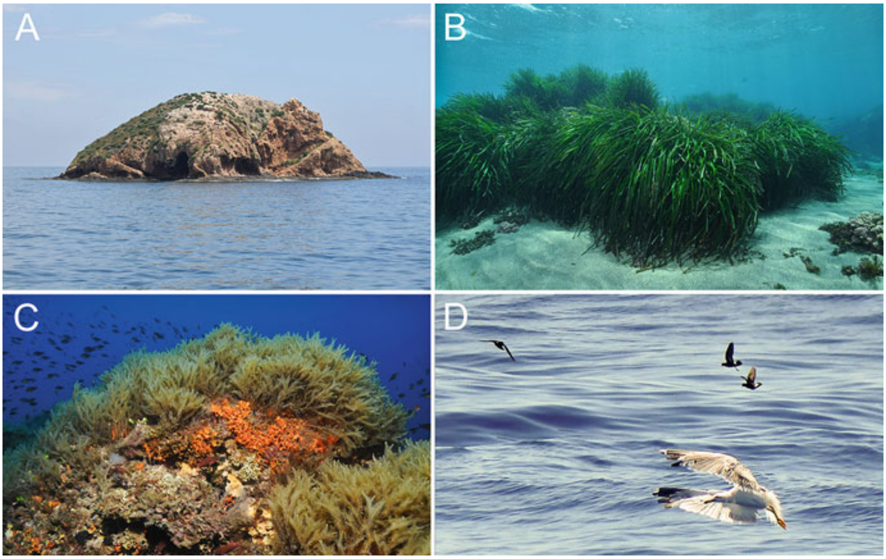

Fig. 25.6 Fondos Marinos del Levante Almeriense SPAMI and collateral protection figures. (**a**) Terreros Island, Natural Monument and part of the IBA "Espacio marino de los Islotes Litorales de Murcia y Almería"; (**b**) *Posidonia oceanica* meadow at depth of 8 m; (**c**) rocky bottom at depth of 15 m with the seaweed *Dictyopteris polypodioides* and the bryozoan ross coral (*Pentapora fascialis*); (**d**) storm petrels and a yellow-legged gull (**a**–**c** Diego Moreno/Sustainable Marine Environment Management Program/Junta de Andalucía; **d** Juan Ramírez)

Levante of Almería) (ES6110010) with an area of 63.13 km^2. In 2001, it was also approved as SPAMI, but the limits were modified several times between 2009 and 2015, partly towards the coastline, until reaching 106.92 km^2. In 2016, it was declared SAC (ES6110010), spanning 45 km from Carboneras village to the border with the Murcia province and a depth range from the coastline to ca. 200 m. A small extension of its southern limit (0.5 km^2) was proposed by the LIFE+ *Posidonia* Andalucía project in order to include the *C. nodosa* meadow located outside the MPA (Aranda and Otero 2014). Within this MPA, there is also one Natural Monument of biotic character called "Isla de Terreros e Isla Negra" (Fig. 25.6), which was declared in 2001 by the Andalusian government. This Natural Monument only protects the emerging part of these two volcanic islets that harbour interesting seabird colonies. The Natural Monument declaration includes basic management criteria and a list of unsupported activities (Castro et al. 2003). Previous to the declaration of this area as SPA (ES0000507) "Espacio marino de los Islotes Litorales de Murcia y Almería" (123.35 km^2) in 2014, the islands Negra and Terreros (ca. 0.17 km^2, Almería) were included inside the IBA (ES170), which are formed by these and the islet Las Palomas (Murcia). The islet of Terreros harbours one of the few breeding colonies in the Mediterranean Sea of the Atlantic Cory's shearwater (*Calonectris borealis*), with 30–35 breeding pairs, and both islets host breeding colonies of European storm petrels (*Hydrobates pelagicus*), a minimum of

100 breeding pairs in the islet of Las Palomas and a lower but unknown population in Terreros (Arcos et al. 2009; Reyes-González and González-Solis 2016) (Fig. 25.6).

Seven marine habitats are represented in the MPA, including *P. oceanica* beds (Habitat 1120 of the HD), caves (8330), sandbanks (1110) or reefs (1170) (Fig. 25.6) (Mateo-Ramírez et al. 2020b). Two clearly differentiated zones can be distinguished. In the northern zone (Almanzora River towards Murcia province), the seabed has extensive and vigorous seagrass meadows Luque and Templado 2004), especially of *P. oceanica* (Moreno et al. 2004a; Arroyo et al. 2015) (Fig. 25.6). Further south, the stretch until reaching Villaricos runs parallel to the Almagrera mountain range that is composed of shales and other minerals and where there was a large mining activity of lead and silver (Navarro et al. 1997). From the south of the Almanzora River to Carboneras, the seabed is predominantly sedimentary with different sediment types, including areas of fine sand, others of gravel and also of mud, as in the canyon in front of Garrucha where they exceed depth of 200 m. In this southern area, *C. nodosa* meadows are well represented (Moreno and Guirado 2003; Moreno et al. 2004b; Arroyo et al. 2015).

From 1995 to 2016, a high number of studies were carried out in this MPA, from *P. oceanica* mapping and demographic studies to faunistic inventories (e.g. Luque and Templado 2004; LIFE+ *Posidonia* Andalucía project 2011–2016). Thanks to the LIFE+ *Posidonia* Andalucía project, six stations of *P. oceanica* were monitored within the POSIMED Network, and eleven ecological buoys were installed along scuba-diving areas and around the island of Terreros to avoid anchoring on the meadows (Mendoza et al. 2014).

The protected species of this MPA are similar to those of Cabo de Gata-Níjar MPA. Nevertheless, the best population of the noble pen shell for the whole Andalusian coast lived on *P. oceanica* meadows of this MPA, and it was monitored annually by the marine environment management programme of the Andalusian administration until its mass mortality in 2016 (Moreno and Barrajón Domenech 2008a; Junta de Andalucía 2008–2019; Vázquez-Luis et al. 2017). In the northern area between San Juan de los Terreros and Villaricos, there are reefs of the vermetid *Dendropoma lebeche* (Vulnerable), which are monitored annually (Junta de Andalucía 2008–2019). There are also several rocky areas (from depth of ca. 5–30 m) that are very visited by sports divers, such as El Calón, Loza del Payo and El Cerro. The hatpin urchin (Annex IV of HD) also showed in these heterogeneous rocky bottoms their densest known population for the Andalusian coasts (Junta de Andalucía 2008–2019; Mateo-Ramírez et al. 2021). Other species inhabiting these rocky bottoms are the sciaphilic algae *Halimeda tuna* and *Dictyopteris polypodioides*, together with the bryozoan ross coral (*Pentapora fascialis*) (Fig. 25.6). In these submerged rocky elevations, there are some cracks and caves. The most important cave is known as La Catedral whose roofs and walls are upholstered with sponges such as *Oscarella lobularis* and *Chondrosia reniformis*, corals such as *Madracis pharensis* and *Leptopsammia pruvoti* and the smooth starfish (*Hacelia attenuata*), the last one included in the LAESRPE (Mateo-Ramírez et al. 2021).

The main threats of this MPA are the increase in tourism, maritime traffic (very intense near Garrucha), illegal trawling, pollution, invasive alien species and the absence of regulations for underwater fishing. Several housing developments have been built mainly on the coast of Vera, Garrucha and Mojácar but also in San Juan de Los Terreros. In spite of the coastal population increase and the associated sewage, the main contamination threat is the discharge of the chemical plant Deretil northwards of Villaricos. This discharge occurs on the shore and has affected the seabed, mainly the *P. oceanica* meadows down to depth of ca. 10 m, leaving large areas of "dead matte" (Moreno et al. 1999, 2001; Arroyo et al. 2015). In 2008, the invasive algae *Caulerpa cylindracea* (previously known as *C. racemosa*) were detected near the island of Terreros at depth of 17 m, representing the first record for the Andalusian coasts (Moreno 2010). In a short time, it extended extensively and covered ca. 1.2 km^2 in 2009, and nowadays, it is mainly affecting rhodolith beds (depth of 15–30 m) (Junta de Andalucía 2008–2019). Other invasive species are also abundant in the area, such as the crab *Percnon gibbesi* (since 2006) and the seaweed *Lophocladia lallemandii* (in Cocedores since 2012) (Junta de Andalucía 2008–2019). The scleractinian *Oculina patagonica*, of an invasive nature, is very abundant locally in the southern area of this MPA, mainly in port areas (Junta de Andalucía 2008–2019) but also in shallow rocky bottoms (0–3 m) (Serrano et al. 2012).

25.4.5 Al Hoceima National Park SPAMI and Collateral Figures (Morocco)

The Al Hoceima National Park (Parc National d'Al Hoceima) was declared in 2004 by the High Commission for Water and Forests. It is the main MPA and the only National Park in the Mediterranean part of Morocco. Due to its significant biodiversity, comparable to that of the main hotspots of the Mediterranean Sea, it was also declared as a SPAMI in 2009. This MPA is located in northern Morocco, close to the city of Al Hoceima, and covers an area of 480 km^2, with a terrestrial part limited to the west by the Mestassa valley and to the east by the Rhis River. The maritime area extends ca. 200 km^2 over approximately 40 km of coastline and a depth range from the coastline to ca. 200 m. This MPA includes a Marine Natural Resources Management Area, a Strict Nature Reserve and a Natural Sanctuary.

The coastline is dominated by steep cliffs (more than 60 m high) of the limestone ridge (Khouakhi et al. 2013) that have significant gravitational instabilities at the top and at times are spaced by small coves and sandy bays as well as some islets (Fig. 25.7). Due to the erosion caused by the intense wave action, there are caves and shallow underwater openings that can exceed 60 m in length. The beaches are relatively rare and not very extensive, and they mostly occur in protected areas of bays such as the beaches of Cebadilla or Tala Youssef or can form isthmus such as those of Cala Iris and Badès. The rest of the coast is mainly conformed of pebble and

Fig. 25.7 Al Hoceima National Park SPAMI and collateral protection figures (Morocco). (**a**) Partial view of the coastline; (**b**) aggregates of the vermetid gastropod *Dendropoma lebeche* and of limpets on the mesolittoral rock; (**c**) an individual of the endangered limpet *Patella ferruginea* and small *Lithophyllum* concretions (Juan Antonio González García, Universidad de Granada)

gravel beaches with some coarse sand. The sublittoral domain is characterized by hard bottoms, made of blocks of fallen rocks, and also by soft bottoms, mostly with medium and fine sands and with fairly gentle slopes. These singular geological features provide a wide environmental variety of great geological and biological value, where several types of marine habitats are present harbouring a high biodiversity (Mateo-Ramírez et al. 2020b).

The geomorphology of the coast, with inaccessible steep cliffs, and the high fish richness and productivity constitute favourable conditions for some individuals of the Mediterranean monk seal (Tunesi et al. 2003), which is included as Critically Endangered in the IUCN Red List (Mateo-Ramírez et al. 2021). It is also possible to spot some cetaceans of conservation interest (i.e. included in Annex IV of the HD) such as the common dolphin, the stripped dolphin and the bottle-nosed dolphin. It is also an important area for the loggerhead turtle (*Caretta caretta*) and more rarely for the leatherback turtle (*Dermochelys coriacea*) or the green turtle (*Chelonia mydas*) (IUCN 2012b; Mateo-Ramírez et al. 2021).

This SPAMI shows a high diversity of seabirds, favoured by the presence of rocky cliffs, caves and islets. The presence of the only breeding nucleus of ospreys in

Morocco is remarkable, with a population of 20–25 adult birds and, at least, six breeding pairs (Monti et al. 2013). The Mediterranean population of osprey shows an unfavourable conservation status and currently holds less than 100 breeding pairs. In Al Hoceima National Park, a strong decrease in population size has occurred during the last decades, from 14–16 pairs in the 1980s to only six in 2012–2013 (Berthon and Berthon 1984; Hodgkins and Beaubrun 1990; Monti et al. 2013), being still exposed to local extinction risk. Other species of interest in the area are Audouin's gull, Scopoli's shearwater, the Mediterranean subspecies of the European shag (*Phalacrocorax aristotelis desmarestii*) (Fig. 25.8), the lesser crested tern (*Thalasseus bengalensis*) during its migration and the sandwich tern (*Sterna sandvicensis*) during winter.

In this protected area 4 types of natural habitats similar to those include in Annex I of the HD are present: sandbanks which are slightly covered by seawater all the time (Habitat 1110), reefs (1170), vegetated sea cliffs of the Mediterranean coasts with endemic *Limonium* spp. (1240) and with *Limonium asparagoides* (endemic to Morocco and Algeria) and submerged or partially submerged sea caves (8330) (Mateo-Ramírez et al. 2020b). The marine vegetation displays a high diversity with more than 300 species reported, including kelps (*Saccorhiza polyschides*, *Laminaria ochroleuca*, *Phyllariopsis purpurascens*, *Phyllariopsis brevipes*) (UNEP-MAP-RAC/SPA. 2014; Moussa et al. 2018). On the coastal rocks, some red algae, such as *Lithophyllum incrustans*, build a formation called "*Lithophyllum* sidewalk" together with other species of Corallinaceae like *Mesophyllum lichenoides* (Moussa et al. 2018). In high hydrodynamic deep areas, some free calcareous red algae form rhodolith beds which shelter a great variety of fauna and flora. The *C. nodosa* meadows, included in the Annex I of the Bern Convention and in the Annex II of the BC, are also abundant in this MPA.

The marine fauna is very diverse and includes most of the Mediterranean species of conservation importance. For example, the ribbed Mediterranean limpet *Patella ferruginea* displays populations in Cala Iris that are important for conservation (Bazairi et al. 2004) (Fig. 25.7). There are also formations of the vermetid *D. lebeche* (Fig. 25.7), and the coralligenous communities are well developed with coral such as the star and red corals as well as gorgonians such as *Eunicella cavolini*, the white sea fan (*Eunicella singularis*) and the violescent sea-whip (IUCN 2012a; MedPAN and SPA/RAC 2019). The ichthyological diversity is high, with more than 100 species, some of them of commercial interest such as the common dentex (*Dentex dentex*), redbanded seabream (*Pagrus auriga*) and several species of groupers including the dusky grouper (IUCN 2012a; Mateo-Ramírez et al. 2021).

Al Hoceima National Park has a great potential for tourism activities, and the human development has slowed down in a large part of its coastal area, due to ecological and environmental constrains. Tourism represents an impact on the environment and on the local people's culture, who may be threatened by uncontrolled housing developments, including massive tourist developments. An ethical debate is currently taking into account the need for preserving the natural and cultural resources of this MPA or, conversely, for promoting the economic

Fig. 25.8 Habibas Islands SPAMI and collateral protection figures. (**a**) Audouin's gull (*Larus audouinii*); (**b**) the Mediterranean subspecies of the European shag (*Phalacrocorax aristotelis desmarestii*); (**c**) the Balearic shearwater (*Puffinus mauretanicus*); (**d**) Scopoli's shearwater (*Calonectris diomedea*); (**e**) Eleonora's falcon (*Falco eleonorae*) (**a**, **b** Antonio-Román Muñoz; **c**–**e** Juan Ramírez, Universidad de Málaga)

development of the local population. Fishing can be considered as one of the main economic activities, with two main ports (Al Hoceima port and Cala Iris port) and seven artisanal fishing sites (Torrès, Badès, Taoussert, Tikket, Boussekour, Inouaren and Adouz). The fishing fleet is mainly composed of trawlers, sardine boats, longliners and boats, and the fishery resources exploited are demersal species, such as the red mullet (*Mullus barbatus barbatus*), small and large pelagics such as European pilchard (*Sardina pilchardus*) and swordfish (*Xiphias gladius*) and small tuna, such as the Atlantic bonito (*Sarda sarda*). After a socio-economic analysis of the sustainability of the fishing activity carried out in 2011, fishermen of this MPA have proposed management measures (e.g. a zonation of the marine area close to the coast) in order to reduce illegal fishing activities.

25.4.6 Habibas Islands SPAMI and Collateral Figures (Algeria)

In 2005, several sites (Banc des Kabyles, the Habibas Islands, Rachgoune Island and Cap de Garde) were listed as potential MPAs in Algeria (UNEP 2005). Only two of them were designated as SPAMIs, Banc des Kabyles and the Habibas Islands (*Les îles Habibas*) being the latter the one located in the Alboran Sea. The Habibas Islands consist of two rocky islands lying 12 km west of the Algerian coastline just below the headland known as “Les Andalouses” (which itself lies 45 km west of Oran). The larger island is called “Gharbia” and reaches 103 m in height. The smaller and more easterly island is called “Charguia” and reaches no more than 25 m in height. They were firstly declared a marine nature reserve in 2003 and SPAMI at the Seventh Meeting of National Focal Points for SPAs of 2005, covering ca. 26 km^2 and a depth range between the coastline and 485 m. The Habibas Islands represent the first MPA and also the first SPAMI, established in Algeria.

The Habibas Islands are of volcanic origin, and they belong to the Sahel d’Oran volcanic complex that has been characterized by rocks of andesitic to rhyolitic composition of the cal-calkaline series and Tortonian age (Bellon et al. 1984).

This MPA was also internationally recognized as IBA in 2001. Under the tutelage of the National Commission for the Littoral (NCL), this MPA has benefited since its creation from a number of activities implemented in the framework of international collaborations and is currently co-managed by the NCL in collaboration with the local NGO “Barbarous.” The management plan for the Habibas Islands was finalized in 2013 as part of the “Development support of the NCL” project by the Conservatoire du Littoral. Its implementation was deferred to 2015 with 5-year management objectives focused on conservation and development (MedPAN web page visited on 06/02/2020, http://medpan.org/main_activities/appels-a-petits-projets/).

Different and interesting bird species use this MPA as a breeding location, including Audouin’s and yellow-legged gulls, Scopoli’s shearwater, the Mediterranean subspecies of the European shag, osprey and Eleonora’s falcon (*Falco* *eleonorae*) (Fig. 25.8) (Mateo-Ramírez et al. 2021). The habitat halonitrophilic thickets (Pegano-Salsoletea) (similar to the Habitat 1430 of the HD) is well represented in the Habibas Islands with important population of plants such as *Salsola longifolia* or *Withania frutescens*.

The sublittoral part of this MPA hosts a high diversity of habitats and species. One of the most abundant habitats are the rocky bottoms (similar to Habitat 1170—Reefs of the HD) in which several species included in various conventions and annexes thrive, such as the ribbed Mediterranean limpet with populations exhibiting high densities, a well-structured size distribution and high reproductive output in mesolittoral bottoms (Espinosa et al. 2014). Other protected species are the macroalgae *Cystoseira* spp. (*C. zosteroides* and *C. amentacea*), some cnidarians such as *A. calycularis* in the infralittoral, echinoderms such as the purple sea star, molluscs such as the knobbed triton or the noble pen shell (probably extinct at the present) and large fishes such as the dusky grouper at larger depths (Bachet et al. 2007; Mateo-Ramírez et al. 2021). Coralligenous communities are the most abundant at the circalittoral zone, with species of interest for conservation, such as the gorgonians violescent sea-whip, the white sea fan or *Leptogorgia sarmentosa*. The second habitat in order of importance is similar to the sandbanks which are slightly covered by seawater all the time of the HD (Habitat 1110) and displays different kinds of bottoms, such as rhodolith beds or detritic bottoms with sea pens and soft bottom octocorals (*Paralcyonium spinulosum*, *Veretillum cynomorium*) (Bachet et al. 2007). The absence of *P. oceanica* westwards to Melilla along the mainland shore, is remarkable (Bachet et al. 2007).

One of the socio-economic benefits of the MPA is recreational diving, which may also represent a threat, because of the potential impact on vulnerable and slow-growing habitats such as the gorgonian aggregations. Nevertheless, the main threats of this MPA are related to fisheries and mainly to underwater fishing. Bachet et al. (2007) presented some evidence of this, the observations of school of commercial fish species with small size as well as their elusive behaviour. This is confirmed by old photos and testimonies of fishing carried out several decades ago, which indicate a great abundance of fish (grouper in particular) and large crustaceans. The increasing presence of invasive species such as the macroalgae *Asparagopsis armata*, *Asparagopsis taxiformis* and *Codium fragile* or the scleractinian *O. patagonica* represents other threats to these islands (Bachet et al. 2007).

25.5 Other Marine Protected Areas and Key Biodiversity Areas from the Northern Alboran Sea and Adjacent Areas

Different MPAs and KBAs located in the northern Alboran Sea and adjacent areas are presented from west to east direction, including remarks on their location, protection figure status, natural heritage, socio-economic importance and main threats.

25.5.1 Parque Natural del Estrecho and SAC (Spain)

Situated in the north-western limit of the Alboran Sea, the “Parque Natural del Estrecho” SAC (Strait Natural Park) (ES0000337) was proposed as Nature Park (Parque Natural) by the Andalusian government and as SCI and as SPA in 2003. Finally, it was declared SCI in July 2006 and SAC in September 2012. The Intercontinental Biosphere Reserve of the Mediterranean, declared in 2006, includes a marine strip of this Natural Park. It is located on the northern part of the Strait of Gibraltar between Getares Cove (westwards of Algeciras Bay) and Gracia Cape (westwards of Bolonia Bay), with a discontinuity in front of Tarifa harbour. It covers an area of ca. 192 km^2 of which 96 km^2 is located in the marine environment and a depth range from the coastline to ca. 300 m. The Strait of Gibraltar is characterized on both banks by the Flysch Complex, which are usually made up of alternating marls and/or shales, grey limestones and micaceous sandstones, deposited in turbidite systems; their age varies from the Upper Cretaceous to the Lower Miocene (Didon et al. 1973; Balanyá et al. 2007). This stratigraphical pattern is reflected in the geomorphology of both terrestrial and marine areas, where the sandstone layers are much better marked in the relief. The MPA is characterized by large areas of rocky outcrops increasing towards Algeciras where the slope is steepest, and sandy sediments are arranged as large bottom form generated by the wave and current action (Maldonado et al. 2003).

The main marine-related habitats included in Annex I of HD are coastal lagoons (Habitat 1150), reefs (1170) and sandbanks which are slightly covered by seawater all the time (1110) (Mateo-Ramírez et al. 2020b). Nevertheless, the SAC contains a total of 25 coastal and terrestrial habitats included in the HD, with some of them interconnected with the marine system. This MPA also has an important natural heritage and a high biodiversity, with more than 1900 species of plants and animals, including endemic species and new species that have been recently described. Some large species are included in Annex II of the HD such as the loggerhead turtle (*Caretta caretta*), the leatherback turtle (*Dermochelys coriacea*), the bottle-nosed dolphin (*Tursiops truncatus*) (Fig. 25.9) and the common porpoise (*Phocaena phocaena*), with some of them frequently detected in the MPA because of its strategic position between two continents (Africa and Europe) and two basins

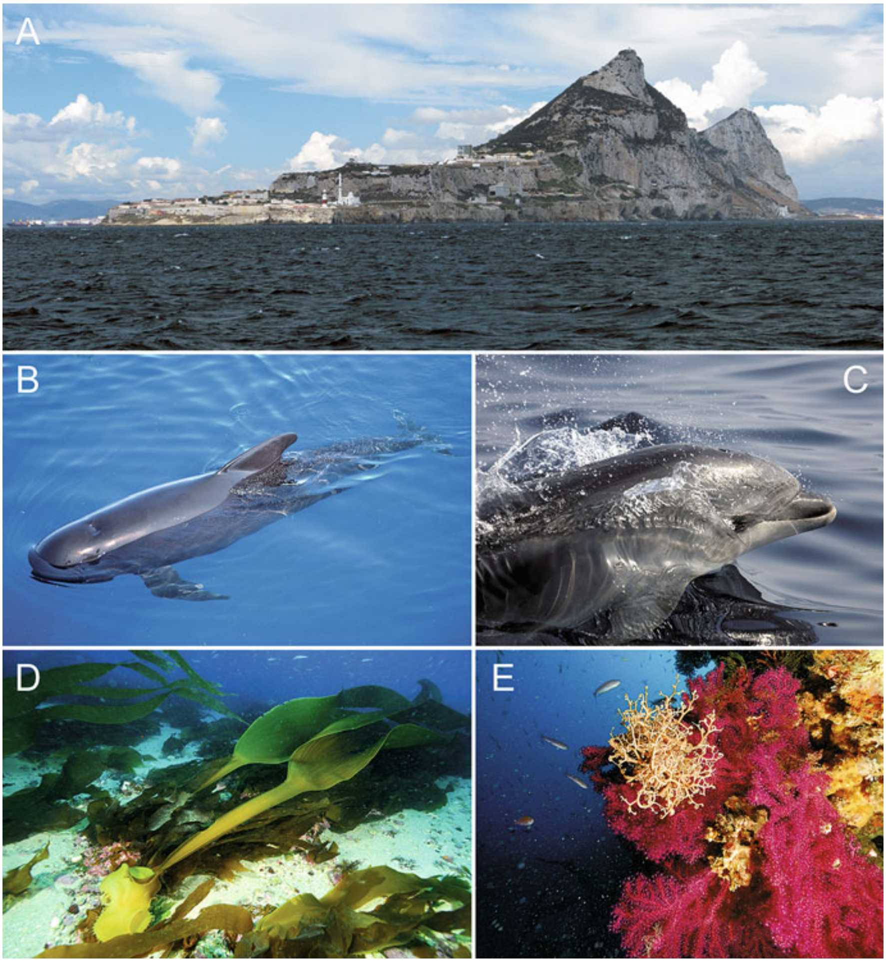

Fig. 25.9 The northern Strait of Gibraltar harbours a great variety of animal and plant species. This has led to the creation of different Marine Protected Areas. (**a**) Rock of Gibraltar where two SACs have been declared; (**b**) the long-finned pilot whale (*Globicephala melas*); (**c**) a close-up of the bottle-nosed dolphin (*Tursiops truncatus*); (**d**) kelp *Saccorhiza polyschides* from Tarifa bottoms; (**e**) the ophiuroid *Astrospartus mediterraneus* on the violescent sea-whip (*Paramuricea clavata*) from the Parque Natural del Estrecho (OCEANA, **a** Gorka Leclercq; **b** Carlos Suarez; **c** Jesús Renedo; **d**–**e** Juan Carlos Calvin)

(Atlantic Ocean and Mediterranean Sea). Other common cetaceans of this MPA are the long-finned pilot whale (*Globicephala melas*) (Fig. 25.9), the common dolphin (*Delphinus delphis*) and the striped dolphin (*Stenella coeruleoalba*), together with larger species such as the sperm whale (*Physeter macrocephalus*) and the orca (*Orcinus orca*). The occurrence of orca populations in this MPA is apparently related to the migration of one of their main prey, bluefin tuna (*Thunnus thynnus*), towards the Mediterranean Sea (Esteban et al. 2016). Moreover, a good variety of seabird species occurs in this MPA such as Scopoli's and Cory's shearwaters (*Calonectris diomedea* and *C. borealis*), northern gannet (*Morus bassanus*), sandwich tern (*Sterna sandvicensis*), the great skua (*Stercorarius skua*), the Balearic shearwater (*Puffinus mauretanicus*) and the European storm petrel (*Hydrobates pelagicus*) (Mateo-Ramírez et al. 2021). In the mainland, it is also possible to spot migratory species, especially soaring birds, that is including in this MPA along their migratory routes towards Africa such as the white stork (*Ciconia ciconia*), the black kite (*Milvus migrans*), the European honey buzzard (*Pernis apivorus*), the booted eagle (*Hieraaetus pennatus*), and the short-toed eagle (*Circaetus gallicus*). Other important birds occurring in the terrestrial part of this MPA are the Spanish imperial eagle (*Aquila adalberti*), the Egyptian vulture (*Neophron percnopterus*) and the bald ibis (*Geronticus eremita*), a critically endangered bird species that disappeared from Europe during the sixteenth century but has been introduced in specific Spanish locations of the Strait of Gibraltar at the beginning of the twenty-first century.

In the intertidal and shallow infralittoral rocks, some protected species display important populations such as the ribbed Mediterranean limpet (*Patella ferruginea*) and the saffian limpet (*Cymbula safiana*; more frequent in the eastern part of the MPA), the vermetid *Dendropoma lebeche* (more frequent in the western part) and some endemics of the Strait of Gibraltar such as the nassarid *Tritia tingitana* (now listed as "vunerable" in the National Catalogue of Threatened Species) and the cerithiid *Cassiella abylensis* (Gofas 1998; Barea-Azcón et al. 2008; Ruiz-Giráldez et al. 2011; Mateo-Ramírez et al. 2021). In some infralittoral hard bottoms (e.g. Tarifa Island), extensive seaweed meadows occur, including those with large kelps exposed to strong bottom currents (e.g. *Saccorhiza polyschides*, *Laminaria ochroleuca* and *Phyllariopsis* spp.) (Fig. 25.9); however, recent observations have indicated a strong decline of these meadows. In the infralittoral hard bottoms, the presence of the knobbed triton (*Charonia lampas*) and the chalice coral (*Astroides calycularis*) on the rocky bottoms represents indicators of a good environmental quality. Seagrass beds conformed by *Cymodocea nodosa* occur in specific areas with soft bottoms of this MPA (e.g. Tarifa), but the Mediterranean *Posidonia oceanica* does not occur in this and other parts of the Strait of Gibraltar.

The socio-economic importance of the MPA is mainly related to tourism activities (e.g. bird watching, whale watching, cultural sites—i.e. the ancient Roman city of Baelo Claudia), sports (e.g. windsurfing, kite surfing, scuba-diving) and artisanal fisheries. The main fishing modalities are small gears and purse seine, from the inshore fleets of Tarifa and Algeciras. There is a specific fishery for the blackspot seabream (*Pagellus bogaraveo*) being the most caught species in the area, mainly by the Tarifa fleet among the Spanish one. Other commercial species caught are horse mackerel (*Trachurus* spp.), blackbelly rosefish (*Helicolenus dactylopterus*), dusky grouper (*Epinephelus marginatus*), bluefin tuna (*Thunnus thynnus*) and Atlantic pomfret (*Brama brama*). There is also an important seafood fishing activity carried out mainly in the intertidal area and therefore on foot. In addition, sport fishing from boats and from the coast is very widespread in the area.

The main threats include marine pollution and eutrophication, maritime traffic, electric lines and wind turbines deployment (bird collisions) and development of human infrastructures (mainly beach bars, pathways, port expansion). Some invasive species such as the brown algae *Rugulopteryx okamurae* have recently colonized massively the rocky bottoms down to depth of 35 m and have displaced other photophilic seaweeds (García-Gómez et al. 2020). This seaweed was detected in 2015 for the first time in Ceuta, south of the Strait of Gibraltar, probably from ballast waters of a ship from Asian origin (Rosas-Guerrero et al. 2018; Baeza 2019). Since then, it has shown a surprising establishment and dispersion that has almost completely displaced the local biota, producing also important negative effects on the local fishermen. Later on, this brown algae has expanded massively on subtidal illuminated marine hard bottoms within the strait of Gibraltar and the adjacent Alboran Sea in the past two years, producing big impacts and economic losses to the fishermen from the area as well as serious impacts on the benthic communities previously established, with accumulation of hundreds of tons of seaweed in nearby beaches and wrack zones and hooks on fishing nets (Junta de Andalucía 2008–2019; García-Gómez et al. 2020). García-Gómez et al. (2020) described a possible linkage with global warming. On December 20, 2019, the Sub-Directorate General for Biodiversity and Natural Environment received the proposal for cataloguing *R. okamurae* as an invasive species, which includes the risk analysis prepared by the University of Málaga. Another invasive species has been recently detected, *Caulerpa cylindracea*, which probably arrived through maritime traffic between Ceuta and Tarifa (Pellón et al. 2017). Although the invasion is incipient, the species should be considered successfully established, because of its wide spread in this MPA (Pellón et al. 2017).

25.5.2 Paraje Natural de Marismas del Río Palmones and SAC: Fondos Marinos Marismas del Río Palmones SAC (Spain)

The Paraje Natural (Natural Area) de Marismas del Río Palmones (Palmones River salt marshes) was first declared a Natural Area (Paraje Natural) by the Andalusian government in 1989. Later on, it was proposed as SCI in January 2001 and declared as SCI in July 2006 and SAC (ES6120006) in November 2013. It is located on the salt marsh area of Palmones River within Algeciras Bay (northern Strait of Gibraltar) (Fig. 25.10), and it covers an area of 1 km^2 of fluvial, estuarine and terrestrial habitats, with a depth range from the coastline down to ca. 4 m. This SAC is connected with another SAC known as Fondos Marinos Marismas del Río Palmones (Marine Bottoms of Palmones River Salt Marshes) (ES6120033), which was proposed as SCI in May 2007 and declared SCI in December 2008 and SAC in August 2015. This last SAC covers an area of 1 km^2 of marine habitats with a depth range from the coastline to ca. 30 m. The mouth of the Palmones River is characterized by a salt marsh area consisting of two levels, high and low, bounded to the northwestern by a system of coalescent alluvial fans, to the east by a system of fossil dunes

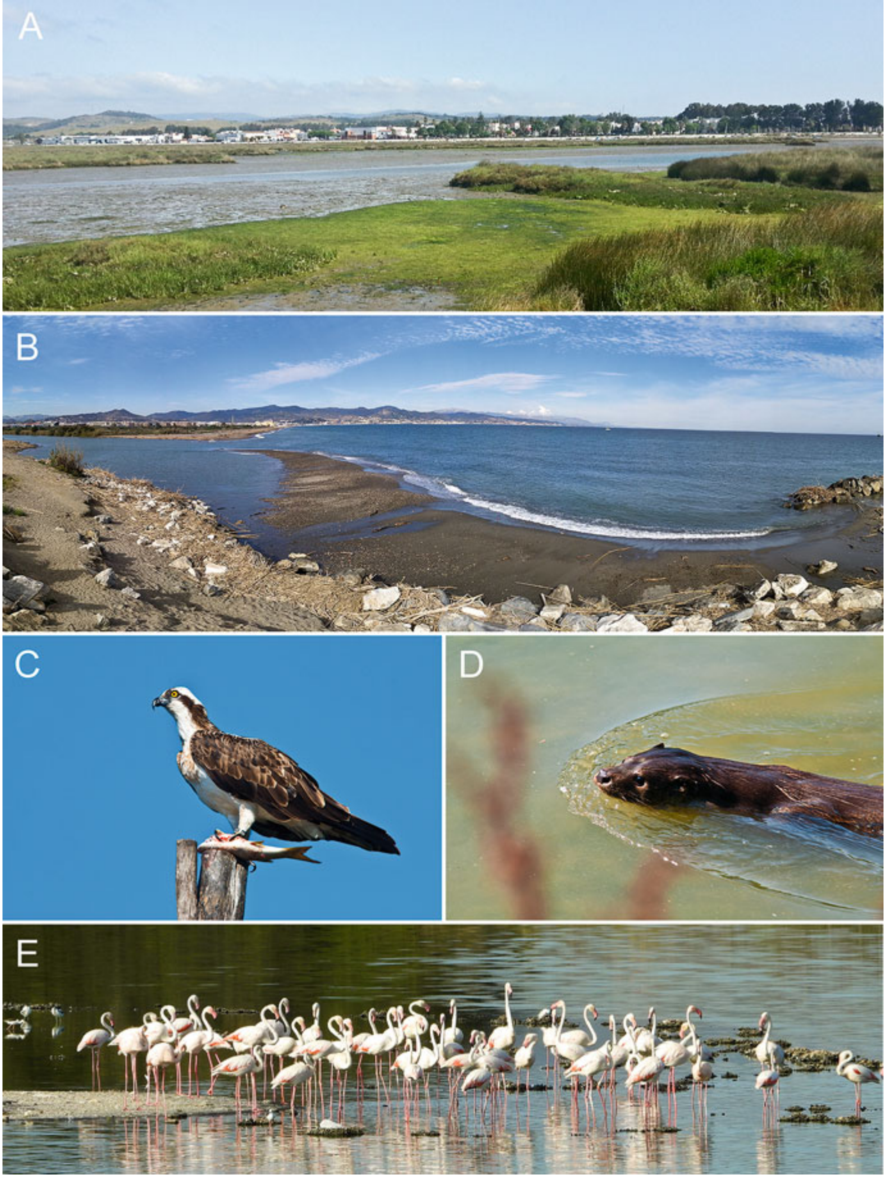

Fig. 25.10 (**a**) Partial view of the seabed of the Marismas del Río Palmones SAC with *Zostera noltei* intertidal meadows and *Spartina* sp.; (**b**) view of the mouth of the Guadalhorce River (Paraje Natural Desembocadura del río Guadalhorce); (**c**) the osprey (*Pandion haliaetus*) with a fish as a prey in the Guadalhorce River; (**d**) the Eurasian otter (*Lutra lutra*) in the Guadalhorce River; (**e**) groups of greater flamingos in the Paraje Natural Desembocadura del río Guadalhorce (**a** Raquel Sánchez de Pedro, Universidad de Málaga; **b** Ángel Mateo-Ramírez, Instituto Español de Oceanografía; **c**, **d** Eduardo Alba Padilla; **e** Antonio-Román Muñoz, Universidad de Málaga)

and to the south by another system of active dunes and the littoral barrier itself (IGME 2012a). In the marine part, outcrops of the Flysch Complex to the east of the Guadarranque River mouth stand out. The main marine-related habitats included in Annex I of the HD are estuaries (Habitat 1130), mudflats and sandflats not covered by seawater at low tide (1140) and sandbanks which are slightly covered by seawater all the time (1110) (Mateo-Ramírez et al. 2020b). Nevertheless, the first MPA also contains a wide variety of terrestrial habitats that are interconnected with the salt marshes.

These two MPAs were proposed because of the presence of more than 40 bird species, as well as two mammals (Eurasian otter *Lutra lutra*) and the bottle-nosed dolphin) (Fig. 25.10) and one reptile (the loggerhead turtle) included in Annex II of the HD, among other species. Due to its strategic geographical position, it is an important area for migratory species, mostly shorebirds and herons, but also raptors and passerines. During winter, it is frequently visited by species such as the white stork, the osprey (Fig. 25.10) and ducks (Mateo-Ramírez et al. 2021).

These MPAs represent one of the few coastal wetlands that still retain the characteristics of the original salt marshes and estuarine areas and the ecological values associated with these natural habitats (Habitats 1130, 1140, 1320, 1410, 1420 of the HD). The Marismas del Río Palmones has a strategic location for migratory birds that cross the Strait of Gibraltar, as a resting, feeding and even reproductive area. Different marine species also take advantage of the ecological characteristics of this space to develop basic functions of its life cycle, such as spawning and feeding. In the intertidal zone, it is possible to spot meadows of the small seagrass *Zostera noltei* (Fig. 25.10), which displays a very limited distribution in the Mediterranean Sea and experienced a strong regression in the last decades. The dune habitat plays an important role in the stabilization of the wetland, housing flora of interest at regional level such as the cat's ear (*Hypochaeris salzmanniana*), which occurs in the nesting habitat of the Kentish plover (*Charadrius alexandrinus*). The strictly marine SAC (Fondos Marinos Marismas del Río Palmones) plays an important role as a connecting element between the fluvial-estuarine and marine environments, for physical and biological continuity and ecological processes. The ecological connectivity of the fluvial-estuarine-marine system provided by the two MPAs is of importance for conservation of different fish species that frequent the marshes and/or the river, either as a refuge, breeding or nursery.

The socio-economic importance is related to tourism activities (e.g. bird watching), sport (e.g. windsurfing, kite surfing, recreational fishing) and artisanal fisheries mainly targeting some fish species (e.g. *Anguilla anguilla*, *Sparus aurata*) as well as estuarine bivalves such as the cockle (*Cerastoderma edule*) and other clams (*Ruditapes decussatus*, *Ruditapes philippinarum*, *Venerupis aureus*). The main threats include marine pollution because of the proximity of an industrial area and eutrophication, electric lines (bird collisions) and invasive species such as the brown seaweed *R. okamurae* (Junta de Andalucía 2008–2019).

25.5.3 Estrecho Oriental SAC (Spain)

The Estrecho Oriental SAC (Eastern Strait of Gibraltar) (ES6120032) was originally proposed as SCI in May 2007, approved as SCI in February 2009 and designated as SAC in December 2012. The SAC is located in the north-eastern part of the Strait of Gibraltar, bordering the Gibraltar Rock and La Línea de la Concepción (Cádiz), covering an area of 236 km^2 and a depth range between the coastline and ca. 880 m. The main geomorphological features of this SAC include two submarine canyons (Algeciras and La Línea) characterized by their proximity to the coastline. The Algeciras submarine canyon has a complex geomorphology with three sectors (headwall, middle course and distal sectors) where the different dominant sedimentary processes reflect a recent sedimentary dynamics along the system (Vázquez et al. 2017). The erosive processes dominate in the middle and distal sectors (especially in the incisive gullies and crescent-shaped bed forms) indicating sediment reworking caused probably by the interaction of the Mediterranean water mass. La Línea turbidite system comprises four architectural elements (canyon, channel, overbank and lobe deposits) that have developed from the continental shelf (15 m depth) towards the basin (835 m depth) (Palomino et al. 2019). Another interesting geomorphological structure present in this area is a pockmark field detected in the deepest part of the SAC (Vázquez et al. 2015b).

The abundance and richness of species are largely influenced by the strong currents and upwellings that are characteristic of the Strait of Gibraltar. This SAC was originally proposed because of the presence of four types of natural habitats included in Annex I of the HD: sandbanks which are slightly covered by seawater all the time (Habitat 1110), reefs (1170) (Fig. 25.11), submarine structures made by leaking gases (1180) and submerged or partially submerged sea caves (8330). Moreover, three species included in Annex II of the HD such as the bottle-nosed dolphin, common porpoise and the loggerhead turtle were also included in the original proposal because they are generally found in this SAC. A total of 14 species of birds were also included in the original proposal, including Audouin's gull (*Larus audouinii*), the Balearic shearwater (*Puffinus mauretanicus*) and Scopoli's shearwater (*Calonectris diomedea*). This area has also been indicated as important for other cetaceans such as the common dolphin, the stripped dolphin, the long-finned pilot whale and the sperm whale as well as for some invertebrates such as the chalice coral and the knobbed triton, classified as "Vulnerables" in the Catálogo Español de Especies Amenazadas (CEEA) and Catálogo Andaluz de Especies Amenazadas (CAEA), or the hatpin urchin (*Centrostephanus longispinus*) included in the Listado de Especies Silvestres en Régimen de Protección Especial (LESRPE) (Fig. 25.11) (Mateo-Ramírez et al. 2021). The location and extension of habitats and associated biota of this SAC have not been detailed in studies so far, but there is some knowledge on the populations of cetaceans (Notarbartolo Di Sciara et al. 2016). A recent study by Vázquez et al. (2015b) listed different habitat types and associated communities of La Línea submarine canyon, including sea pen and cerianthid communities, gorgonians aggregations and cold-water coral banks (mainly of the

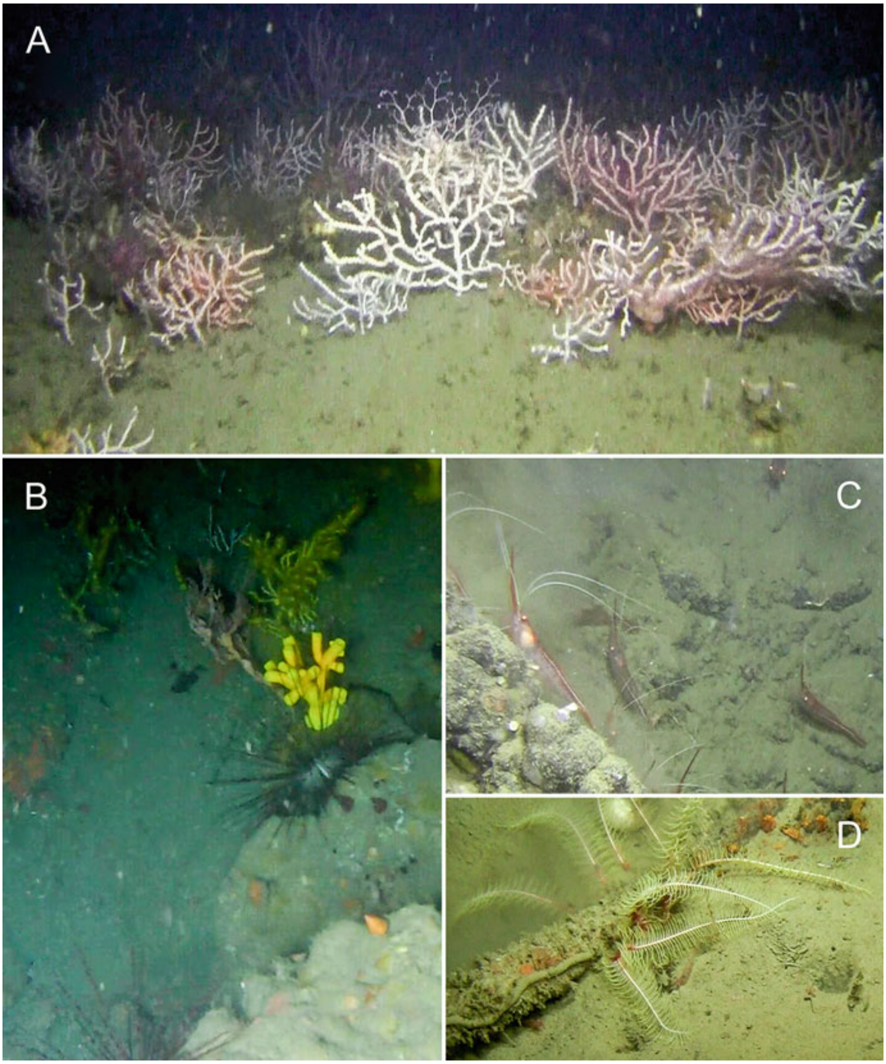

Fig. 25.11 Different habitats and species found in and around La Línea submarine canyon within the Estrecho Oriental SAC. (**a**) Gorgonian aggregations (dominating *Eunicella verrucosa*); (**b**) detail of two threatened species, the hatpin urchin (*Centrostephanus longispinus*) and the yellow tree coral *Dendrophyllia cornigera*; (**c**) crustacean decapods of the genus *Plesionika*; (**d**) the ophiuroid *Ophiothrix* sp. (Instituto Español de Oceanografía)

white coral *Madrepora oculata*, the yellow tree coral *Dendrophyllia cornigera* and *Coenocyathus*) (Fig. 25.11).

The socio-economic importance of this SAC is mainly related to fisheries, aquaculture and tourism. Regarding fisheries, the artisanal fleet of mechanized dredging that targets bivalves (e.g. *Acanthocardia tuberculata*, *Chamelea gallina*) is of importance in the infralittoral bottoms, together with the artisanal fleet using trammel nets, purse seine and longlines. One of the most valuable species fished in the area (with its eastern limit in front of Gibraltar) is the blackspot seabream which is caught by a locally designed hook line known as "voracera." In circalittoral and bathyal zones, bottom trawling is the most common fisheries type and is performed by trawlers coming from harbours located close by (e.g. Algeciras, Estepona). Aquaculture practices have experienced a decline in the last decades, but mussel culture still occurs close to the La Atunara harbour. An increasing socio-economic activity in the area since the 1980s is whale watching, mainly for spotting different species of dolphins and small cetaceans.

The main threats of this SAC include the intense marine traffic across the Strait of Gibraltar (mainly for cetaceans and marine turtles), bunkering (fuel delivery to anchored ships), marine pollution and eutrophication, coastal infrastructures and material deposition for beach regeneration, deployment of submarine cables and pipes, bottom trawling and other types of fisheries that may be in contact with the seabed (e.g. bottom-set longline). Recently, the area has also been colonized by some invasive macroalgae, being the brown seaweed *R. okamurae* the one that is causing the greatest impact on the habitats and socio-economic activities of the area (e.g. artisanal fisheries) (Junta de Andalucía 2008–2019).

25.5.4 Southern Waters of Gibraltar SAC (the United Kingdom)

The Southern Waters of Gibraltar was approved as SCI in July 2006; however, a protection regime has been in existence since 1991 through the Nature Protection Act. Following its approval as SCI, the Government of Gibraltar declared the Southern Waters of Gibraltar as a dual SAC (UKGIB0002) and SPA in March 2011. The MPA is located around the southernmost tip of Gibraltar, covering an area of 55 km^2 and a depth range from the coastline to ca. 800 m. This MPA overlaps with the Estrecho Oriental SAC proposed by the Spanish government, and the questions of sovereignty and jurisdiction over the waters around Gibraltar are still in debate between the United Kingdom and Spain (Fig. 25.9). Moreover, the withdrawal of the United Kingdom from the European Union (known as Brexit) in February 2020 may change the administrative status of this MPA because SACs are based on EU-derived legislation to member states.

Regarding its natural heritage, habitats and species in this MPA are those of Estrecho Oriental SAC. This MPA was proposed because of the presence of two types of natural habitats included in Annex I of the HD: reefs (Habitat 1170) and submerged or partially submerged sea caves (Habitat 8330). Moreover, species included in Annex II such as the bottlenose dolphin (Fig. 25.9), the loggerhead turtle and 36 bird species were also included in the original proposal Mateo-Ramírez et al. 2021). The MPA is also located in an important migration route for seabirds, and several species stop over and feed during their migratory journeys, such as Scopoli's shearwater. Other species use the area during winter in variable numbers depending on weather conditions (e.g. high numbers of northern gannets feeding during storms). The Rock hosts several resident breeding pairs of European shags (*Phalacrocorax aristotelis desmarestii*) (Fig. 25.8). Seasonal abundance due to migratory movements between the Mediterranean and the Atlantic results in a multitude of pelagic and predatory fishes along with cetaceans including the common and the stripped dolphins which breed in the Bay of Algeciras (Ruiz et al. 2018). The rocky shores display important populations of the endangered ribbed Mediterranean limpet (Espinosa et al. 2005; Mateo-Ramírez et al. 2021).

The socio-economic importance of the Southern Waters of Gibraltar is related to tourism activities (two beaches, viz. Camp Bay and Little Bay), sport and recreational angling along with scuba-diving and fisheries that are regulated through the Marine Protection Regulations of 2012 which build on the legislative provisions of the Nature Protection Act of 1991. The main threats are somehow similar to those of the Estrecho Oriental SAC and include marine traffic, bunkering, marine pollution and eutrophication, coastal infrastructures and material deposition for beach regeneration and increasing the coastal area and invasive species such as the brown seaweed *R. okamurae* (Junta de Andalucía 2008–2019).

25.5.5 Estuario del río Guadiaro SAC and Fondos Marinos Estuario del Río Guadiaro SAC (Spain)

The Estuario del río Guadiaro (Guadiaro River Estuary) was firstly designated Paraje Natural (Natural Area) in 1989 and posteriorly proposed as SCI (ES6120003) in December 1997 and declared as SCI in July 2006 and as SAC in November 2013. It is located on the western part of the Guadiaro River, between the Málaga and Cádiz provinces (northern Alboran Sea). It covers an area of less than 1 km^2 of estuarine and terrestrial habitats and a depth range from the coastline to ca. 4 m. It is connected with another SAC known as Fondos Marinos Estuario del río Guadiaro (Marine Bottoms of Guadiaro River Estuary) (ES6120034), which was proposed as SCI in May 2007 and declared SCI in December 2008 and SAC in August 2015. This last SAC covers an area of 1 km^2 of marine habitats with a depth range between the coastlines and ca. 20 m. The Guadiaro River Estuary is framed by hillside deposits from nearby reliefs located both to the south-west and north-east where sandstone and shales formations of the Flysch Complex predominate, Lower Miocene in age (IGME 2012b). The most resistant layers of these units also outcrop on the outer continental shelf, near the Guadiaro submarine canyon, although the inner continental shelf is dominated by the deltaic deposits related to the Guadiaro River mouth.

The main estuarine-marine-related habitats represented in these two SACs are estuaries (Habitat 1130 of the Annex I of the HD) and sandbanks which are slightly covered by seawater all the time (1110). Nevertheless, the first SAC also contains a couple of terrestrial-riparian habitats that are interconnected with the estuarine system. The former SAC contains lush riparian vegetation associated with the Guadiaro River, which constitutes the habitat of some migratory birds. Despite the small size of this wetland, its strategic location on the north-eastern side of the Strait of Gibraltar favours the presence of birds such as the purple heron (*Ardea purpurea*), the purple gallinule (*Porphyrio porphyrio*) or the common little bittern (*Ixobrychus minutus*). Other species are directly linked to the aquatic environment such as the southern straight-mouth nase (*Pseudochondrostoma willkommii* an endemic river fish of the south-western Iberian Peninsula), great sea lamprey (*Petromyzon marinus*) (included in Annex II of the HD) and the Eurasian otter (Mateo-Ramírez et al. 2021). The marine SAC represents an important area for the ecological connectivity function the Guadiaro River, being part of a fluvio-tidal system. The two SACs stand out as one of the few estuaries on the northern Alboran Sea, harbouring an ecosystem with an important ecological function, as a refuge, breeding and feeding area for various birds, invertebrates and fishes highlighting among them the great sea lamprey.

The socio-economic importance of the two SACs is related to tourism activities (e.g. bird watching), sport (e.g. windsurfing, kite surfing, recreational fishing) and artisanal fisheries. The main threats include marine pollution and eutrophication, electric lines (bird collisions), development of human infrastructures (mainly pathways), illegal aggregate extraction and debris deposition, invasive terrestrial plant species (e.g. *Arundo donax*, *Cortaderia selloana*) and the brown algae *R. okamurae* (Junta de Andalucía 2008–2019).

25.5.6 Fondos Marinos de la Bahía de Estepona SAC (Spain)

The Fondos Marinos de la Bahía de Estepona SAC (Estepona Bay Marine Bottoms) (ES6170036) (Fig. 25.12) was designated as SCI in December 2000 with an extension of 5.5 km^2, but it was increased to ca. 6 km^2 when it was declared as SAC in August 2016. This SAC is located in front of Estepona between the harbour of Estepona and Punta de la Plata, separated ca. 150 m from the coastline and with a depth range from 1 to ca. 50 m. The Estepona Bay geology is dominated by the outcrop of the Estepona Flysch units dated from Lower Miocene (IGME 1978a) and the submerged part by the development of sandy deposits associated with the littoral wedge.

This SAC was initially designated due to the presence of *Posidonia oceanica* beds (Habitat 1120 of the HD), which are associated with shallow rocky bottoms, at depths not exceeding 4 m. These are distributed in two zones which occupy an area of 0.023 km^2 and a linear coverage of less than 30%. Other habitats such as reefs (1170) and submerged or partially submerged sea caves (8330) were detected once the SAC was declared. Reefs are represented by photophilic biocoenoses of the upper infralittoral rock in calm mode (depth of 1.5–4 m) and by circalittoral hard bottoms with coralligenous communities and some kelp. The most characteristic

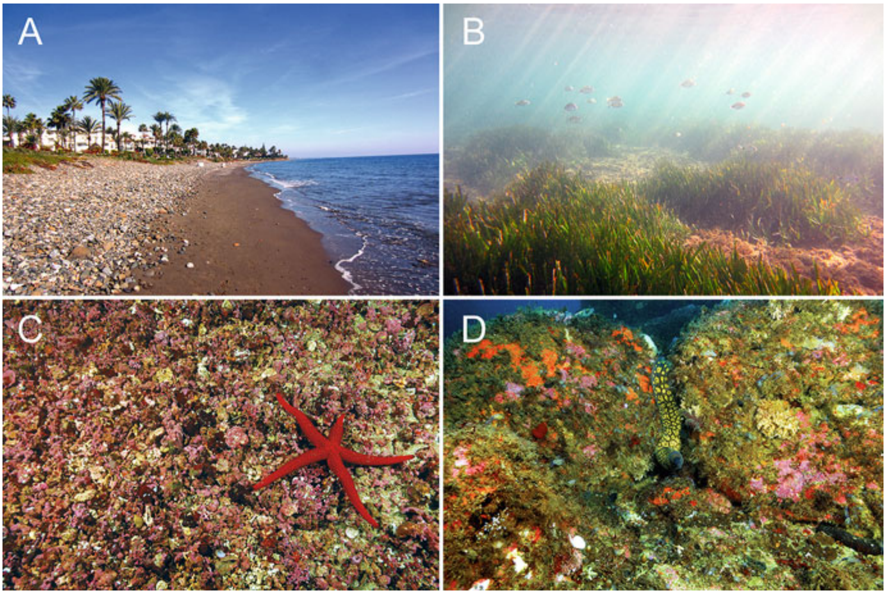

Fig. 25.12 SAC El Saladillo—Punta de Baños. (**a**) Partial view of the SAC coastline; (**b**) *Posidonia oceanica* meadows occurring in the shallow bottoms of the SAC; (**c**) rhodolith beds covering the deepest bottoms of the SAC; (**d**) specimen of *Muraena helena* in the coralligenous bottoms of Placer de las Bóvedas, a reef mound included in this SAC (**a**, **b** Ángel Mateo-Ramírez; **c**, **d** OCEANA, Juan Carlos Calvin)

macroalgae vary with depth, including *Sargassum vulgare*, *Cystoseira usneoides*, *L. ochroleuca*, *P. purpurascens*, *Mesophyllum alternans*, *Lithophyllum sticiforme*, *Lithophyllum incrustans* or *Peyssonnelia rubra*. Regarding fauna, it is interesting to highlight the presence of species included in Annexes II and III of the HD such as the molluscs saffian limpet and knobbed triton, the broad lobster (*Scyllarus arctus*), the red sea squirt (*Halocynthia papillosa*), the bryozoan ross coral (*Pentapora fascialis*) or the fishes seahorse (*Hippocampus hippocampus*) or dusky grouper. Other species occurring in this MPA are included in conservation or threatened lists (e.g. CAEA, Libro Rojo de los de Invertebrados de Andalucía) such as sponges (*Spongia* sp.) or gorgonians (*Eunicella verrucosa*, *Eunicella labiata*, *Leptogorgia sarmentosa*). The cave habitats have special relevance because of the fragility and vulnerability of their associated species, including invertebrates from Annex II of the HD such as the hatpin urchin or the chalice coral (Mateo-Ramírez et al. 2021).

Tourism is one important socio-economic activity with a large number of hotels, beach bars, nautical channels and boathouses located nearby. The marina of Estepona has a large number of moorings (more than 400). Other economic activities are scuba-diving, nautical activities and recreational fisheries. The fishing port of Estepona has an important fishing activity, with a fleet of 75 boats, representing the second in importance in the Málaga province. The majority of these boats are dedicated to small-scale gear (60 boats) as well as bottom trawling (7) and purse seining (6). The main target species are the European sardine (*Sardina pilchardus*), anchovy (*Engraulis encrasicolus*), Atlantic bonito (*Sarda sarda*) and European hake (*Merluccius merluccius*) as well as the common octopus (*Octopus vulgaris*). Regarding seafood fisheries, the target species in the SAC include bivalves such as the banded venus (*Polititapes rhomboides*), the warty venus (*Venus verrucosa*), striped venus clam (*Chamelea gallina*), wedge clam (*Donax trunculus*), smooth clam (*Callista chione*) and rough cockle (*Acanthocardia tuberculata*) and St. James' shell (*Pecten maximus*); gastropods such as the trunk murex (*Hexaplex trunculus*) and the purple dye murex (*Bolinus brandaris*); the sea anemone (*Anemonia sulcata)* and echinoderms such as the stony sea urchin (*Paracentrotus lividus*).

The main threats are related with tourism, housing developments and maritime constructions that can cause burial and/or physical alteration of the seabed, modifications of environmental characteristics (increase in turbidity, modification of stream dynamics, erosion and sedimentation processes), marine pollution and eutrophication. In relation with scuba-diving, some impacts can be caused by the damage produced by physical contact, accumulation of bubbles, sediment resuspension, and collection of protected species or detachment of colonies of chalice coral from the substrate. Regarding fisheries, the main impacts are mechanical abrasion of the seabed, marine pollution and illegal collection of protected species. Different invasive species have also been detected in the SAC such as *A. taxiformis*, *C. cylindracea* and the brown seaweed *R. okamurae* (Junta de Andalucía 2008–2019).

25.5.7 El Saladillo-Punta de Baños SAC (Spain)

El Saladillo-Punta de Baños SAC (Saladillo-Baños Point) (ES6170037) (Fig. 25.12) was proposed as SCI in May 2007, designated as SCI in November 2012 and designated as SAC in August 2016. This SAC is located on the continental shelf, between Marbella and Estepona, covering an area of ca. 32 km^2 and a depth range between the coastline and ca. 50 m. It also includes the rocky knoll known as "Placer de las Bóvedas" that rises from depth of 60 m to 23 m located 5.6 km from the coast and situated close to the head of a submarine canyon. The coast is controlled by a series of coalescing alluvial fans from the nearby reliefs generated in different phases (IGME 1978b), with the seabed close to the coast characterized by hardened bottoms of various characteristics and rocky outcrops.

This SAC was firstly proposed by the presence of *P. oceanica* beds (Habitat 1120 of the HD) (Mateo-Ramírez et al. 2020b). The small *P. oceanica* patches develop on rocky outcrops between depth of 3.5 and 6 m covering an estimated area of ca. 0.01 km^2 (Fig. 25.12). Nevertheless, rocky reefs (Habitat 1170) were also included in this SAC after the inclusion of Placer de las Bóvedas inside the SAC. The rocky bottoms are represented by *Cystoseira* spp. beds on rock and detritic bottoms as well as by precoralligenous and coralligenous communities in the area of Placer de las Bóvedas, occupying 3.03 km^2 (Fig. 25.12). The presence of rhodophytes such as *Lithophyllum stictaeforme* and *Peyssonnelia* spp. is highlighted

(Fig. 25.12), as well as species included in the Annex II of Bern and Barcelona convention such as the chalice coral, the knobbed triton or the hatpin urchin. Other species included in conventions and threatened species lists are the gorgonians *Leptogorgia sarmentosa*, *Eunicella gazella*, *E. labiata, E. verrucosa* and *Paramuricea clavata*; the orange tree coral; the echinoderms *A. mediterraneus* and the smooth starfish (*Hacelia attenuata*), the bryozoan ross coral, the decapod crustaceans spider crab (*Maja squinado*) and the spiny lobster (*Palinurus elephas*) and fishes such as the dusky grouper (Mateo-Ramírez et al. 2021). Another interesting habitat occurring in the SAC is the rhodolith beds, which are especially abundant between 25 and 35 m around Placer de las Bóvedas. These rhodolith beds are one of the very few occurring along the coasts of Málaga and are conformed by the coralligenous algae *Phymatolithon calcareum* and *Lithothamnion valens*.

The socio-economic importance of this SAC is mainly related to tourism, fisheries and aquatic activities such as scuba-diving, sport fishing and recreational boats, all of them of importance in the area around Placer de las Bóvedas. Regarding tourism, there is a high coastal development and urban services in the SAC and adjacent areas, including beach bars, hammocks, nautical channels and boathouses. The fishing fleet operating in this SAC is the same in the Fondos Marinos de la Bahía de Estepona SAC. The main threats are punctual mechanical seabed abrasion (anchoring, artisanal fishery), bottom trawling in prohibited bottoms, marine pollution (Guadalmansa EDAR waste water treatment plant, longlines, plastic debris and litter), accidental capture of protected species and seabed alterations (increase in turbidity and sedimentation) due to beach restoration. At present, in addition to the occurrence of the algae *C. cylindracea* and *A. taxiformis*, the new recently arrived brown algae *R. okamurae* is increasing its populations (Junta de Andalucía 2008–2019). This species has spread eastwards from the Strait of Gibraltar, producing impacts on fisheries and tourism because of the enormous quantity of seaweed wastes.

25.5.8 Calahonda SAC (Spain)

The coastline between Punta de Calaburras and Calahonda in the Málaga province was proposed as SCI (Fig. 25.13) in January 2001, approved as SCI in July 2006 and designated as SAC in August 2015 (Calahonda, ES6170030). The SAC is located in along ca. 10 km of coastline between Fuengirola and Marbella and an area of 14 km^2 and a depth range from the coastline to ca. 30 m. The coastal geomorphology and lithology display natural rocky outcrops in very few locations along the coast of Málaga province, being the area of Calahonda one of them. This area is characterized by rocky outcrops, abrasion surfaces and sandy deposits on the infralittoral wedge (Fig. 25.13). The main characteristics of this coastal sector are an active dune belt located to the west of the Cabopino harbour (also known as Artola harbour) and an alluvial fan system between the eolic system and the Palaeozoic rock outcrops that constitute the reliefs located to the north (IGME 1978c).

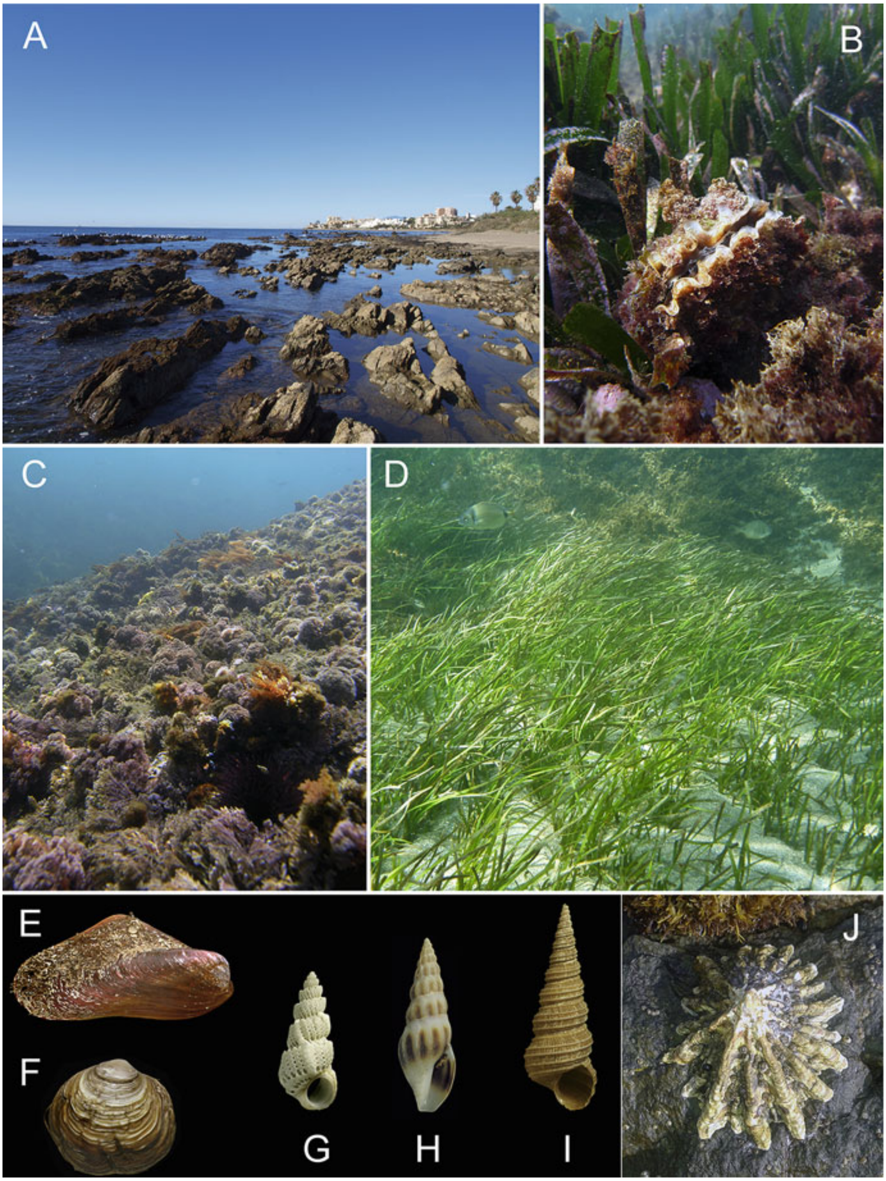

Fig. 25.13 Different habitats and species of interest detected within the Calahonda SAC. (**a**) Intertidal rocky outcrops; (**b**) *Pinna rudis* in a *Posidonia oceanica* meadow; (**c**) photophilous algal communities dominated by *Halopteris scoparia*; (**d**) *Cymodocea nodosa* meadows on soft bottoms and molluscs of African affinity and/or included in conservation lists (**e** *Modiolus lulat*, **f** *Ungulina rubra*, **g** *Cirsotrema pumiceum*, **h** *Bela powisiana*, **i** *Mathilda quadricarinata*, **j** *Patella ferruginea*) (**a**, **c**, **e**, **f**, **g**, **h**, **i** Javier Urra; **b** Pablo Marina, **d** Ángel Mateo-Ramírez; **j** Serge Gofas, Universidad de Málaga)

In the north-western sector of the Alboran basin, there are upwellings of cold, deep and nutrient-rich waters due to hydrological and oceanographical features that promote an abundant phytoplankton production (Sarhan et al. 2000; García Raso et al. 2010). This high productivity and nutrient availability, together with the diversity of soft and hard bottoms, promote a great diversity of species which have led the Calahonda SAC to be recognized as a biodiversity hotspot for the European waters (García Raso et al. 2010).

This MPA was proposed because of the presence of three types of habitats included in Annex I of the HD: sandbanks which are slightly covered by seawater all the time (Habitat 1110), *Posidonia* beds (1120) and reefs (1170) (Fig. 25.13) (Mateo-Ramírez et al. 2020b). Moreover, two species included in Annex II of the HD such as the bottle-nosed dolphin and the loggerhead turtle and three species included in the Annex IV of the HD such as the hatpin urchin, the ribbed Mediterranean limpet and the noble pen shell (*Pinna nobilis*) were also included in the original proposal (Fig. 25.13). The offshore area bordering Calahonda is of importance for other cetaceans such as the common dolphin, the stripped dolphin and the long-finned pilot whale, all of them included in Annex IV of the HD. In addition, fin whales (*Balaenoptera physalus*) and occasionally orca, pilot whales and common minke whales (*Balaenoptera acutorostrata*) (also included in the Annex IV) are spotted close to the SAC (Mateo-Ramírez et al. 2021).

Other species with different protection status occur in the SAC, with the presence of emblematic species with a key role in the ecosystem, and therefore representing good ecosystem health indicators. This group of species includes the seagrass *C. nodosa*, included in the Annex I (strictly protected flora species) of the Bern Convention and in the Annex II (endangered or threatened species) of the BC, as well as two sponges (e.g. common antlers sponge (*Axinella polypoides*)), nine molluscs (e.g. knobbed triton, zoned mitre (*Episcomitra zonata*)), five crustaceans (e.g. spiny lobster) and two echinoderms (e.g. purple sea star), all of them included in Annexes II and III of the BC and some of them classified as “Vulnerable” or “in Risk of Extinction” in the CEEA and CAEA (Mateo-Ramírez et al. 2021). The location and extension of some habitats and their associated biota of this SAC have been studied in detail by García Raso et al. (2010), with detailed works focused on dominant faunal groups such as molluscs (Urra et al. 2011, 2013a, 2013b, 2017) and decapod crustaceans (García Muñoz et al. 2008; Mateo Ramírez and García Raso 2012; Mateo-Ramírez et al. 2016, 2018), including the description of some new species for the science such as *Pagurus pseudosculptimanus* (García Muñoz et al. 2014). A large proportion of tropical West African species is found in the SAC, with some of them reaching their distributional limit towards the Mediterranean Sea, such as the bivalves *Ungulina rubra* and *Modiolus lulat* (Fig. 25.13). The rocky outcrop located at the western sector of the SAC (locally known as “Laja del Almirante”) harbours an interesting coralligenous community, which is considerably shallower than in other Mediterranean areas due to the high turbidity levels. This coralligenous community is conformed, besides mobile groups (e.g. molluscs and decapods), by colonial organisms such as the gorgonians *Eunicella singularis*, *E. verrucosa*, *E. labiata* and *L. sarmentosa* as well as the *Pentapora fascialis* and

Myriapora truncata (Fig. 25.13), which are supported by the almost permanent high-nutrient upwellings occurring in the area. The presence of these bioconstructing species promotes a higher complexity that enhances the number of niches that can be potentially occupied by a large number of species, as found in Calahonda for decapod crustaceans (García Muñoz et al. 2008) and molluscs (Urra et al. 2012).

The socio-economic importance of this SAC is mainly related to fisheries, both professional and recreational, and tourism. Regarding fisheries, small-scale gear fleets operating in the area include those using mechanical dredges targeting the wedge clam, the striped venus clam, the smooth clam and the rough cockle, with the former three species being the most important ones in the regional market. Other artisanal fleets include those using minor gears, purse seine and traps. Main professional fishing harbours are located close by in Fuengirola and Marbella, whereas recreational ones are located in Cabopino (Marbella) and Fuengirola. The tourism sector is essential for the economy of the area. The strategic location within the Costa del Sol attracts many tourists because of its warm and sunny weather all year-round, beaches and restaurants, with many small lodging establishments and hotels that offer overnight accommodation along the coastline of the SAC.

The main threats include the use of fishing gears that may cause seabed abrasion, especially when impacting the seagrass meadows; non-professional shell fishing such as the collection of intertidal sea anemones, holothurians, urchins and limpets; pollution by marine outfalls discharging local or industrial waste waters and uncontrolled dumping; the alteration of the coastline by coastal infrastructures and material deposition for beach regeneration; the extraction of aggregates from marine deposits; and the presence of invasive species. The presence of the new invasive species *R. okamurae* should be highlighted, which was detected at a depth of 20 m in the Laja del Almirante in 2018 (Junta de Andalucía 2008–2019).

25.5.9 Paraje Natural Desembocadura del río Guadalhorce (Spain)

The Paraje Natural Desembocadura del río Guadalhorce (Mouth of the River Guadalhorce Natural Area) is a coastal wetland included in the Inventory of Wetlands of Andalusia (code 617024) (Fig. 25.10) and listed as IBA by SEO/BirdLife (ES224). This site was proposed as Natural Area in July 1989, but before that, the council of Málaga City declared it as a protected area in 1982 and prohibited housing developments. This MPA is located westwards of Málaga, covering an area of ca. 0.7 km^2. The original marsh at the mouth of the river was reduced by the construction of the Guadalhorce Dam (1914–1921). Later on, although it was an agricultural area, the extraction of aggregates began in the 1970s, forming the current lagoons which brought the water to the surface. Since then, it was protected after several discussions and agreements with the previous land owners. Nowadays, it is delimited by two channels of the Guadalhorce River, plus a third auxiliary one, forming an alluvial delta composed of detritic carbonated materials in which there are five small artificial lagoons of brackish and of fresh waters covering the gaps from the extraction of aggregates. The Guadalhorce River mouth is characterized by the development of a deltaic deposit inside an estuary that has progressively filled. The fluvial deposits and the littoral wedge are separated by a dune belt. In the submerged area, the fluvial flows and sediment loads form a submarine deltaic deposit off the Guadalhorce River, representing the main geomorphological feature. These deposits are generally composed of muddy sediments (Medialdea et al. 2014). Other submarine morphologies such as undulations field and creeping areas developed on the submarine deltaic deposit, infralittoral wedge, scarp or abrasion surface areas occur off the coast of this MPA (Fernández-Salas et al. 2015). In adjacent areas to the deltaic system, the sedimentary cover is composed of fine and coarse sands. The predominant littoral drift to the south-west produces a dynamic of active bars oblique to the coastline.

In the wetland area, different habitats included in the Annex I of the HD are present such as coastal lagoons (Habitat 1150) or Mediterranean and thermo-Atlantic halonitrophilic thickets (*Sarcocornetea fruticosi*) (1420) (Mateo-Ramírez et al. 2020b). The salt marsh and riparian vegetation is diverse, including *Sarcocornia perennis*, *Scirpus maritimus*, *Juncus maritimus*, *Othanthus maritimus*, *Medicago marina*, *Ruppia maritima* and *Tamarix canariensis*.

This MPA was designed because of its high ornithological diversity and its value as a stopover area for migratory birds. A large number of species included in the BD and lists of protections and conventions (Mateo-Ramírez et al. 2021) use this MPA. Although it is located within the urban footprint of Málaga City and despite its small size, it is unique for its extremely high diversity of birds, remarkable in the context of the Iberian Peninsula. The diversity and number of individuals seen rise dramatically during spring and autumn migrations and also during winter, when numerous ducks (northern shovelers (*Anas clypeata*), common pochards (*Aythya ferina*) and Eurasian teals (*Anas crecca*)), grebes (little grebe (*Tachybaptus ruficollis*) and black-necked grebe (*Podiceps nigricollis*)), egrets, herons, greater flamingos, great cormorants (*Phalacrocorax carbo*), gulls (e.g. Mediterranean, black-headed Audouin's, lesser black-backed and slender-billed gulls), sandpipers, plovers, raptors (mostly ospreys, booted eagles (*Hieraaetus pennatus*) and marsh harriers (*Circus aeruginosus*)) (Mateo-Ramírez et al. 2021) and a variety of passerines can be observed. The presence of three Critically Endangered Species along the year is particularly noteworthy, the ferruginous duck (*Aythya nyroca*), the marbled teal (*Marmaronetta angustirostris*) and the white-headed duck (*Oxyura leucocephala*), which breeds in the lagoons. Along the coastal fringe, it is possible to watch a variety of seabirds, such as Scopoli's and Balearic shearwaters, terns and gulls, during migration, and northern gannets and common scoters (*Melanitta nigra*) during winter (Mateo-Ramírez et al. 2021). The beach hosts a breeding population of Kentish plovers. Other protected or endangered vertebrate species occurring on this MPA are the Eurasian otter (Fig. 25.10) and the Mediterranean turtle (*Mauremys leprosa*), among others (Mateo-Ramírez et al. 2021).

The main socio-economic values are tourism and environmental education in a protected area located close to Málaga, the largest city in the Alboran Sea. The tourism and guided tours oriented to environmental education can enjoy a natural beach, trails and observatories for exploring the high diversity of birds, with up to 80 different species spotted within the same day and 308 different species observed in the area to date. On the other hand, the protected area contains historical heritages, such as the Phoenician city of Cerro del Villar (S. IX BC).

The main threat of this natural area is the pressure of Málaga City over this MPA (e.g. Málaga wasterwater treatment plant). Other important threats are the introduction of invasive species such as the Florida turtle (*Trachemys scripta elegans*), which compete with some native species (e.g. *M. leprosa*), or the monk parakeet (*Myiopsitta monachus*). Another important factor is related to the high affluence of people to the beach during spring and summer months that do not respect the delimited breeding zone in the MPA. The lack of specific regulations in the number of visitors leaves opportunities for bad practice.

25.5.10 Acantilados y Fondos Marinos de la Punta de la Mona SAC (Spain)

The Acantilados y Fondos Marinos de la Punta de la Mona SAC (Cliffs and Marine Bottoms of Punta de la Mona) (ES6140016) were proposed as SIC in December 2003, approved in July 2006 and appointed SAC in August 2015. This SAC that occupies an area of ca. 1.2 km^2 is located in the coast of Almuñécar (Granada), limiting to the east with the Peñón de las Caballas and to the west with the northern part of Las Terrazas development. It comprises small strips of coastal cliffs and a coastal strip, with a depth range from the coastline to depth of ca. 60 m. Similar geological characteristics as the ones described in the Maro-Cerro Gordo Cliffs occur in this MPA (Sect. 4.1 of this chapter).

Regarding habitats, its election as SCI was due to the presence of rocky bottoms (reefs, Habitat 1170 of the HD), which in some areas reach depth of 49 m and harbour precoralligenous and coralligenous communities with a great richness of benthic species (Mateo-Ramírez et al. 2020b). Another habitat type is represented by submerged and semi-submerged caves (8330). Some threatened species, such as the ribbed Mediterranean limpet, the chalice coral, the hatpin urchin and the common antlers sponge, inhabit these areas (Fig. 25.14). Populations of other species included in the Libro Rojo de los Invertebrados de Andalucía, such as the gorgonian violescent sea-whip and the scleractinian orange tree coral, are also present in this SAC (Fig. 25.14) (Mateo-Ramírez et al. 2021).

Snorkelling and scuba-diving, apart from other touristic activities, are the main socio-economic activities, with several diving centres offering diving tours and with a large number of divers using Marina del Este beach as the point of origin for their dives. Small-scale fishing gear, with two boats that use the trammel nets, longlines and pots, targeting cephalopods and rockfish, operates in the SAC. Since 1980, this area has been subjected to a continuous series of anthropogenic disturbances. The main one was the construction of the artificial beach of Marina del Este, in the inlet

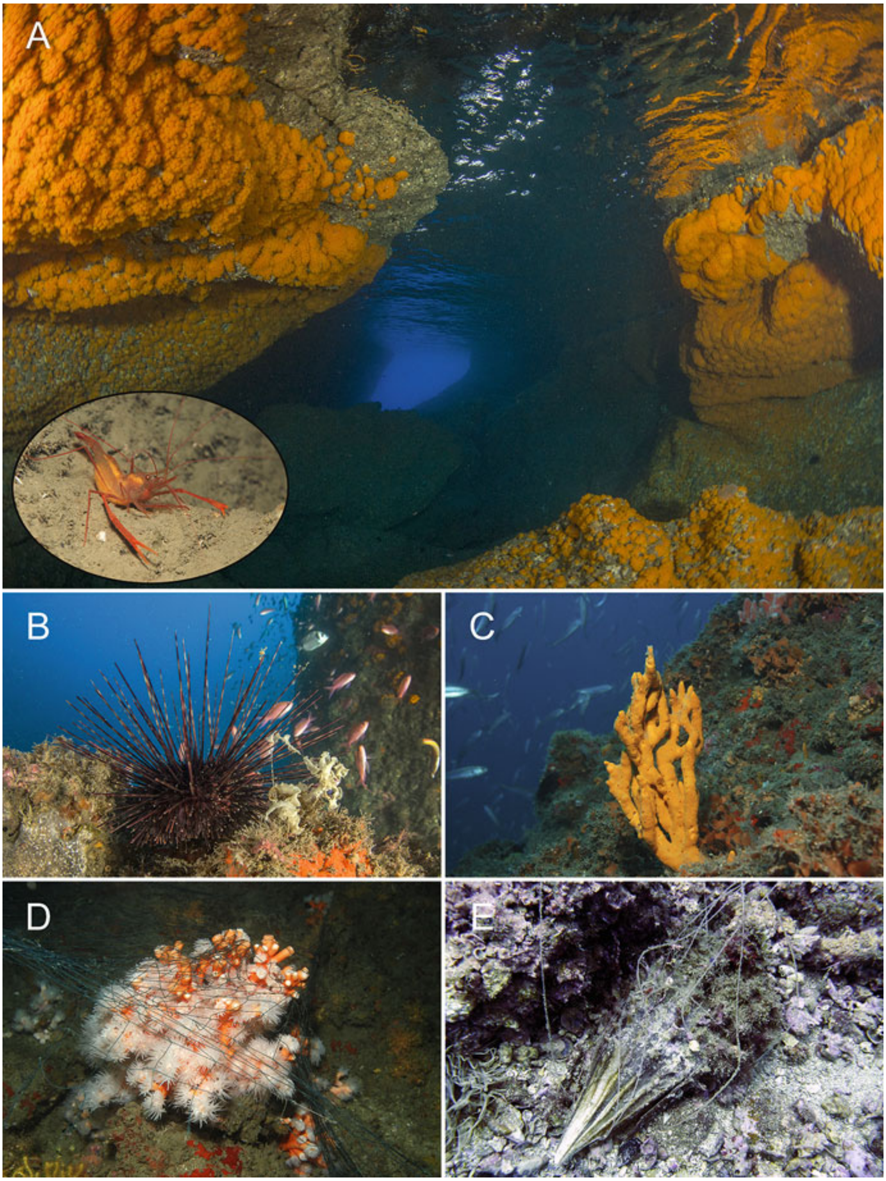

Fig. 25.14 Different habitats and threatened species present in the Acantilados y Fondos Marinos de la Punta de la Mona SAC as well as impacts caused by different fishing gears. (**a**) The chalice coral (*Astroides calycularis*) covering submerged cave walls and the decapod (*Stenopus spinosus*) associated with this sciaphilic habitat; (**b**) the hatpin sea urchin (*Centrostephanus longispinus*); (**c**) the common antlers sponge (*Axinella polypoides*); (**d**) the orange tree coral (*Dendrophyllia ramea*) hooked on a trammel net; (**e**) individual of the rough pen shell (*Pinna rudis*) uprooted by a fishing line (Luis Sánchez Tocino, Universidad de Granada)

of Los Berengueles, and the recreational harbour of Marina del Este in the Peñón de las Caballas, destroying areas with a high environmental value. These two constructions resulted in a massive housing development that still continues with the construction of new urbanizations. These cliffs hosted the last breeding pair of ospreys in mainland Spain, which disappeared in 1982 due to the urban development pressures. Although osprey has been recently reintroduced in western Andalusia, it can be observed only during migration. The increase of tourism led to an increase in waste water discharges, boat anchoring, the number of sport fishers, illegal fishing and shellfish, etc. (Fig. 25.14). Fishing, both artisanal and sport, has led to the disappearance of large serranids (e.g. large dusky grouper) and other large fishes, and it has had a great impact on benthic communities. The ropes of pots and longlines, the trammel nets and fishing lines and hooks tear or split sponges and colonies of corals, gorgonians and bryozoans. The designation of this SAC should be supported by an effective management plan regulating all the activities that are causing current impacts.

25.5.11 Acantilados y Fondos Marinos Tesorillo-Salobreña SAC (Spain)

The Acantilados y Fondos Marinos Tesorillo-Salobreña SAC (Coastal Cliffs and Marine Bottoms of Tesorillo-Salobreña) (ES6140013) was proposed as SCI in January 2001, approved in July 2006 and appointed as SAC in August 2015. This SAC occupies an area of ca. 10 km^2 and is located in the coasts of Almuñécar and Salobreña (Granada), limiting eastwards with El Pozuelo beach and westwards with Caleta de Salobreña. It comprises coastal cliffs reaching up to 15 m in height from the sea and a marine strip with a depth range from the coastline to depth of ca. 70 m. The cliffs located west of Salobreña correspond to graphite schists with quartzites and quartz mica schists with a medium to high metamorphic degree; although the town of Salobreña is located on an outcrop of marbles, all of them are of Palaeozoic age belonging to units of the Alpujarride Complex. To the west of Salobreña, the submerged marine area is characterized by muddy and sandy sediments on the infralittoral wedge, while the east corresponds to the deltaic plain and the submarine prodeltaic area of the Guadalfeo deltaic system.

Its election as SCI was due to the presence of *Zostera marina* meadows (Habitat 1110 of the HD), which unfortunately disappeared in 2009, and to the marine bird diversity with protected species such as sanderlings (*Calidris alba*), the little egret (*Egretta garzetta*) or the Balearic shearwater, as well as cetacean species as the common or bottle-nosed dolphins, among others (Mateo-Ramírez et al. 2021). The reef habitat (Habitat 1170 from HD) is well represented in this SAC, with threatened species such the ribbed Mediterranean limpet, the chalice coral and numerous colonies of the gorgonian *L. sarmentosa* can be also highlighted (Fig. 25.15) (Mateo-Ramírez et al. 2021). Since 2016, the presence of an incipient *C. nodosa*

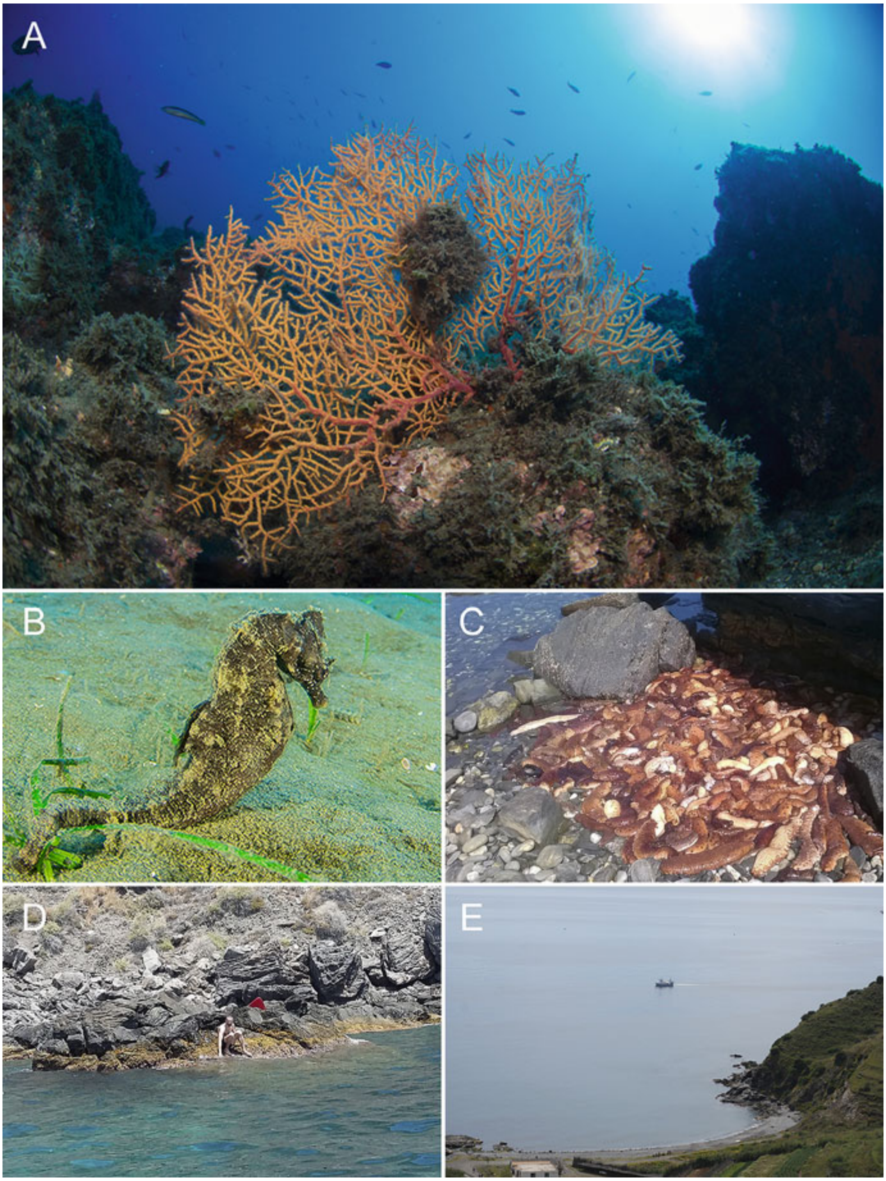

Fig. 25.15 Acantilados y Fondos Marinos Tesorillo-Salobreña SAC. (**a**) Colony of the gorgonian *Leptogorgia sarmentosa*; (**b**) the seahorse *Hippocampus hippocampus* in a fragmented *Cymodocea nodosa* meadow. Some threats of the SAC; (**c**) eviscerated holothurians in a small creek; (**d**) furtive shellfish poaching; (**e**) bottom trawler fishing close to one of the beaches (**a**, **b**, **d**, **e** Luis Sánchez Tocino, Universidad de Granada; **c** http://litoraldegranada.ugr.es)

meadow has been observed in the bottoms previously occupied by *Z. marina* (Fig. 25.15).

Tourism is the main socio-economic activity, especially in Almuñécar, where beaches for swimming are more accessible by car. Recreational and artisanal fishing are both used in this area, with some of the target species being common pandora (*Pagellus erythrinus*), seabream (*Pagellus* spp.), forkbeard (*Phycis phycis*), the cuttlefish (*Sepia officinalis*), striped venus clam and the rough cockle, among others.

There is also an installation of aquaculture cages in the north-eastern part that is currently obsolete. The illegal capture of invertebrates is one of the main threats, both the furtive shell fishing of molluscs and crustaceans, which occurs especially during the summer months, as well as the catch of the Sea Anemone. The great demand of this anemone in other Andalusian provinces has practically resulted in its disappearance in this area. In recent years, the illegal catch of holothurians for the Chinese market must be also mentioned (Fig. 25.15). The different types of fishing, without specific restricting rules, have resulted in a decrease of fish populations. Particularly important is the pressure on the large serranids such as the dusky and goldblotch groupers. Poachers catch juveniles of these species that they sell to bars and restaurants. Although less frequently, some trawlers do not respect the limits of depth and/or distance, approaching a few metres from the coast. On some occasions, the remains and debris of works carried out on the National 340 road and in housing developments are dumped on the cliffs, covering the vegetation and sometimes reaching the mesolittoral rocks.

25.5.12 Acantilados y Fondos Marinos de Calahonda-Castell de Ferro SAC (Spain)

The cliffs and marine bottoms located between the rocky coastlines of Gualchos and Motril were proposed as the Acantilados y Fondos Marinos de Calahonda-Castell de Ferro SIC (Cliffs and Marine Bottoms of Calahonda-Castell de Ferro) (ES6140014) in December 2003, approved as SCI in July 2006 and designated as SAC in August 2015. The SAC is located in the central part of the Granada coast and covers an area of ca. 9 km^2 with a depth range between the coastline and ca. 65 m. The coastal strip within the SAC is mainly configured by high cliffs and rocky formations with submerged and semi-submerged caves promoted by karst processes (Fig. 25.16). The cliffs are conformed by phyllites and quartzites, Lower to Middle Triassic age, and limestones or marbles of Middle to Upper Triassic age; however, a unit of graphite schists with quartzites of medium metamorphic grade and Palaeozoic age emerges to the east of Cape Sacratif and Castell de Ferro (IGME 1981). There is only one pebble beach within the SAC known as "Rijana beach" with ca. 250 m length and located in a sheltered area. "The Llanos de Carchuna" has been characterized as a Holocene delta fan system. Massive rocky outcrops occur on the shelf, as well as unconsolidated sediments covering from very fine sand to medium-coarse sand on

Fig. 25.16 The Acantilados y Fondos Marinos de Calahonda-Castell de Ferro SAC. (**a**) Some cliffs and submerged caves present in the SAC; (**b**) a close-up of the pagurid *Pagurus mbizi*, a species of western Africa affinity; (**c**) the noble pen shell (*Pinna nobilis*), the largest bivalve in the Mediterranean Sea, standing in a *Posidonia oceanica* meadow; (**d**) pair of yellow-legged gull (*Larus michahellis*) (**a**, **c** Pablo Marín; **b** Instituto Español de Oceanografía; **e** Antonio-Román Muñoz, Universidad de Málaga)

the infralittoral wedge and continental shelf. Off Castell de Ferro, the Gualchos River has generated small prodeltaic deposits both to the west and east (Bárcenas et al. 2018).

The Atlantic anticyclone gyre promotes an upwelling of cold, deep and nutrient-rich waters along the coasts of Málaga and Granada, which is enhanced by the westerly winds that usually blow in this area (Cebrián and Ballesteros 2004). This makes the area within the SAC to be subjected to a high productivity and nutrient availability, as detected in other MPAs located close. Furthermore, bottom currents and upwellings may favour the connectivity among deep and shallow soft bottoms, promoting the existence of bathyal species in circalittoral bottoms within the SAC (Marina et al. 2015).

This SAC was proposed because of the presence of nine types of natural habitats included in Annex I of the HD, of which five belong to the marine realm including sandbanks which are slightly covered by seawater all the time (Habitat 1110), *Posidonia* beds (1120), large shallow inlets and bays (1160), reefs (1170) and submerged or partially submerged sea caves (8330) (Fig. 25.16) (Mateo-Ramírez et al. 2020b). Moreover, two species included in Annex II of the HD such as the bottle-nosed dolphin and the loggerhead turtle and at least five species included in the Annex IV such as the ribbed Mediterranean limpet, the date mussel (*Lithophaga lithophaga*), the leatherback marine turtles and the common and striped dolphins were also included in the original proposal (Mateo-Ramírez et al. 2021). During migration, it is easy to detect Audouin's gulls and Balearic shearwaters, while during the breeding period, the most common seabird is the yellow-legged gull (*Larus michahellis*) (Fig. 25.16). The eastern area bordering Calahonda-Castell de Ferro is also of importance for the endemic Mediterranean seagrass *P. oceanica* (included in the Annex I of the Bern Convention and in the Annex II of the BC), which presents extensive meadows down to depth of ca. 10 m (Junta de Andalucía 2008–2019). These beds provide a high ecological value, being the refuge and recruitment area for numerous species of commercial interest (Urra et al. 2015).

In addition, several species with different protection status have been found in the area, such as the knobbed triton, the noble pen shell (probably extinct since 2017) (Fig. 25.16), the Mediterranean reef-building vermetid gastropod (*D. lebeche*), the chalice coral (*Astroides calycularis*) and the orange puffball sponge (*Tethya aurantium*) (Mateo-Ramírez et al. 2021), all of them included in the Annex II of the BC and some of them classified as "Vulnerable" in the CEEA and CAEA (Mateo-Ramírez et al. 2021).

Sublittoral soft bottom assemblages within the SAC were detailed studied by Marina et al. (2015) in relation to sediment and water column variables. These authors documented the presence of some rare and poorly known invertebrates that are scarce in other areas of the Mediterranean Sea, such as the hippolytid decapod *Bythocaris cosmetops* and the tropical hermit crab *Pagurus mbizi* (García Raso et al. 2011, 2014) (Fig. 25.16). Some bathyal molluscs (e.g. *Poromya granulata*, *Alvania testae*) display populations at shallower depths in the circalittoral zone of this MPA (Marina et al. 2015). The geographical location of the SAC, which represents a transitional and settlement zone for Atlantic species; the heterogeneity of soft bottoms; and the occurrence of upwellings may favour the high biodiversity found in the studied soft bottoms.

The socio-economic importance of this SAC is mainly related to fisheries, both professional and recreational; aquaculture; agriculture; and tourism. The activity of the artisanal fleet in the SAC is scarce; the remoteness of the closest port, located in Motril, influences this low activity. The main small gears used are gillnets for mullets (*Mullus* sp.) *S. officinalis* and sparids such as *Diplodus sargus*, *Pagellus erythrinus*, *Pagellus acarne* and pots (called "Alcatruz" in the area) to catch common octopus. Recreational fishing from coasts and boats is usual in this SAC using surf-casting, trolling and jigging and targeting sparids, with the white seabream (*D. sargus*) standing out. Aquaculture is an activity that is beginning to have some relevance on the coast of Motril, with one fishing farm located off Carchuna for the production of European sea bass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus aurata*). The tourism sector is also very important in the area. The SAC stands out for its beautiful cliffs, which attract many visitors looking for activities related to scuba-diving, which is a deeply rooted activity in the seabeds of Calahonda-Castell de Ferro. The main threats include the use of fishing gears that may be in contact with the seabed, especially considering the seagrass meadows located close by; trampling over intertidal and upper infralittoral areas and illegal extraction of invertebrates such as the rock-boring date mussel, whose harvesting causes significant environmental damage; and diving activities, which are very intense in summer and can affect populations of some species but also the overall community structure through physical injury or the removal of certain species. One of the most endangered invertebrates of the Mediterranean, the ribbed Mediterranean limpet, presents a population within the SAC, and it is affected by recollection for human consumption, as bait for fishing, coastal developments, habitat modification and contamination.

25.5.13 Sur de Almería-Seco de los Olivos SCI (Spain)

The Sur de Almería-Seco de los Olivos SCI (Southern Almería-Seco de los Olivos) (ESZZ16003) was designated as SCI in December 2014 and incorporated in the Natura 2000 network in November 2015. This SCI will become a SAC after the development of its corresponding management plan, including integrated measures to ensure the conservation of the habitats and species for which it was created.

The SCI is located in front of the Almería province, covering an area of ca. 2830 km^2 and a depth range from the coastline to depth of ca. 1000 m. From the coast to the bathyal zone, there is a great diversity of bottoms types, both rocky outcrops and sedimentary ones with different lithologies such as sands on the infralittoral of the continental shelf and muds on the continental slope, providing a wide diversity of habitats and marine organisms. Over the continental shelf, a series of geomorphological features such as submarine escarpments, abrasion surfaces, sand wave fields and submarine fluvial deposit associated with the Adra River occur. Other geomorphological structures occur on the continental slope at greater depths such as submarine canyons (e.g. one section of the Almería canyon) and underwater elevations such as the promontory of Cabo de Gata and some banks such as Avenzoar-El Sabinar Complex, Pollux and Chella, the latter also known as the Seco de los Olivos Seamount. This seamount is a volcanic outcrop included in the peri-Alboran Neogene volcanism. It is constituted by a central edifice, partially eroded, and covered by a sedimentary shelf wedge around it that generates a small isolated platform, and two NW-SE-directed ridges are located to the NE and SW, respectively, of the main edifice.

This SCI was proposed because of the presence of two habitats included in Annex I of the HD, *Posidonia oceanica* beds (Habitat 1120) and reefs (1170), and two species of Annex II of the HD such as the loggerhead turtle and the bottle-nosed dolphin. Moreover, this SCI is also of importance for other occasional cetaceans, including Cuvier's beaked whale, the long-finned pilot whale and the common minke whale, as well as for different birds including the Balearic shearwater and Audouin's gull (Mateo-Ramírez et al. 2021).

More than 600 species including fish and invertebrates have been listed so far in this SCI (de la Torriente et al. 2014). Many of these invertebrates are of importance because they appear in high densities and form three-dimensional structures that are home to other species, which settle, feed and take shelter in those habitats. In the coastal area, different seagrasses (mainly *P. oceanica* and *C. nodosa*) form extensive meadows (Habitats 1120 and 1110 of the HD). Rhodolith beds and coralligenous bottoms (Habitat 1170 of the HD) also appear in the coastal area but mainly over the summit of some seafloor elevations, such as over the central "guyot" of the Seco de los Olivos Seamount (Mateo-Ramírez et al. 2020b). Further away, a variety of habitats distributed in a patchy mosaic (some of them related to Habitat 1170) occur on Avenzoar Bank and the Seco de los Olivos Seamount, including cold-water coral reefs (*Desmophyllum pertusum* and *Madrepora oculata*), bamboo corals (*Isidella elongata*) and black corals (*Leiopathes glaberrima*, *Antipathes dichotoma*, *Antipathella subpinnata*) aggregations, glass sponges (*Asconema setubalense*, *Sympagella delauzei*) and demosponges (*Phakellia* spp., *Pachastrella monilifera*, *Thenea muricata*) aggregations, giant oyster banks (*Neopycnodonte zibrowii*), large gorgonian gardens containing more than a dozen species (*Eunicella verrucosa*, *Paramuricea clavata*, *Swiftia dubia*, *Callogorgia verticillata*, *Viminella flagellum*, *Acanthogorgia hirsuta*, *Dendrobrachia bonsai*, among others), soft corals (*Alcyonium palmatum*, *Paralcyonium spinulosum*, *Nidalia studeri*) and red coral (*Corallium rubrum*) banks (Fig. 25.17) (Mateo-Ramírez et al. 2021). A good representation of sedimentary habitats with habitat-forming species occurs in the SCI including sea pen communities (*Funiculina quadrangularis*, *Kophobelemnon* spp., *Pennatula rubra*, *Pennatula phosphorea*, *Pteroeides griseum*, *Virgularia mirabilis*) and bamboo coral aggregations (Fig. 25.17).

The conservation of the cited habitats as well as many of their associated species depends on the development of appropriate management measures for the SCI. Considering just Seco de los Olivos Seamount, 45 species have been identified as protected and included in national and/or international conservation lists, including chordates (11 species), cnidarians (16 species), sponges (8 species), molluscs (5 species), crustaceans (2 species), echinoderms (1 species), tunicates (1 species) and bryozoans (1 species) (Mateo-Ramírez et al. 2021).

The socio-economic importance of this SCI is mainly related to fisheries and tourism. In the area, fishermen use a great diversity of fishing techniques to catch different resources: purse seine fishing for Atlantic mackerel (*Scomber scombrus*), European sardine (*Sardina pilchardus*) (Atlantic horse mackerel (*Trachurus trachurus*) and round sardinella (*Sardinella aurita*); bottom trawling for Atlantic horse mackerel, European hake (*Merluccius merluccius*) and blue and red shrimp

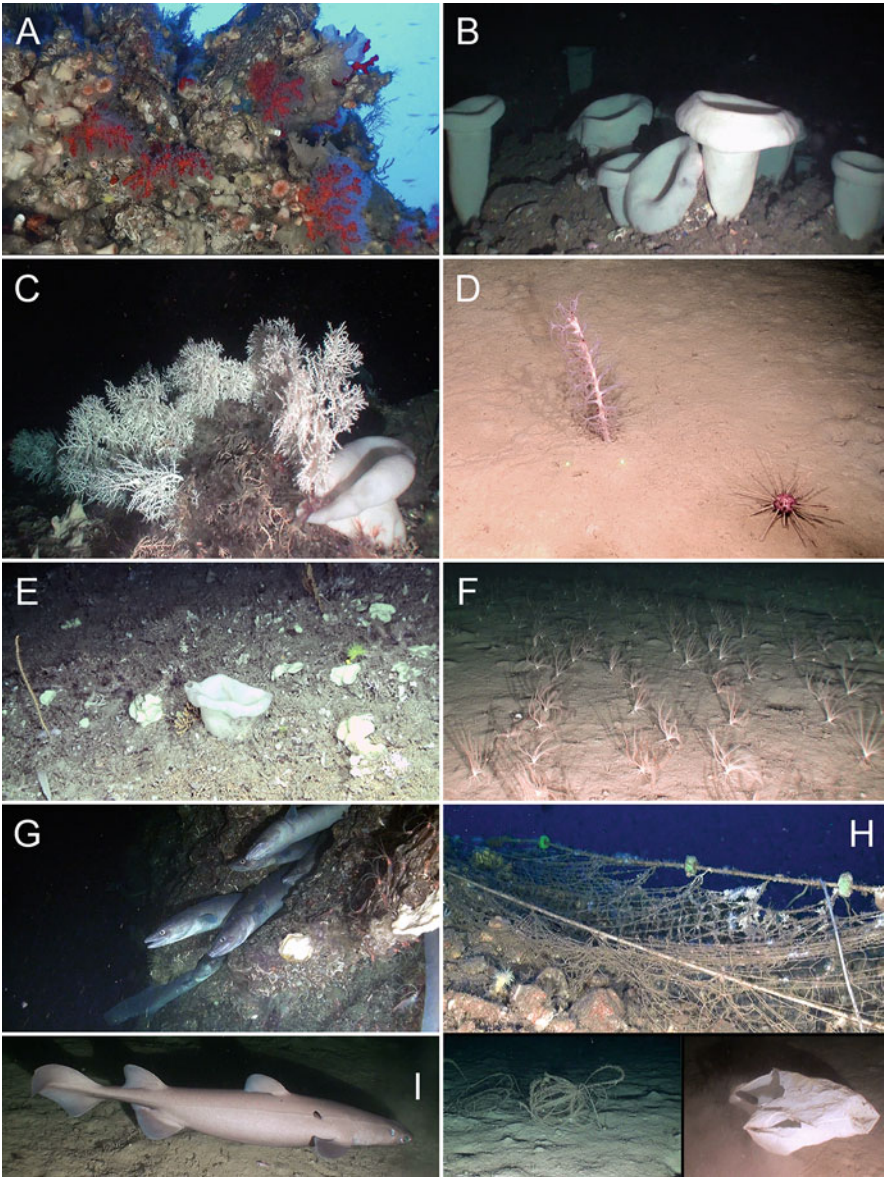

Fig. 25.17 Different habitats, species and threats found within the Sur de Almería-Seco de los Olivos SCI (Almería). (**a**) The endangered red coral (*Corallium rubrum*) in a coralligenous habitat; (**b**) an aggregation of large glass sponges *Asconema setubalense*; (**c**) colonies of the white coral (*Madrepora oculata*); (**d**) *Kophobelemnon* sp. and *Cidaris cidaris* on soft bottoms; (**e**) coral rubble bottoms with a high diversity of structuring species (e.g. *A. setubalense*, *Acanthogorgia* sp., *Dendrophyllia cornigera*); (**f**) aggregations of the crinoid *Leptometra phalangium* in circalittoral detritic bottoms; (**g**) a group of European congers (*Conger conger*) in a deep reef surrounded by *Plesionika* sp.; (**h**) some of the threats present in the SCI such as abandoned nets, lines and plastic bags; (**i**) the kitefin shark (*Dalatias licha*). [OCEANA]

(*Aristeus antennatus*); bottom longline fishing for blackspot seabream; gillnet fishing for scorpion fish (*Scorpaena* spp.), mullets (*Mullus* spp.) and cuttlefish; and fishing with traps or pots for soldier striped shrimps. Moreover, recreational fishing has increased in the area, especially in specific seafloor elevations with steep rocky bottoms where species such as the dogtooth grouper (*Epinephelus caninus*) occurs. Additionally, the area is highly frequented by tourists, including sport boat navigation and scuba-diving in the coastal areas of Almería and, more recently, activities associated with whale watching. The main threats facing the biodiversity of this SCI include some types of fishing such as bottom trawling, which generate incidental by-catch of sharks and cetaceans and the abrasion of the seabed and their benthic habitats, and marine traffic responsible for pollution caused by both the ship's bilge water releases and by plastics and waste disposal (Fig. 25.17).

25.5.14 Fondos Marinos de Punta Entinas-Sabinar SAC (Spain)

The Fondos Marinos de Punta Entinas-Sabinar SAC (Marine Bottoms of Punta Entinas-Sabinar) (ES6110009) is located in the submerged platform in front of the Punta Entinas-Sabinar SAC (ES0000048), in the west of the Almería province (Fig. 25.18). This area was proposed as SCI in 1997, approved in 2006 with ca. 20 km^2 and declared SAC in 2016 with an area of ca. 40 km^2.

The seabed of the SAC constitutes the submerged continuation of the great plain located at the foot of the Gador mountain range between the housing developments of Roquetas de Mar and Almerimar (El Ejido harbour) characterized by sandstones and silts of Messinian-Lower Pliocene age. All this coast is low and is part of the Punta Entinas-Sabinar SAC and contains some coastal lagoons, wet areas and old salt marshes that are no longer used (Pérez Hurtado de Mendoza 2004), as well as a strip of Holocene dunes with Phoenicean junipers (*Juniperus phoenicea* subsp. *turbinata*) and mastic trees (*Pistacia lentiscus*) (López-Martos et al. 2010).

The SAC occurs on the infralittoral wedge and is mainly characterized by fine sands, small areas with gravels and rhodolith beds together with some flattened rocks associated with rocky outcrops, on which *P. oceanica* also develops (Moreno and Guirado 2003; Moreno et al. 2004a; Arroyo et al. 2015) (Fig. 25.18). The main habitats of this SAC are the seagrass meadows of *P. oceanica* (Habitat 1120 of the HD); the sandbanks which are slightly covered by seawater all the time (1110) in which *C. nodosa* frequently forms meadows (Moreno et al. 2004b) and the reefs (1170), in some areas of flattened rocks with macroalgae meadows of the *Cystoseira* spp. between depths of 10 and 20 m (Fig. 25.18). The cartography of seagrass meadows was firstly carried out using scuba-diving in 1995–1996 (Luque et al. 2004) and later on updated with side-scan sonar during the LIFE+ *Posidonia* Andalucía Project (2011–2016) (Mendoza et al. 2014; Arroyo et al. 2015). In 2008, OCEANA conducted a restoration experience of *C. nodosa* meadows by

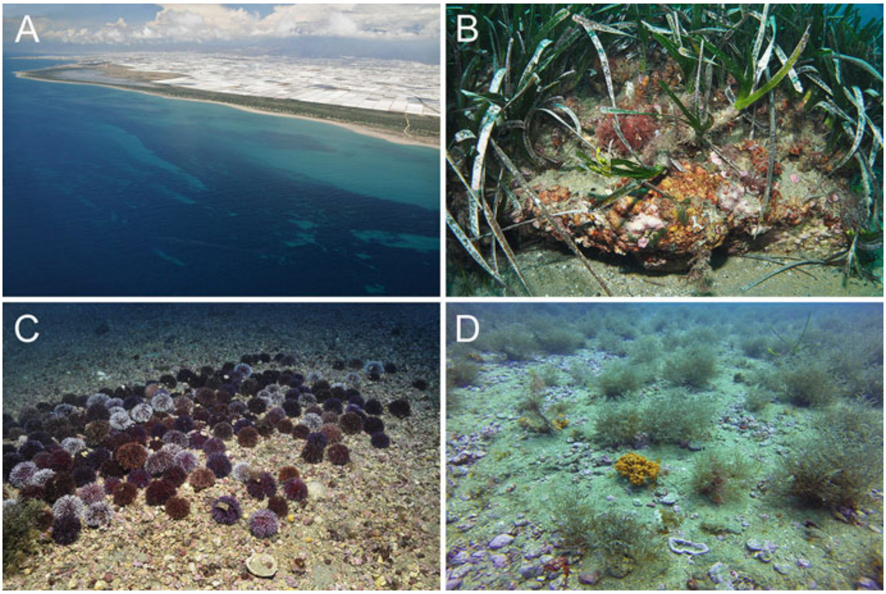

Fig. 25.18 Fondos Marinos de Punta Entinas-Sabinar SAC. (**a**) Aerial view displaying extensive *Posidonia oceanica* meadows (dark colour) and the sandy bottoms (light colour), together with abundant greenhouses of El Ejido and Almerimar in the background; (**b**) *Posidonia oceanica* meadow with a flowering event, on rocky bottoms at depth of 12 m; (**c**) rhodolith bed with a massive concentration of the sea urchin *Sphaerechinus granularis* at depth of 20 m; (**d**) flattened rocky bottom with *Cystoseira* and coralline algae at depth of 15 m (Diego Moreno/Sustainable Marine Environment Management Program/Junta de Andalucía)

collecting seeds in front of Punta Elena (next to the Cerrillos tower) and planting them in Roquetas de Mar and Punta Elena (García et al. 2009).

In this SAC, a *P. oceanica* sampling station with demographic grids has been monitored every year within the POSIMED Network under the framework of the LIFE+ *Posidonia* Andalucía Project (Junta de Andalucía 2008–2019). During this project, censuses of fish, macroalgae, epiphytes and macro-invertebrates were carried out for studying the biodiversity of those meadows (Junta de Andalucía 2008–2019).

Some threatened invertebrate species such as the hatpin urchin and the knobbed triton (Vulnerable) occur in this SAC (Junta de Andalucía 2008–2019; Mateo-Ramírez et al. 2021). The noble pen shell was scarce in the seagrass meadows, and no individuals could be detected in 2016 after a massive mortality event that has affected 100% of the population of the northern Alboran Sea (Junta de Andalucía 2008–2019; Vázquez-Luis et al. 2017).

The entire west coastline of the Almería province, except just the narrow strip of the adjacent SAC, is very urbanized and intensively used for agriculture appearing from satellites covered by plastic greenhouses (Campo de Dalías-El Ejido and Roquetas de Mar). Therefore, this SAC could be affected by spills from nearby urban and agricultural areas, as well as waste of all kinds, mainly of plastics. This coast is very open and receives storms coming from the east as well as from the west, so it could receive potential contamination from maritime traffic accidents such as oil spills. In addition, overfishing, including recreational fisheries, can affect the ichthyofauna that is already very scarce in the SAC.

25.5.15 Arrecife barrera de Posidonia Natural Monument and Arrecifes de Roquetas de Mar SAC (Spain)

The area known as "Los Bajos de Roquetas," located between Roquetas de Mar and Aguadulce in the western part of the Bay of Almería, has a low and sandy coast and predominantly soft bottoms on which extensive seagrass meadows develop on the infralittoral wedge. One of the most notable formations is the barrier reef of *P. oceanica* (Fig. 25.19), which is next to the wetland area called Ribera de la Algaida and the Turaniana site, where there was a small Roman port (Cara

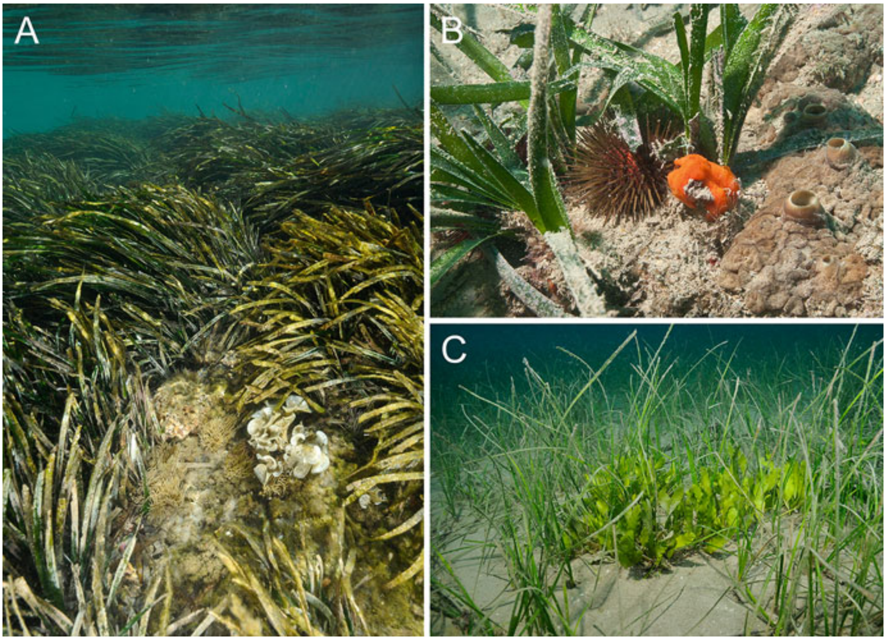

Fig. 25.19 Arrecife barrera de *Posidonia* Natural Monument-Arrecifes de Roquetas de Mar SAC. (**a**) Upper part of the *Posidonia oceanica* reef with leaves reaching the surface, the photophilic algae *Padina pavonica* and the cnidarian *Anemonia sulcata*; (**b**) *Posidonia oceanica* meadow at depth of 10 m with the sea urchin *Paracentrotus lividus*, the bivalve *Arca noae* covered by the sponge *Crambe crambe* and the drilling sponge *Cliona viridis*; (**c**) *Cymodocea nodosa* meadow at depth of 9 m with the green seaweed *Caulerpa prolifera* (Diego Moreno/Sustainable Marine Environment Management Program/Junta de Andalucía)

Barrionuevo and Cara Rodríguez 1994). This remarkable reef of *P. oceanica* is the largest and most complete in the northern Alboran Sea. It was declared in 2001 as a Natural Monument (Monumento Natural) of biotic character, with the name of Arrecife barrera de *Posidonia* (Barrier Reef of *Posidonia*) and covering an area of ca. 1.1 km^2 (Guirado et al. 2002; Castro et al. 2003). The declaration of this Natural Monument was done by the Andalusian government and included basic management criteria and a list of unsupported activities, such as anchoring and trawling. This MPA is 2 km long and 550 m wide (50 m stretch along the beach) and has a depth range between the coastline and ca. 10–12 m. Subsequently, this MPA was approved as SCI in 2006 with the name Arrecifes de Roquetas de Mar (Roquetas de Mar Reefs) (ES6110019), occupying an area of ca. 2 km^2, and finally designated SAC in 2016.

The main value of this SAC is *P. oceanica* meadows (Habitat 1120 of the HD) that conform an extraordinary barrier reef, where seagrasses reach the surface. The structure of the *Posidonia* reef is similar to that of tropical hermatypic (or reef-building) corals that conform a separate coastline ridge where waves break and an inland lagoon with muddy sediments colonized by other marine angiosperms such as *C. nodosa* and *Z. noltei* (Habitat 1110 of the HD) (Moreno 2003; Luque et al. 2004; Arroyo et al. 2015) (Fig. 25.19). It should be highlighted that the four species of native marine angiosperms of European waters (*P. oceanica*, *C. nodosa*, *Z. noltei* and *Z. marina*) occurred in the SAC at the end of the twentieth century, before the acute regression of *Z. marina* in the northern Alboran Sea during 2006–2007 (Moreno and Guirado 2003). The cartography of these seagrass meadows was firstly carried out using scuba-diving in 1995–1996 (Luque et al. 2004) and later on updated with side-scan sonar during the LIFE+ *Posidonia* Andalucía Project (2011–2016) (Mendoza et al. 2014; Arroyo et al. 2015). Demographic grids and biodiversity census were carried out in this SAC from 2011 to 2018 during the latter project (Junta de Andalucía 2008–2019).

In the *P. oceanica* meadows, the concretions of the coralline algae *Mesophyllum alternans* are frequent, which are home to a rich and diverse fauna with abundant polychaetes, crustaceans and small molluscs (Salas and Hergueta 1986; Hergueta and Salas 1987). The macrofauna of the seagrass meadows is known from different studies (Ballesteros et al. 1986), including the results of cartography campaigns (Luque et al. 2004). It is important to note that the waves bring a large amount of debris from the nearby *P. oceanica* (leaves, rhizomes) to the shore that accumulate on the beach and support an interesting detritivorous fauna adapted to this habitat, with different species of amphipods, isopods and polychaetes, among others (Luque and Templado 2004).

Different species of echinoderms, mainly of the genus *Holothuria*, and the sea urchin *Paracentrotus lividus* (Annex II of the BC) (Fig. 25.19) (Mateo-Ramírez et al. 2021) are very abundant in the SAC, which could contribute to seagrass degradation because that sea urchin feeds on *P. oceanica* (Junta de Andalucía 2008–2019). The endangered noble pen shell was scarce in these meadows, but it no longer lives there because of the aforementioned massive mortality event in 2016 (Junta de Andalucía 2008–2019; Vázquez-Luis et al. 2017).

The main socio-economic activities are related with tourism, scuba-diving (prohibited inside the Natural Monument) and fisheries. In the fishing port of Roquetas de Mar, the main gears used are small-scale fishing gear, e.g. trammel (ten boats). Nevertheless, other boats use other gears such as longline (4), shellfish dredges and purse seine fishing (3). The main target species of those fisheries are common octopus and cuttlefish. In addition, the port of Roquetas has 183 moorings for recreational boats, with some of them fishing in the MPA. Different human pressures, such as mass tourism and urban discharges as well as marks of dredges and illegal trawlers, have been mentioned for this MPA (Arroyo et al. 2015). The latter affected the *Posidonia* meadows outside depth of 12–14 m at the end of the twentieth century which caused meadow degradation with a large area of "dead matte." In addition, the green algae *C. cylindracea* were detected for the first time at a depth of 14 m on "dead matte" in 2014, which may represent a very suitable bottom for the development of this exotic invader (Junta de Andalucía 2008–2019).

25.5.16 Isla de San Andrés Natural Monument and SAC (Spain)

The island of Carboneras (also known as Isla de San Andrés) is located at the north-eastern limit of the Alboran Sea, in front of Carboneras (Almería) (Fig. 25.20). It was declared a Natural Monument of mixed nature (geological and biotic), with the name of "Isla de San Andrés," in 2003 by the Andalusian government (Castro et al. 2003). The protected area covered ca. 0.7 km^2 and included both the emerged part of the island and the infralittoral bottoms around it. In 2006, the area was approved as SCI with the name Islote de San Andrés (San Andrés Islet) (ES6110020), covering a larger area (0.35 km^2) and including both the island and one small islet located close to the beach. In 2015, it was declared SAC, covering the same area of 0.35 km^2. The 180 m-long island is quite flattened and reaches a height of only 14 m above sea level, but in the submerged part, it reaches depth of 40–50 m relatively close to the shore. The island is constituted of volcanic materials, mainly dacites and andesites from the cal-calkaline series of the Neogene volcanic peri-Alboran Sea domain. These materials are covered by Quaternary-age alluvial deposits made up of conglomerates with a great diversity of boulders. The seabeds are rocky corresponding to the volcanic materials and are characterized by the presence of cornices, cracks and caves.

The main biological values are found in the submerged part where a very steep rocky substrate dominates, with walls and passages, which harbour extraordinary dives for dive centres. In the mesolittoral, there are some aggregates of the vermetid gastropod *Dendropoma lebeche*. In addition, there are excellent *P. oceanica* meadows (Habitat 1120 of the HD), partly on rock, as well as sand bottoms with *C. nodosa* meadows (1110). In those *P. oceanica* meadows, there was an annual

Fig. 25.20 Isla de San Andrés Natural Monument and SAC. (**a**) Aerial view of the island of San Andrés with the islet and Carboneras in the background; (**b**) the coral *Leptopsammia pruvoti* on the roof of a cave at depth of 25 m; coralligenous communities with the gorgonian *Leptogorgia sarmentosa* at depth of 22 m (Diego Moreno/Sustainable Marine Environment Management Program/Junta de Andalucía)

monitoring station of the endangered noble pen shell until its massive mortality and extinction in 2016 (Junta de Andalucía 2008–2019; Vázquez-Luis et al. 2017).

In 2008, the Sustainable Management Program of the Marine Environment of the Andalusian government carried out the bionomic mapping of this SAC and its adjacent areas, covering 0.75 km^2 in total, of which 0.08 km^2 corresponded to *P. oceanica* meadows (Junta de Andalucía 2008–2019). There are also an interesting coralligenous bottoms (Habitat 1170 of the HD) with gorgonians, mainly *Leptogorgia sarmentosa* as well as caves and rocky passageways with solitary corals such as *Leptopsammia pruvoti* (Fig. 25.20) (Mateo-Ramírez et al. 2021).

In this MPA, a *P. oceanica* sampling station with demographic grids has been monitored every year from 2011 within the POSIMED Network under the framework of LIFE+ Posidonia Andalucía Project (Junta de Andalucía 2008–2019). Within the same project, biodiversity census were carried out in this SAC (Junta de Andalucía 2008–2019). This MPA displayed the highest species richness for fish

(21 species) and macro-invertebrates (19 species) after comparisons with other sampling stations of the northern Alboran Sea (from Almería, Granada and Málaga) (Junta de Andalucía 2008–2019; Mateo-Ramírez et al. 2021).

The socio-economic importance is related to fisheries and tourism. The port of Carboneras has the highest influence within the MPA, being the main fishing gear surface longline and small-scale fishing gear. Tourism activities are related with the recreational fishing and scuba-diving/snorkelling. The main threat to this MPA is the increase of diving activities because four dive centres from Carboneras perform dives continuously in fragile environments such as small caves. During the LIFE+ *Posidonia* Project, the Junta de Andalucía installed four ecological buoys around the island to avoid anchoring in the seagrass meadows (Mendoza et al. 2014). In addition, this MPA is located in the area of influence of two underwater emissaries of urban activity located in front of Playa del Lacón.

25.6 Other Marine Protected Areas and Key Biodiversity Areas from the Southern Alboran Sea and Adjacent Areas

Different MPAs and KBAs located in the southern Alboran Sea and adjacent areas are presented from west to east direction, with remarks on their location, figure status, natural heritage, socio-economic importance and main threats.

25.6.1 Jbel Moussa Nature Reserve, Site d'Intérêt Biologique et Écologique (SIBE) and Réserve de Chasse Permanente (RCP)

Jbel Moussa was designated a Biological and Ecological Interest Site (Site d'Intérêt Biologique et Écologique) with priority 1 because of its interest and uniqueness. It is also part of the Intercontinental Biosphere Reserve of the Mediterranean, declared by UNESCO in 2006, which covers various protected natural areas in Andalusia (Spain) and Morocco. Moreover, it has also been recognized as an Important Bird and Biodiversity Area (IBA) and in 2014 was proposed as Nature Reserve. This MPA occupies a total area of 48 km^2 from which ca. 11 km^2 are marine area with depths range from coastal lines to of more than 400 m.

This is the northernmost protected natural area of Morocco, and its boundaries include the rural communes of Tighremt and Ksar Majaz, as well as the village of Belyounech.

This karstic limestone massif, rising more than 800 m above sea level, is constituted by units from the internal Rif domains, represented by the Séptides, Gomárides and the Dorsal units, where Jbel Moussa himself is made up of the latter, and also by the domain of the Flysch Complex, formed by the Tariquides and Mauritanides units. Limestones and dolomites of the Upper Triassic-Lower Liasic dominate in the area. The coastal section is characterized by capes, steep cliffs, coastal abrasion platforms, small beaches and two rocky islets, one of them consisting of limestones (known as Perejil) and the other forms by sandstones (known as El Guardián).

The maritime area of this MPA is represented by several habitats that are similar to the ones listed in Annex I of the HD that can be identified in the area such as reefs (Habitat 1170), sandbanks which are slightly covered by seawater all the time (1110), mudflats and sandflats not covered by seawater at low tide (1140) or submerged or semi-submerged marine caves (8330). Vegetated bottoms are predominantly located at the northern area of the MPA, with rocky outcrops dominated by stratified algal communities that are organized from green to brown and red algae following a depth gradient down to ca. 25 m (Kazzaz 1989). Seagrass meadows are also found on soft bottoms of the MPA (1110 and 1140), mainly composed of *Zostera noltei* and *Cymodocea nodosa* (Mateo-Ramírez et al. 2020b). Furthermore, the islet of Perejil (island of Leila in Moroccan) is located 200 m off the coast, and it represents a refuge for many species due to its isolation and the difficulty of access. This islet harbours interesting underwater seawalls, caves and coral formations.

Regarding birds, this MPA represents an important migration hotspot for the pass of migrating seabirds between the Atlantic Ocean and the Mediterranean Sea, with a large number of species of seagulls (*Larus* spp.) with a nesting colony of yellow-legged gull (*Larus michahellis*) in Perejil islet. Due to its strategic geographic position migratory species, such as the threatened Balearic shearwater, Scopoli's shearwater, Sandwich and lesser-crested terns, and cormorants can be observed in the area and around (Mateo-Ramírez et al. 2021).

Marine mammals are commonly observed, as they cross the Strait of Gibraltar in their migratory routes. Common species include the bottle-nosed dolphin (*Tursiops truncatus*), the common dolphin (*Delphinus delphis*), the striped dolphin (*Stenella coeruleoalba*), the common porpoise (*Phocaena phocaena*), the orca (*Orcinus orca*), the long-finned pilot wale (*Globicephala melas*), the sperm whale (*Physeter macrocephalus*) and the fin whale (*Balaenoptera physalus*) (Mateo-Ramírez et al. 2021). Other threatened and/or endangered species include marine turtles (e.g. loggerhead (*Caretta caretta*), leatherback (*Dermochelys coriacea*)), fishes such as the bluefin tuna (*Thunnus thynnus*) and the dusky grouper (*Epinephelus marginatus*) and sharks such as the sweet William (*Mustelus mustelus*) and common hammerhead shark (*Sphyrna zygaena*) (Mateo-Ramírez et al. 2021).

The seawater quality provides the optimal conditions for threatened/endangered and vulnerable invertebrate species such as the red coral (*Corallium rubrum*) and the crustaceans slipper lobster (*Scillarides latus*) or spider crab (*Maja squinado*) (Mateo-Ramírez et al. 2021).

The main socio-economic activities are tourism and fishing. The surrounding cities and towns have an important urban and tourist-residential component. The whole area has an important potential for outdoor activities such as hiking, trekking, ornithological or scientific tourism, environmental education, diving and sport fishing, apart from the traditional sun and beach tourism (Anonymous 2013). The presence of large numbers of whales fed a highly lucrative whaling industry at both sides of the Strait, and the remains of the old whaling stations can be found at Belyounech (Morocco) and Algeciras (Spain). A permanent and locally important artisanal fishing activity, with trammel nets, purse seine from coast, longlines and jigging, can be found in this MPA, targeting species such as the European sardine (*Sardina pilchardus*), European sea bass (*Dicentrarchus labrax*), European conger (Conger conger), axillary seabream (*Pagellus acarne*), common octopus (*Octopus vulgaris*), Mediterranean mussel (*Mytilus galloprovincialis*) or the pink spiny lobster (*Palinurus mauritanicus*) (Anonymous 2013).

The main threats of the area are trawling and overfishing, as well as a potential large-scale industrial and maritime trade development. In addition, the lack of regulation of some traditional activities such as fisheries, lack of adequate infrastructures for fishing and poor waste and waste water management, together with low sensitivity to waste dumping and its visual impact, poaching and lack of a management plan for the MPA, are also important weakness (Anonymous 2013). Further studies and analyses on the different uses of the area and their possible impacts on biological communities and ecosystems are needed.

25.6.2 Zona marítimo-terrestre del Monte Hacho SAC (Spain)

The Zona marítimo-terrestre del Monte Hacho SAC (Maritime-terrestrial zone of Monte Hacho) (ES6310002) was proposed as SCI in April 1999 and declared SAC in July 2012. This SAC occupies ca. 9 km^2 of which 96% are of marine character, with a depth range from the coastline down to depth of 200 m. The coastline of Monte Hacho presents an irregular and rugged relief where cliffs are the predominant structures with lesser extent areas of medium-thick material deposits, with similar characteristics for the sublittoral areas. The Monte Hacho massif is constituted by metabasites and amphibolites with local outcrops of peridotites and leucogranite that corresponds to the mafic formations present in the Septide Complex (IGME 2013).

In this SAC, some habitats included in Annex I of the HD are reefs (Habitat 1170), followed by submerged or semi-submerged marine caves (8330) and vegetated sea cliffs of the Atlantic and Baltic coasts (1230) (Mateo-Ramírez et al. 2020b). Associated with the reefs, a wide diversity of communities has been detected, including different gastropods included in conservation lists (e.g. the ribbed Mediterranean limpet *Patella ferruginea*, the vermetid *Dendropoma lebeche*) as well as coralline algae (*Lithophyllum byssoides*) at the intertidal level, photophilous macroalgae beds (*Cystoseira* spp.) as well as pre-coralligenous and coralligenous communities with the filigreed coral-worm (*Filograna implexa*) or the chalice coral (*Astroides calycularis*) in the shallow infralittoral level and some gorgonians and red coral aggregations with the whip gorgonian (*Ellisella paraplexauroides*, Annex II from BC), *Phyllangia americana mouchezii* (Barea-Azcón et al. 2008) or the endangered red coral at larger depths (Mateo-Ramírez et al. 2021). Sand and detritic bottoms are also abundant at the circalittoral level with high abundances of pennatulaceans dominated by *Veretillum cynomorium*.

This SAC is an important area for migratory seabirds, especially for Scopoli's shearwater (*Calonectris diomedea*), because every autumn more than half a million of individuals leave the Alboran Sea and pass very close to the coast. Other species are Audouin's gull (*Larus audouinii*), recently established as a breeding species in Ceuta, and the sandwich tern (*Sterna sandvicensis*) during winter and migration. The cliffs and abrupt walls are used by cliff nesting species such as the peregrine falcon (*Falco peregrinus*), the kestrel (*Falco tinnunculus*), the crag martin (*Ptyonoprogne rupestris*) and blue rock thrush (*Monticola solitarius*) for nesting and wintering (Mateo-Ramírez et al. 2021).

Regarding socio-economic activities, some of them are recreational marine fishing, in its different modalities, from the shore or using boats and snorkel equipment. Scuba-diving is an activity that has been on the rise in recent years with several dive centres operating from Ceuta. There are also two beaches (Santa Catalina and El Desnarigado) with a low affluence. In contrast, the main threats are related to the presence of the invasive macroalgae *Rugulopteryx okamurae* which was detected in Ceuta during 2015 and which has had a huge expansion in the last years (Rosas-Guerrero et al. 2018), competing over other invasive species such as *Asparagopsis armata* and *Caulerpa cylindracea* (MTERD 2020) and affecting both photophilic/sciaphilic algae to pre-coralligenous and coralligenous habitats. Other threats are the presence of a submarine emissary in the northern area of the SAC, development of transport systems (roads), construction of residential or recreational areas, modifications of the coastline, reductions of fish populations and physical damage of marine habitats by fisheries and recreational activities such as scuba-diving.

25.6.3 Lagune de Smir SIBE and Collateral Figures of Protection (Morocco)

The Smir lagoon is one of the coastal wetlands with the highest natural value for the Mediterranean Moroccan coasts. In 1995, it was declared a SIBE by the High Commission for Water and Forests for combating desertification. In 2006, this wetland was included in the Intercontinental Mediterranean Biosphere Reserve Andalusia-Morocco (Reserva Intercontinental de la Biosfera de Andalucía-Marruecos), of the UNESCO MaB programme, and as a Ramsar site in 2019.

The Smir lagoon is located on the coastal plain of the Smir River north of the city of M'diq. It is flanked to the north by the Jebel Zem-Zem mountain range, to the south by the Koudiet-Taifo mountain range and to the west by limestone and dolomitic ridges. The MPA has an extension of 2.46 km^2 occupied by a permanent lagoon and some marshes, located in the lowest area of the valley. This lagoon has a maximum depth of 2.5 m, and it is mainly fed by the sea because it is connected by a permanent channel that passes under a bridge on the national road that leads to the Port of Kabila. This ecosystem, which functioned before as a lake, has been transformed into a coastal lagoon. The lake had an area of about 2 km^2, but its functioning was affected by the construction of a water dam on the Smir River and the construction of a port at its mouth, which have modified the hydrological system and induced a progressive salinization of the waters. This increase in salinity has affected the composition, structure and functioning of the biological communities, benefiting halophytic plant communities and the intrusion of marine species with the total disappearance of freshwater species.

This SIBE is represented by coastal and halophytic vegetation habitats, similar to the ones listed by the European HD such as estuaries (Habitat 1130) and *Salicornia* and other annuals colonizing mud and sand (1310), as well as by sandbanks which are slightly covered by seawater all the time (1110) (Dakki et al. 2005; Mateo-Ramírez et al. 2020b). Different habitats conformed by aquatic angiosperms occur in the lagoon. At the mouth of the Smir River, where a confluence of fresh water and seawater occurs, vegetated habitats dominated by *Potamogeton pectinatus* and *Z. noltei* occur. However, the southern sector near the channel is dominated by *R. maritima* and *C. nodosa*. Finally, the communities closer to the sea are dominated by macroalgae (Benhissoune et al. 2005).

The Smir lagoon is a stopover area for the birds that cross the Strait of Gibraltar, and the high variety of biotopes and the heterogeneity of its plant formations promote a high ornithological richness. Most of the birds are similar to the ones listed on the Annexes of the European BD with migratory species such as shorebirds, herons, the glossy ibis (*Plegadis falcinellus*), raptors such as the osprey (*Pandion haliaetus*) or the marsh harrier (*Circus aeruginosus*) and passerines (Mateo-Ramírez et al. 2021). Other birds are subject of special conservation measures, such as the pied avocet (*Recurvirostra avosetta*), the purple heron (*Ardea purpurea*) or the black-headed gull (*Chroicocephalus ridibundus*). Furthermore, every year, thousands of birds winter in this lagoon, mainly Anatidae such as the northern pintail (*Anas acuta*), the northern shoveler (*Anas clypeata*) or the common pochard (*Aythya ferina*). The presence and reproduction of the red-knobbed coot (*Fulica cristata*) is remarkable (Castro et al. 2006; Mateo-Ramírez et al. 2021).

In the Smir lagoon, an important diversity of other vertebrates occurs, with similar fishes as included in Annexes of the HD like the greater pipefish (*Syngnathus acus*) and the seahorse (*Hippocampus hippocampus*) together with gobies or mammals such as the Eurasian otter (*Lutra lutra)* (https://rsis.ramsar.org/ris/2380). The benthic macrophytes of this lagoon host a diverse community of benthic invertebrates with amphipods, isopods, polychaetes, bivalves and gastropods as dominant groups (Chaouti and Bayed 2005).

Tourism is the most important socio-economic activity for the city of M’diq and the surrounding urban areas. Agro-pastoral activities are also a source of income, mainly from cereal crops and the production of local cattle. Currently, the MPA is under high urban pressure, related to population growth throughout the coastal area.

Tourism pressure and summer residences are causing the expansion of the city of M'diq, which threatens the lagoon to the south and east. Despite being a SIBE and a biosphere reserve, no agency has intervened to stop the advance of the developments that are proliferating around the lagoon, which may seriously affect its vegetation. The destruction of the habitat and the discharge of waste water into the lagoon are seriously affecting the life cycle of the birds. Birds are also greatly affected by human pressure, mainly from illegal hunting.

25.6.4 Koudiet Taifour SIBE and Réserve de Chasse Permanente (Morocco)

Koudiet Taifour was declared as SIBE in 1995 by the High Commission for Water and Forests and combating desertification, and it was included in the third level of priority for conservation. The reason it was listed as SIBE was the presence of species and habitats of conservation interest for the Mediterranean; ecological, biological and aesthetic integrity of the site involved; and the socio-economic importance of the area (fishing, recreational and tourism activities). Additionally, Koudiet Taifour was designated a Permanent Hunting Reserve (Réserve de Chasse Permanente, RCP) in 2012.

The RCP occupies an area ca. 11 km^2, whereas the MPA covers an area of 5.32 km^2, but only 0.65 km^2 correspond to marine area which goes down to depth of 30 m from the coastal line. It is bounded to the north by Cabo Negro and the city of M'diq and to the south by the Martin River that runs between Motril and Tétouan. Koudiet Taifour is a highly urbanized area with ports and tourist accommodations, which has led to the loss of its character and its high-quality landscape.

In this MPA, different types of habitats have been listed, with some of them representing similarities with the ones listed in Annex I of the HD. In the terrestrial part, dunes with *Pinus pinea* (similar to Habitat 2270 of HD) are present. Strictly, marine habitat are sandbanks which are slightly covered by seawater all the time (1110) with seagrass meadows conformed by *C. nodosa*. The second main habitat is reef (1170) (Mateo-Ramírez et al. 2020b), with mesolittoral communities and associated species such as the saffian limpet (*Cymbula safiana*) and the ribbed Mediterranean limpet, and vermetid reefs of *D. lebeche*, with coralligenous communities formed by red algae *L. byssoides*, the chalice coral and molluscs species such as the rough pen shell (*Pinna rudis*) on infralittoral bottoms (MedMPAnet 2012). All these species are included in the Annex I (strictly protected species) of the Bern Convention and/or in the Annex II (endangered or threatened species) of the BC (Mateo-Ramírez et al. 2021).

Although the fishing activity in the area is carried out on a small scale by artisanal fishing boats docked in the port of M'diq, the tourism is the main socio-economic activity in this coast (Jiménez and Almonacid 2008). In spite of being a SIBE, the coast of Koudiet Taifour has suffered a landscape and functional transformation in the last decades, caused essentially by the boom in the construction of urbanizations for tourism. This expansive strategy of tourism infrastructure, which has had a great impact on the environment, threatens to continue in the future due to its high economic importance.

25.6.5 Côte Rhomara SIBE and RCP (Morocco)

Côte Rhomara was proposed as SIBE under the framework of the Protected Areas Master Plan of Morocco of 1996 (AEFCS 1996) because of its aesthetic value and scientific and educational interest. Its declaration as SIBE was done because of certain artisanal fishing practices in this sector of the Mediterranean Moroccan coasts but also in relation to the landscape quality and the heritage value of this area. Additionally, Côte Rhomara was designated as an RCP in 2012.

The RCP has an area of 68 km^2, whereas the SIBE occupies an area about ca. 42 km^2 and reaches a maximum depth of 8 m. This MPA is on the province of Chefchaouen and is located between Oued Ouringa and the locality of Kaâ Sras. It is a trimmed and relatively inhospitable coast formed by a succession of small sandy beaches and rocky capes isolating a few islets at their base.

The best represented habitat of the MPA is similar to reefs (Habitat 1170) of the Annex I of the HD. A total of ten species of conservation interest appear occasionally on cliffs of this MPA such as Audouin's gull, the osprey and the European shag (*Phalacrocorax aristotelis desmarestii*). Some species of the mesolittoral and infralittoral rocks are the macroalgae *L. byssoides* and *Peyssonnelia squamaria*, together with the chalice coral and ribbed Mediterranean limpet (Mateo-Ramírez et al. 2021). In specific infralittoral rocky bottoms, there are macroalgae communities with *Cystoseira compressa*, *Cystoseira humilis*, *Sargassum vulgare* and *Saccorhiza polyschides* (UNEP-MAP-RAC/SPA 2009). In some sublittoral bottoms, the giant tun (*Tonna galea*) can be relatively common unlike other parts of the Mediterranean Sea.

The main socio-economic activity of Côte Rhomara is the artisanal fishing, complemented with the growing tourism and its derived recreational activities. The main threat is the illegal fishing mainly that of bottom trawling that usually takes place near the coast of the regions Amtar, Chmaâla, Stihat and Targha. Nevertheless, there are other illegal types of fisheries in the area such as the collection of common octopus in the area from Iâraben and suspected dynamite fishing in the localities of Takamount/Sidi Ftouh. Another important threat is related to the development of the road network in the region (Mediterranean bypass), construction of residential or recreational areas and touristic coastal developments that modify the coastal line and increase the discharges of waste water and litter.

25.6.6 Cirque d'El-Jebha SIBE and RCP (Morocco)

The Cirque d'El-Jebha was proposed as SIBE for its aesthetic value and scientific and educational interest and is currently part of the Intercontinental Mediterranean Biosphere Reserve Andalusia-Morocco. This SIBE occupies an area of 0.85 km^2 and reaches down to depth of 27 m. In 2012, Cirque d'El-Jebha was also designated as a RCP with an area of ca. 3.6 km^2.

This MPA is located east of the city of Jebha, just after the fishing port, in the province of Chefchaouen, that is located in the Rif Central (Morocco). The Cirque d'El-Jebha is a horseshoe depression developed over a folded and trusted sequence of Jurassic limestones and Aquitanian turbidites (Vitalea et al. 2015). The Cirque d'El-Jebha is a remarkable geomorphological structure, with an amphitheatre form limited by high cliffs and connected to the sea northwards. It is a very small rib, formed of a succession of small sandy beaches, coves and rocky capes isolating a few islets at their base. A series of ravines cut the relief into very narrow valleys perpendicular to the coast.

In this MPA, a high diversity of species has been detected, with 20 of them included in different conventions of protection (Mateo-Ramírez et al. 2021). In their cliffs, threatened birds nest such as Audouin's gull and the osprey. The predominant habitat in this MPA is similar to the reefs (Habitat 1170) of the HD. In steep cliffs and slopes and ledges exposed to waves and strong hydrodynamics, the mesolittoral community is conformed by cirripeds (barnacle *Pollicipes pollicipes*), the red algae *L. byssoides* and other protected species such as the ribbed Mediterranean limpet and saffian limpet (Mateo-Ramírez et al. 2021). In the subtidal zone, other threatened species are the chalice coral and some macroalgae such as *Cystoseira zosteroides*, *Cystoseira amentacea* and *Cystoseira elegans*. In the central part of the horseshoe depression, the seabed is composed of large blocks that host a very interesting biodiversity, including macroalgae such as *Dictyopteris polypodioides*, *S. polyschides* and *Sargassum vulgare*; sponges like *Ircinia* sp.; the dusky grouper; the knobbed triton; and an important diversity of coralligenous communities with different corals and gorgonians such as the red coral, the orange tree coral, the violescent sea-whip (*Paramuricea clavata*), the white sea fan (*Eunicella singularis*) and *Leptogorgia* sp. (UNEP-MAP RAC/SPA 2009). Some of those aforementioned species are included in the Annex II of the BC. Small cetaceans such as the common dolphin have also been frequently observed in the area (Mateo-Ramírez et al. 2021).

The Cirque d'El-Jebha has a high socio-economic importance for the town of Jebha. The proximity to the town and the port facilitates the artisanal fishing that exploits a wide variety of fishes (more than thirty species). Some of the target species are the very valued dusky grouper, cuttlefish (*Sepia officinalis*), common octopus, spider crab and the spiny lobsters (*Palinurus elephas*). The main threats are the increase of housing developments, as well as the urban discharges from the port and town that constitutes a source of significant contamination to the adjacent ecosystems. Other threats are the lack of waste water and garbage treatment plants; the release of litter such as bottles, tires and ghost nets; and the overfishing and illegal fishing, in particular of species included in conservation lists such as groupers and the red coral.

25.6.7 Cap des Trois Fourches SIBE and Collateral Protection Figures (Morocco)

The Cap des Trois Fourches (Cape of Three Forks) was declared SIBE in 1996 and Ramsar site in 2005 (CAR/ASP—PNUE/PAM 2012). Later, the terrestrial part was designated as RCP in 2012, with an area of 24 km^2. Finally, in 2014, a Réserve Naturelle was proposed that included most of the terrestrial area of the RCP and a maritime area of 68.2 km^2 ranging from coastal line to more than 230 m.

This MPA is located at the Trois Fourches peninsula, in the Moroccan commune of Beni Chiker (province of Nador) and north of Melilla (Fig. 25.21). This MPA is characterized by a cliff coast, containing small coves. In this area, the outcrop of two geological units occurs, separated by an extensional fault of NE-SW trend, towards the south of the fault micaschists with orthogneiss, quarzites and marbles of Tarjât unit and lower greenschist shales and quarzites of the Taïdant unit and to the north of the fault, cal-calkaline series, volcanoclastic rocks and detritic sediments of Tortonian age (Azdimousa et al. 2019). One aspect to consider is the different physiognomy of the eastern and western coasts of the Cap des Trois Fourches. Due to the geological nature, the eastern coast is much steeper, with deep bottoms just few metres from the coast, but the western coast is smoother. This could also be related to the different hydrodynamics with stronger easterly winds compared to westerly ones.

Terrestrial ecosystems, without large human populations and minimal touristic influence, are rich and varied, with several habitats that are similar to those included in the Annex I of the HD. Some of the terrestrial habitats are thermo-Mediterranean and pre-esthetic scrubland (Habitat 5330) and the most coastal cliffs with vegetation on the Mediterranean coast with endemic *Limonium* spp. (1240) and halonitrophile scrubs (Pegano-Salsoletea) (1430) (Mateo-Ramírez et al. 2020b).

The marine life of this MPA is influenced by the nutrient-rich waters and the biogeographic confluence of Atlantic species that are not common eastwards and of Mediterranean species that are not common westwards (González García 1994). This is clearly reflected in the algal communities, with the presence of the typical Atlantic algae *Fucus spiralis*, *Cystoseira gibraltarica* or *Gelidium sesquipedale* and of the typical Mediterranean *Rissoella verruculosa*, *Cystoseira crinita* and the seagrass *P. oceanica*.

The first marine expedition in the Alboran Sea was carried out in 1910 by Odon de Buen, including the area of Cap des Trois Fourches to the Moulouya River mouth (Camiñas 2018). Recently, the marine habitats of this MPA have been explored in the framework of the MedMPAnet Project by Espinosa et al. (2015). These authors found ten different habitats, including some key conservational habitats such as

Fig. 25.21 Different Marine Protected Areas of the southern sector of the Alboran Sea and species that can be found in them. (**a**) Cap des Trois Fourches (Cape of Three Forks) (Morocco); (**b**) Sebkha Bou Areg (also known as Mar Chica) (Morocco); (**c**) group of different species of migratory shorebirds such as the black-winged stilt (*Himantopus himantopus*), the ringed plover (*Charadrius hiaticula*), the dunlin (*Calidris alpina*), the sanderling (*Calidris alba*) and the curlew sandpiper (*Calidris ferruginea*); (**d**) picture taken in 1991 of a Mediterranean monk seal (*Monachus monachus*) called “Peluso” that lived in the surroundings of the Chafarinas Islands and finally disappeared in the 1990s; (**e**) the Seahorse *Hippocampus hippocampus* on a *Cymodocea nodosa* meadow at low tide; (**f**) specimen of the loggerhead turtle (*Caretta caretta*) (**a**, **b**, **e** Juan Antonio González García, Universidad de Granada; **c** Antonio-Roman Muñoz, Universidad de Málaga; **d** Isidoro Bueno, **f** OCEANA, Carlos Minguell)

C. nodosa meadows (similar to Habitat 1110 of HD), dark and semidark cave communities (similar to Habitat 8330 of the HD), coraligenous assemblages (similar to Habitat 1170 of the HD) and rhodolith beds (Mateo-Ramírez et al. 2020b).

In the mesolittoral reefs, well-preserved populations of the vermetid *D. lebeche* (Vulnerable) have been detected as well as of the ribbed Mediterranean limpet (Critically Endangered), the latter with more than 20,000 individuals (González García et al. 2006). In sublittoral rocky bottoms, protected or regulated commercial species occur such as the common antlers sponge (*Axinella polypoides*); the cnidarians chalice coral (*Astroides calycularis*), pink sea fan (*Eunicella verrucosa*), violescent sea-whip (*Paramuricea clavata*), whip gorgonia (*Ellisella paraplexauroides*), orange tree coral (*Dendrophyllia ramea*), yellow tree coral (*Dendrophyllia cornigera*), Mediterranean pillow coral (*Cladocora caespitosa*), *Eunicella verrucosa*, *Eunicella gazella*, *Savalia savaglia* and *Leptogorgia lusitanica*; the molluscs knobbed triton (*Charonia lampas*), rough pen shell (*Pinna rudis*), zoned mitre (*Episcomitra zonata*), pear cowry (*Zonaria pyrum*), date shell (*Lithophaga lithophaga*), wandering triton (*Ranella olearium*) and brown cowry (*Luria lurida*); the crustaceans spider crab, spiny lobster, slipper lobster and European lobster (*Homarus gammarus*); the echinoderms hatpin urchin (*Centrostephanus longispinus*), purple sea star (*Ophidiaster ophidianus*), smooth starfish (*Hacelia attenuata*); and the large fishes dusky grouper, brown meagre (*Sciaena umbra*) and moray eel (*Muraena helena*) (Yus et al. 2013; Mateo-Ramírez et al. 2021).

Another interesting habitat of the MPA is the kelp beds that are located in the most reophilic areas, specifically between "Los Farallones" and the tip of the "Farola" as well as in the vicinity of the "Tío Pinar" slab. The main kelp species are *S. polyschides* and *Phyllariopsis brevipes* that form extensive and dense meadows between depth of 8 and 30 m with fronds up to 2 m high (González García and Conde Poyales 1993). In the submerged and semi-submerged caves, a rich fauna of invertebrates has been detected, especially in those of "Los Farallones" canal, the "Tío Pinar" slab, the tip of the "La Farola", the "Puntilla" and "Cabo Viejo" (CAR/ASP—PNUE/PAM 2012).

In this MPA, some large pelagic species of marine vertebrates that are passing or stranding are common. Among fishes, the most singular ones are sharks (*Isurus oxyrhynchus*, *Prionace glauca*), bluefin tuna and swordfish (*Xiphias gladius*). There are some records of the leatherback and loggerhead turtles and of cetaceans such as the common dolphin, the stripped dolphin, bottle-nosed dolphin, long-finned pilot whale, Risso's dolphin (*Grampus griseus*), sperm whale and the fin whale (Mateo-Ramírez et al. 2021). The monk seal (*Monachus monachus*) deserves special mention, "Critically Endangered", of which, in the beaches of the volcanic caves of the tip of Cap des Trois Fourches, resting specimens can be sporadically seen (Fig. 25.21) (Mateo-Ramírez et al. 2021).

The main socio-economic activity in the MPA is artisanal fisheries. There are 70 boats from the village of Kahf Dounia, Tibouda and Ouled Lahsen that operate in the area. All of these use artisanal fishing gears, and the target species are the common octopus, groupers, axillary seabream (*Pagellus acarne*), albacore (*Thunnus alalunga*) and the red mullet (*Mullus surmuletus*). Another complementary and important activity is tourism. All year-round, the fisherman rent their houses to tourists during weekends and in summer (CAR/ASP—PNUE/PAM 2012).

Human influence on the coast is still scarce, because the abrupt terrain of the MPA has not allowed important human developments that could threat the landscape. Nevertheless, three negative human activities should be mentioned such as the use of explosives for fishing that were carried out by the coastal population of “Cala Viñas” in the area of the “Farallones” for decades, which has reduced populations and sizes of large fish, especially groupers; the punctual bottom trawling and longline fishing carried out at short distance from the coast; and scheduled trips of one or several days of small vessels carrying underwater fishing experts that decisively influenced the decline of populations, especially of the dusky grouper, the Atlantic wreckfish (*Polyprion americanus*) and the goldblotch grouper (*Epinephelus costae*). Nevertheless, this is something that seems already in decline, perhaps due to the decrease in the availability and size of large fish in the MPA.

25.6.8 Zona marítimo terrestre de los acantilados de Aguadú SAC (Spain)

The Zona marítimo terrestre de los acantilados de Aguadú SAC (Maritime-terrestrial zone of the Aguadú cliffs) (ES6320001) (Fig. 25.22) was designated as SCI in March 2006 and as SAC in September 2013, with a final area of ca. 0.55 km^2 (0.44 marine and 0.11 terrestrial). It is located in the northern part of the Melilla City, with an altitude of 120 m of “Quemadero” ravine and a depth range between the coastline and depth of ca. 30 m. On the land side, in addition to the aforementioned ravine, the cliffs of Aguadú occur from the seawater desalination plant to the border with Morocco, about 700 m of coastline. On the cliffs of Messinian formations outcrops, from base to top, there is a succession of conglomerates, calcarenites, limestones of algae and breccia and sands and silts and finally, it is covered by caliches and carbonate crusts of Holocene age.

Several habitats listed in Annex I of the HD can be identified in the SAC, with two of them being of marine character such as reefs (Habitat 1170) and submerged or semi-submerged marine caves (8330) and three terrestrial ones: thermo-Mediterranean and pre-steppic scrub (5330), cliffs with Mediterranean coastal vegetation with endemic *Limonium* spp. (1240) and halonitrophile scrub (Pegano-Salsoletea) (1430). In those terrestrial habitats, interesting vascular flora occurs such as the thuya *Tetraclinis articulata* and *Helianthemum caput-felis* (protected in the HD) and the North African endemic *Bupleurum balansae*. In these areas, Audouin’s gull displays a nesting population of several hundreds of specimens since 2015 (González García and Enrique Mirón 2018a) (Fig. 25.22) (Mateo-Ramírez et al. 2020b).

Regarding marine life, there are two protected molluscs associated with mesolittoral reefs with strong hydrodynamics (Habitat 1170 of the HD): the ribbed Mediterranean limpet (Critically Endangered IUCN list), which forms dense populations of ca. 3000 adult specimens and a high number of immature specimens

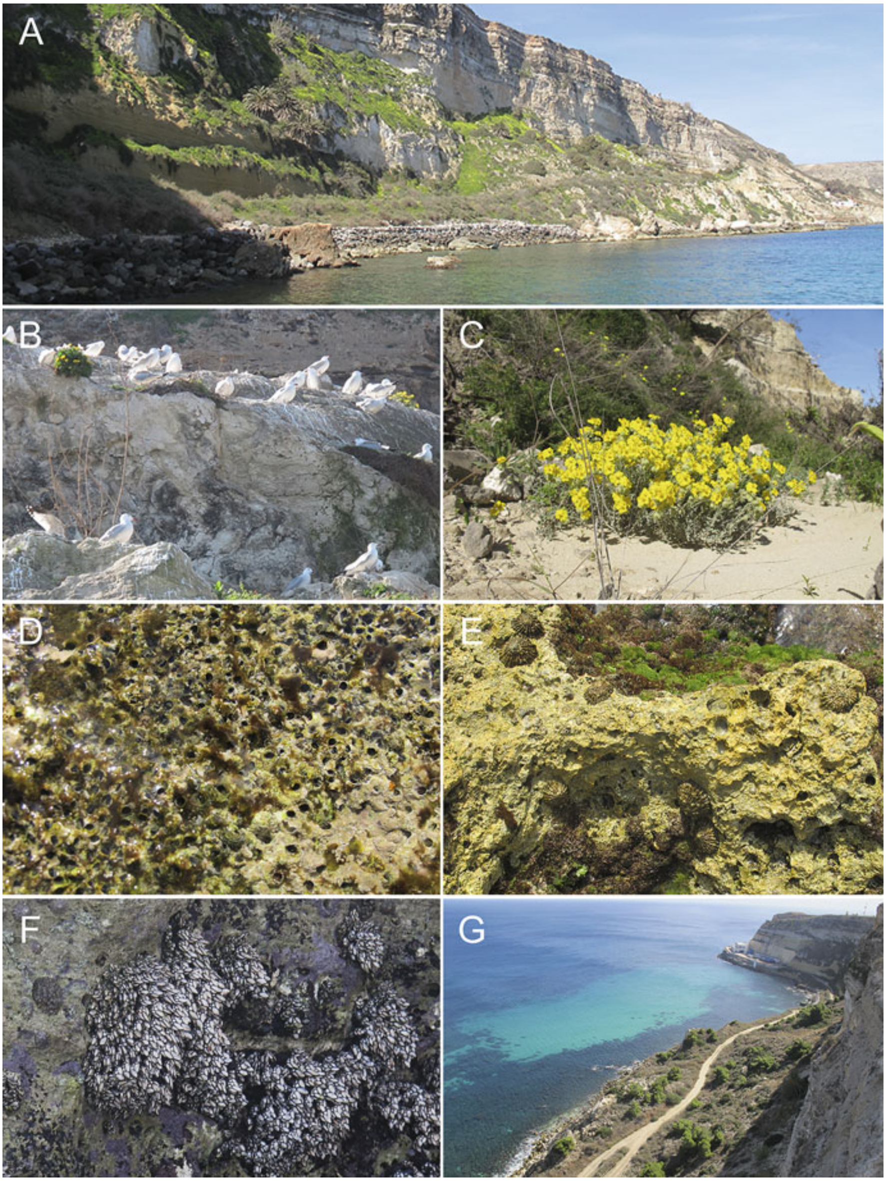

Fig. 25.22 Different habitats and species of the Zona marítimo terrestre de los acantilados de Aguadú SAC. (**a**) Cliffs of Aguadú; (**b**) nesting colony of Audouin's gull (*Larus audouinii*); (**c**) *Helianthemum caput-felis* on sandy substrate near the coast; (**d**) reefs of *Dendropoma lebeche*; (**e**) high density of the ribbed Mediterranean limpet (*Patella ferruginea*) on the mesolittoral; (**f**) barnacle *Pollicipes pollicipes* under the brine cascade of the desalination plant; (**g**) coastline of the SAC with the Punta de Rostrogordo desalination plant at the end (Juan Antonio González García, Universidad de Granada)

(González García et al. 2013, 2015; González García and Enrique Mirón 2019) and the vermetid *D. lebeche* (Vulnerable) conforming small groups of individuals or forming small continuous aggregates (González García et al. 2014) (Fig. 25.22). Other vulnerable protected species of the SAC are the barnacle and the saffian limpet (Fig. 25.22). In addition, some protected species of rocky-mixed bottoms, vertical walls, hollows or small caves at depths of more than 10 m (Habitat 8330 of the HD) are found in the SAC such as the chalice coral, the knobbed triton, the rough pen shell, the gorgonians *Eunicella verrucosa* and *E. gazella*, the starfishes purple sea star and smooth starfish and the solitary red sea squirt (*Halocynthia papillosa*) (González García and Enrique Mirón 2018b; Mateo-Ramírez et al. 2021).

This MPA has no human activities due to the prohibition and the restricted access, and it has only been explored by the Spanish army for the last 15 years. The main threat comes from the desalination plant located in Punta de Rostrogordo that occupies 8000 m^2 at the foot of the cliffs located adjacent to the SAC. This desalination plant discharges the brine in the same area ("Overflow on a cliff," as defined in the CEDEX technical report for the Ministry of the Environment, Rural and Marine Affairs in 2011) (Fig. 25.22), as well as through an underwater outfall of 1 m in diameter at a depth of 9 m. Other substances are also discharged such as biocides, anticoagulants, flocculants, antifoulants, detergents and pH adjusters. Currently, the project to expand the plant, already approved, with the further destruction of the habitat that this will imply, reinforces the threat. In 2005 and 2006, the works of the desalination plant (dredging, blasting and concreting, installation of pipes and a water tower, construction of a coastal breakwater, destruction of the cliff, etc.) and of a coastal road with anti-immigration purposes caused a strong landscape and ecological impact, but paradoxically, in the medium term and due to the total isolation of the human presence, the recovery of the diversity in 15 years has been very high.

25.6.9 Sebkha Bou Areg SIBE and Collateral Figures of Protection (Morocco)

The Sebkha Bou Areg Réserve Naturelle (Nature Reserve) and RCP, also known as Mar Chica, is a coastal lagoon located close to Nador and Melilla that reaches depth of 8 m, representing a unique formation within the Alboran Sea (Fig. 25.21). This lagoon is bounded to the east by the Gourougou volcanic massif, formed by pyroxene-biotitic andesites of a cal-calkaline series, to the north by rocky outcrops of Mesozoic and Neogene sedimentary units and to the south by the plains of Bou Areg, constituted by marls and sandstones of Miocene and Pliocene age (Torcal Sainz and López Barmúdez 1997). It is separated from the open sea by a sandy littoral bar of about 24 km in length that is currently communicated with the sea through two channels or artificial "mouths" of about 300 m wide. The terrestrial area is a RCP declared in 2012 with 93 km^2. In 2014, the marine area was proposed as

Nature Reserve, increasing the area up to 169 km^2 with 111 km^2 of marine area, with a maximum depth of ca. 6 m.

In the littoral bar, there is vegetation that is typical of coastal sandy beaches conforming some protected habitats that are similar to those of the Annex I of the HD, such as annual vegetation on accumulated marine debris (Habitat 1210), cliffs with vegetation of the Mediterranean coasts with endemic *Limonium* spp. (1240), Mediterranean and thermo-Atlantic halonitrophilic thickets (*Sarcocornetea fruticosi*) (1420) and halonitrophilic thickets (Pegano-Salsoletea) (1430) (Mateo-Ramírez et al. 2020b).

Sebkha Bou Areg was also declared as IBA by the BirdLife International Program in 2001 and SIBE and Ramsar site in 2005. This was mainly due to its importance for biodiversity and breeding area, with nesting birds such as the sandwich tern, pied avocet, marsh harrier, little tern (*Sternula albifrons*), the lesser crested tern (*Thalasseus bengalensis*) and the Kentish plover (*Charadrius alexandrinus*). Other wintering and migratory species are the little ringed plover (*Charadrius dubius*), black-tailed godwit (*Limosa limosa*), black tern (*Chlidonia sniger*), Eurasian curlew (*Numenius arquata*), greater flamingo (*Phoenicopterus roseus*) and purple heron (*Ardea purpurea*) (Fig. 25.21) (Mateo-Ramírez et al. 2021).

Muddy sand occupies almost all of the lagoon bottoms, with the exception of the coast of the volcanic elevation of El Atalayón and the small sandstone formations of some areas of the littoral bar. Depth and sediment characteristics (e.g. organic matter concentration) determine the presence of different vegetated habitats such as small meadows of *Z. noltei*, meadows of *C. nodosa* and the macroalgae *C. prolifera*, sometimes mixed with those seagrasses (Habitat 1110 of the HD) (Fig. 25.21). Other macroalgae species proliferating in shallow areas of the lagoon with high salinity and clear signs of eutrophication are *Ulva rigida*, *Enteromorpha* spp. and *Chaetomorpha linum*. In boulders and small vertical barrels of the sleeve of El Atalayón, the vegetated habitats are conformed by fucoid meadows (*C. crinita*, *C. compresssa* and *S. vulgare*) and other species such as *Gelidium pusillum*, *Laurencia obtusa*, *Spyridia filamentosa or Acetabularia acetabulum*.

Animal diversity is reduced compared to the open sea, but there are some protected species that inhabit the lagoon, including the rough and the noble pen shells, the latter until its decline in 2016 (Fig. 25.21), as well as the long-snouted seahorse (*Hippocampus guttulatus*), the brown cowry in sparse and only under sandstone cornices, the captain star (*Asterina gibbosa*) under stones in El Atalayón, the Mediterranean pillow coral and the orange puffball sponge (*Tethya aurantium*). Other species are the triple-grooved shrimp (*Penaeus kerathurus*), abundant in freshwater outcrops of the internal part of the lagoon and the eel (*Anguilla anguilla*) breeding in cane field ditches with agricultural discharges. Other marine species, most of them associated with macrophytes, are the holothurian (*Holothuria tubulosa*), the shore crab (*Carcinus maenas*), pink cuttlefish (*Sepia orbignyana*), the golden grey mullet (*Chelon aurata*), muricid gastropods (*Hexaplex trunculus*, *Bolinus brandaris*), nudibranchs (*Aplysia punctata*, *Pleurobranchaea meckelii*, *Berthella stellata*), epizoic colonial bryozoans of *C. nodosa* (*Botryllus schlosseri*, *Botrylloides leachii*) and a wide variety of bivalve molluscs.

Regarding socio-economic activities, the MPA has been a fishing source of triple-grooved shrimp, cuttlefish (*S. officinalis*, *S. orbignyana*), common octopus, striped seabream (*Lithognathus mormyrus*) and sand smelt (*Atherina presbyter*). In the 1980s, the MAROST Company introduced marine farms of various species in El Atalayón, including the chequered venus (*Ruditapes decussatus*), kuruma shrimp (*Penaeus japonicus*), gilthead seabream (*Sparus aurata*) and common oyster (*Ostrea edulis*). Tourism is concentrated on the coast of Nador and Beni-Enzar where the Melilla population spends their holidays.

The main threats are the increasing tourism pressure as well as the urban-associated discharges and wastes of nutrients and herbicides from irrigated crops of the internal section between Nador and the south-western end. There are also some invasive species such as the opistobranch *Bursatella leachii*, the American brine shrimp (*Artemia franciscana*) or the kuruma shrimp which has displaced some native shrimp species. The future of the MPA remains uncertain because of the transformation that has already begun, which aims to transform the area into an extensive tourist complex. In this way, the disposal of urban waste has improved, two artificial mouths have been opened to the sea, important dredging have been done in the bottoms and the so-called seven Cités de la Mar Chica are under construction at the moment, with “marinas,” lagoons and artificial islets. This may represent an important threat for the persistence of some of the habitats and species of this MPA.

25.6.10 Islas Chafarinas National Refuge of Hunting and SAC (Spain)

The Chafarinas Islands are an archipelago that consists of three islands: Congreso, Isabel II and Rey Francisco that are located in the southern Alboran Sea, 48 km west of Melilla City and ca. 3 km in front of Cabo de Agua and also located 11 km to the north-west of the Moulouya River mouth, very close to the border between Morocco and Algeria (Fig. 25.23). The presence of specimens of the monk seal (*M. monachus*) (Fig. 25.21), a large colony of Scopoli’s shearwater and Audouin’s Gull, endemic flora species and well-preserved bottoms communities motivated its designation as National Refuge of Hunting (Refugio Nacional de Caza) in April 1982. Later on, these islands were declared as SPA in 1989. In November 1998, a SCI was proposed, approved in 2006 (ES6300001) and designated as SAC in 2018. Currently, these islands are under the shared administration of the Spanish Army and the Organismo Autónomo Parques Nacionales (OAPN) of the Ministerio para la Transición Ecológica (Spanish Ministry for the Ecological Transition). These islands have been described as the eroded remains of a volcanic massif Upper Miocene-Pliocene in age (Barrera and Pineda 2006). These authors indicated the presence of

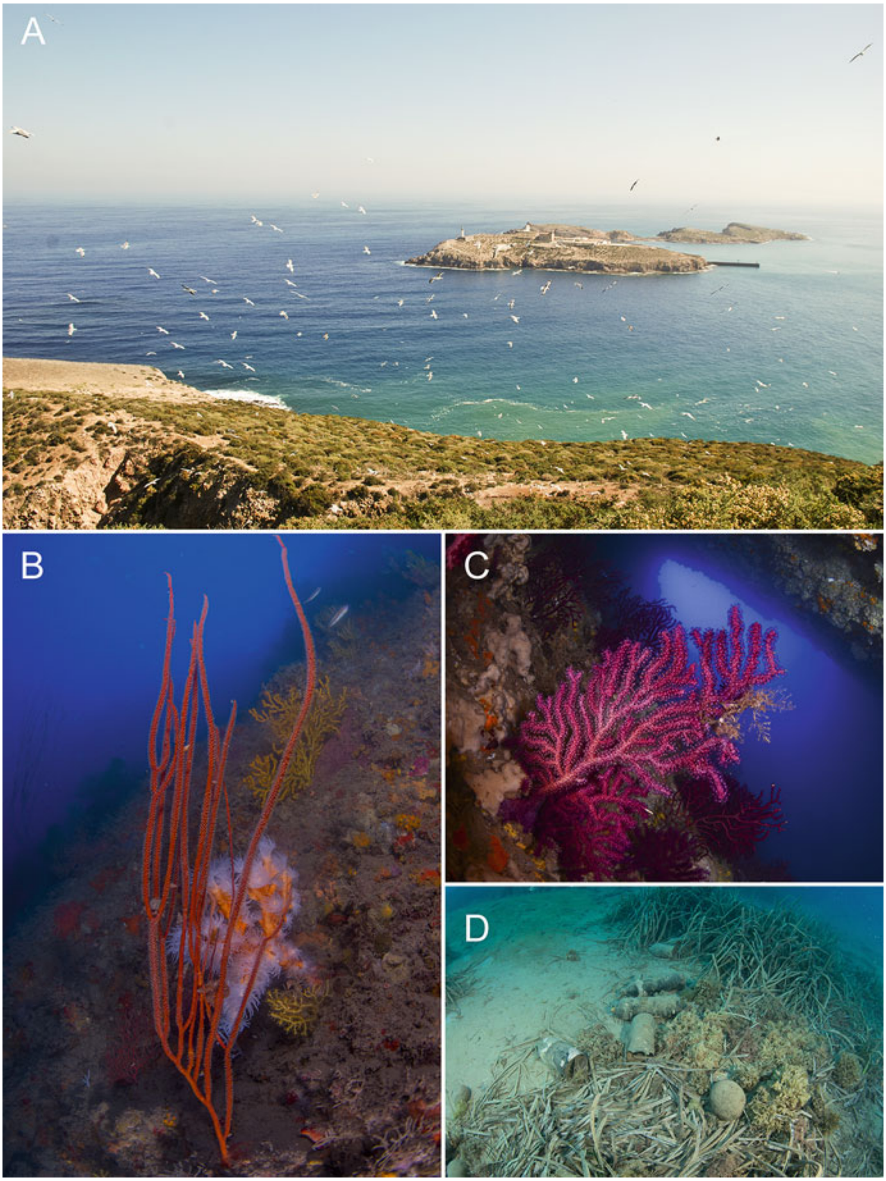

Fig. 25.23 Some emblematic species and impacts that affect marine communities of the Chafarinas Islands. (**a**) View of Chafarinas Islands; (**b**) coralligenous communities with the large gorgonian *Ellisella paraplexauroides* and the orange tree coral (*Dendrophyllia ramea*) at the back; (**c**) the violescent sea-whip (*Paramuricea clavata*) within a cave; (**d**) plastic bottles and litter next to a *Posidonia oceanica* meadow (Luis Sánchez Tocino, Universidad de Granada)

mainly andesitic units from the cal-calkaline series (breccia, lava flows, domes and pythons) and basalts from the alkaline series. Covering these materials, carbonate crusts, hillside and eolic deposits appear, while the seabed is largely sedimentary due to the deposition of sediments transported by the coastal drift, predominantly westwards, from the Moulouya River (Barrera and Pineda 2006).

In this MPA, there are habitats included in the Annex I of HD such as *P. oceanica* meadows (Habitat 1120) displaying a healthy status, submerged or semi-submerged marine caves (8330) and reefs (1170) with interesting and rich associated benthic communities (Fig. 25.23) (Mateo-Ramírez et al. 2020b). The littoral and the sublittoral bottoms harbour different species included in the Annex II of the BC, such as the critically endangered ribbed Mediterranean limpet which is one of the most important populations (Guallart and Templado 2016), the hatpin urchin, the vermetid gastropod *D. lebeche* or the common antlers sponge *Axinella polypoides* (Maldonado et al. 2011; Templado et al. 2016; Mateo-Ramírez et al. 2021). The peculiar characteristics of its waters, with a high degree of turbidity due to its proximity to the Oued Moulouya River mouth, enhance suspended sediment supply. This is probably one of the reasons for the presence at shallow waters of characteristic species of deeper areas such as the *Ellisella paraplexauroides* that displays here the largest known population for the Alboran Sea (Maldonado et al. 2013) (Fig. 25.23), the black coral *Antipathella subpinnata* (Sánchez-Tocino et al. 2014) or the gold coral *Savalia savaglia* (Maldonado et al. 2011; Mateo-Ramírez et al. 2021). The large populations of the violescent sea-whip and the presence of the orange tree coral are also remarkable (Sánchez-Tocino et al. 2019) (Fig. 25.23) (Mateo-Ramírez et al. 2021). Furthermore, a high species richness of molluscs has been highlighted by Oliver et al. (2015) in the bottoms around the islands.

Because the access to the islands is nowadays restricted, the only economic activity in the area is some small-scale fishing by Moroccan fishermen from "Cabo del Agua" and also some recreational fishing activity. This has been done both by Moroccan fishermen and the military detachment over several years, and it has caused significant damage on sessile benthic invertebrates. Some nets, lines and hooks have especially damaged the large *E. paraplexauroides*, with different colonies having fishing lines and pieces of net material tangled in their branches (Maldonado et al. 2013). On the other hand, the increase in spear fishing, due to the professionalization of the outstanding troops on the islands, resulted in a sharp reduction of large fish, especially groupers and sparids. Likewise, the lack of recycling by the Moroccan population of plastic bottles and litter favours their accumulation in the *P. oceanica* meadows. Moreover, some mortality events of the gorgonians violescent sea-whip and white sea fan have been detected in recent years (de la Linde Rubio et al. 2018) (Fig. 25.23), and no living specimens of the noble pen shell were found in 2019 due to the aforementioned massive decline in 2016. Finally, the presence of the invasive algae *C. cylindracea* and *R. okamurae* was confirmed in 2018 and 2019 (Sánchez-Tocino, personal observation).

The declaration of these islands as SAC and the regulation of fishing activities have been fundamental for stopping (or at least slowing down) the degradation of their habitats and associated communities. Nevertheless, in addition to these measures, it is necessary to intensify the surveillance to prevent the less visible areas of the islands from being used by Moroccan fishermen that throw their gillnets close to the coastline and by furtive underwater fishermen and for other types of activities that use the islands as an anchorage place, leaving the bottoms full of remains of their unsustainable activities (Fig. 25.23). At present, the increase in the breeding colony of yellow-legged gulls (*Larus michahellis*) seems to be affecting Audouin's gull, whose population is significantly decreasing.

25.7 Gaps of Knowledge and Future Management Ideas

The Alboran Sea is an area of importance regarding historical, social, geopolitical, strategic and scientific aspects, and it is the engine for different Mediterranean aspects. Its characteristic oceanography, as well as its strategic location, makes the Alboran Sea one of the areas with the greatest biodiversity in Europe and with a high amount of protected/threatened habitats and species, as it has been presented in this chapter: a natural marine heritage off the coasts of the southern Iberian Peninsula and northern Morocco and Algeria that should be protected in its entirety due to its uniqueness. Nevertheless, its management and protection entail a difficulty arising from the need of designing a strategy of collaboration between different countries, which in this case belong to different continents and cultures. Therefore, in order to ensure the conservation of the biodiversity and the sustainable use of the resources of the Alboran Sea, it is necessary to adopt a coordinated management strategy based on different approaches including a network of Marine Protected Areas (MPAs), an Integrated Coastal Zone Management (ICZM), an effective plan for the protection and recovery of threatened and endangered habitats and species and a sustainable use of exploited resources (Robles 2010).

25.7.1 Marine Protected Areas and Key Biodiversity Areas Network

For consolidating the Marine Protected Areas and Key Biodiversity Areas (MPAs and KBAs), a network is needed for increasing the number and extension of MPAs as well as for implementing effective conservation measures in order to increase the protection of the Alboran Sea. The network should increase the number of MPAs in all surrounding countries, moving ahead to equilibrate the protected surface and the number of MPAs concerning the coastline length of each country. Currently, the main problem to the sustainability of the good condition of the MPAs-KBAs is related to the needs for improving the human resources in relation to the control and surveillance in MPAs that are still inadequate regarding the number of officers and vessels for surveillance. A second gap is related to the lack of coordination and collaboration in terms of regulations and shared actions among local, regional and national governments and between countries.

The unbalanced number of protected areas between the northern and southern sectors of the Alboran Sea is remarkable, because all MPAs-KBAs (including only IBAS) of the Alboran Sea accumulate a total area of ca. 5661 km^2, but ca. 91% belongs to those of the northern sector. The MPAs-KBAs network of the Alboran Sea is complex because MPAs-KBAs are very diverse from different points of view, both in terms of their conception and objectives and in terms of their scope and responsibility for their management. It is important to distinguish between MPAs that are effectively protected and those that are in the process of improving their management (e.g. some KBAs, SCIs). There are only ca. 15 of the ca. 35 detected MPAs-KBAs (including only IBAS) that incorporate some protection figure and/or a management plan (Natural Park, Permanent Hunting Reserve, Natural Monument or Natural Site), which depends on the country where they are located. There are very few of them with effective protection measures. In parallel for increasing human and funding resources in the existing MPA-KBAs, the inclusion of new MPA or KBA should be accompanied of financial resources in order to provide surveillance and monitoring systems. Moreover, adequate infrastructures and services (e.g. waste water treatment plants, delimitation of restricted areas) should be provided in those areas where significant human developments and unsustainable practices are still occurring.

The current conservation and protection measures are not sufficient, and it should be amplified and extended to all MPAs from the northern and southern Alboran Sea, which is especially needed for the MPAs of the southern sector. Moreover, there is a need for improving the integration and visibility of the Alboran Sea in the governance processes of the Mediterranean Sea, particularly those related to the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention).

Furthermore, there are a high number of MPAs-KBAs that have not been explored in detail regarding habitat mapping, associated biodiversity and status of the populations of endangered/threatened species, among other aspects. According to IUCN (2012) and the suggestions made by NGOs (e.g. Oceana) and marine experts, there are other KBAs that should be incorporated to the current MPAs-KBAs network such as the submarine canyons of Algeciras, Ceuta and Almería; the seamounts Banc de Xauen, Banc de Tofiño, Banco de Avempace, Banco de Djibouti Ville, Cabliers Coral Mound Province, Banco de Catifas or carbonate mounds of Melilla as well as others areas with poor current information (e.g. submarine canyon of Guadiaro or Almería, mud volcanoes of the Alboran Sea) or no information (the seamounts of Trois Fourches and Provençaux). In those areas, protected habitats and species have been reported by previous studies (Gil et al. 2009; de Mol et al. 2011; Pardo et al. 2011; Aguilar et al. 2013; OCEANA 2014; Palomino et al. 2015; Corbera et al. 2019). Some of these habitats are reefs formed by cold-water corals (harbouring protected species such as *Madrepora oculata*, *Desmophyllum pertusum*, *Dendrophyllia ramea*), gorgonian and black coral aggregations (with protected species such as *Callogorgia verticillata*, *Antipathes dichotoma*, *Leiopathes* *glaberrima*), sponge aggregations, sea pen and bamboo coral communities, and protected species of elasmobranches (*Oxynotus centrina*, *Centrophorus granulosus*, *Leucoraja circularis*, *Cetorhinus maximus*, and *Squalus acanthias*) and molluscs such as giant oysters (*Neopycnodonte zibrowii*). In order to incorporate those new areas to the current MPAs-KBAs network, the relationships between administrations and scientists of each country and at regional level should be created if necessary or at least improved. For example, the communication of the results obtained by the scientists to managers and policymakers concerning new results, additional needs and new proposals of protected areas should be done in an easier and more didactic way.

25.7.2 Conservation of Habitats and Diversity

Regarding cetaceans, it would be essential to implement the recommendations of the Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS), of which both Spain and Morocco are members. A management plan for cetaceans in the entire Alboran Sea, which has been identified by ACCOBAMS and IUCN as an “Area of Conservation Interest,” should be implemented. Experts also recommended the implementation of management plans already developed for the bottle-nosed dolphin and the common dolphin. In 2007, Spain requested that ships crossing the Strait of Gibraltar may not exceed the speed of 13 knots, with precautions during those months when sperm whales return to the Strait of Gibraltar for feeding (IUCN 2007; Robles 2010).

In relation to marine turtles, a “Strategy for the conservation of the Loggerhead Turtle (*Caretta caretta*) and other marine turtles in Spain” is under elaboration under the framework of the Action Plan for the Conservation of Mediterranean Marine Turtles (Barcelona Convention, BC) and for the fulfilment of the commitments established by other international conventions ratified by Spain such as OSPAR, Bonn and Bern. The Ministry for Ecological Transition and Demographic Challenge (MTERD), through the General Directorate for Sustainability of the Coast and the Sea, and the regional and autonomous city governments are preparing this national strategy, drafting the basic technical document within the Working Group of Marine Turtles of the Committee of Wild Flora and Fauna. The Spanish strategy should be reviewed by the State Commission for Natural Heritage and Biodiversity. There are some other national initiatives for the loggerhead turtle which includes limiting accidental catches by fishing gear. Nevertheless, this action plan is not yet being applied because of the lack of approach between the different parts concerned (IUCN 2007; Robles 2010).

For the monk seal, there is a need for reducing significantly human impacts and affluence in some MPAs and creating new MPAs that may harbour the habitats and resources needed for the establishment of monk seal populations, in both the southern and northern Alboran Sea.

Some habitats are experiencing a current decline (e.g. seagrass beds on soft bottoms, sea pen-bamboo coral communities) (Waycott et al. 2009; Fabri et al. 2014), and there is a need to achieve their recovery through restocking in specific areas and effective conservation of the remaining patches of such habitats. For an effective conservation, water quality should be improved, illegal bottom fishing should be controlled as much as possible, boats should be prevented from anchoring on them and coastal erosion should be mitigated (IUCN Grupo de Coordinación Alboran).

Even though The MPAs-KBAs network of the Alboran Sea seems to present a good representation of habitats from the Habitat Directive and Barcelona Convention, such as *Posidonia oceanica* beds (Habitat 1120 of the HD), reefs (Habitat 1170) or sandbanks which are slightly covered by seawater all the time (Habitat 1110), there are others such as submarine structures made by leaking gases (Habitat 1180) and caves (8330) that are still underrepresented. Subtypes of the Habitat 1170 such as cold-water coral reefs or antipatharian aggregations are also not well represented. The inclusion of new MPAs-KBAs that may have these habitats (e.g. mud volcanoes of the Alboran Sea or the Cabliers Coral Mound Province with the biggest CWC reef of the Alboran Sea) would help to increase the conservation of these habitats in the MPAs-KBAs Alboran network.

Regarding habitats with good representation, the lack of updated habitat mapping for the total Alboran Sea still represents a key factor for its effective conservation and management (see Rueda et al. 2021, Chap. 9 of this book). Some projects (e.g. LIFE + INDEMARES, LIFE+ *Posidonia* Andalucía, LIFE Blue Natura) have done significant efforts for improving habitat mapping in specific areas, but accurate mapping is generally absent in most MPAs-KBAs. This kind of information is essential for a good management and marine spatial planning that can ensure the effective conservation of the habitats.

Inclusion of new MPAs-KBAs as mentioned in the previous section as well as effective conservation of the populations in the already designated MPAs-KBAs would also improve the connectivity between populations of threatened species. The number of protected species in MPAs of the Alboran Sea is relatively high, but it is remarkable that most of them are for vertebrates, particularly birds and mammals (cetaceans), probably because invertebrates and macroalgae despite its undeniable importance for ecosystems have less interest to the general public and always been underrepresented in official conservation lists. Some invertebrate species such as gorgonians, corals or sponges are slow-growing organisms with a low reproductive output that are very threatened. Some of them provide shelter, food provision and nursery habitats to a wide variety of species, but most of them are still not included in national conservation lists. Moreover, there is a need for increasing the knowledge on the biology and ecology of some of these invertebrates as well as on their resilience to human impacts (see Templado et al. 2021, Chap. 10 of this book). Regarding this, it is important to create a hub of research and knowledge on marine biodiversity between local, regional and national governments as well as between countries, including new projects based on research, ecosystem management, transfer of information, education/awareness and the integration of the experiences of different sectors that use each MPA and KBA.

25.7.3 Sustainable Exploitation of the Resources and Main Threats

The fishing resources from the Alboran Sea are managed under the framework of two regional fisheries organization (RFOs): the General Fisheries Commission for the Mediterranean (GFCM) and the International Commission for the Conservation of Atlantic Tunas (ICCAT). The main aim is achieving a sustainable management of the different exploited resources. All countries surrounding the Alboran Sea are members of these two RFOs, and therefore, they are involved in the implementation of joint regulations and agreements adopted by the parties aiming for the protection of the tuna and tuna-like species (ICCAT) and the demersal and small pelagic species and respective fisheries. Unfortunately, there is no automatic compliance with all regulatory measures adopted by the RFOs, and if these measures are translated into national regulations, the existence of the necessary means, tools and human resources to verify and control the implementation is still lacking.

Although important progress has been made for the conservation of the Alboran Sea, it is necessary to improve the role of political and social (e.g. fishermen) sectors towards the environment and sustainable development.

The status of most of the Mediterranean exploited resources stated that ca. 78% of the stocks assessed, including stocks of all priority species, were over-exploited (FAO 2018). This percentage has slightly decreased since 2014 (88%), which reflects the different recent management measures that have been made but underlines the need to go further. Nevertheless, the last GFCM Report of 2019 (FAO 2020) underlined that ca. 11% of the Mediterranean stocks assessed were considered sustainably exploited while 80% of the stocks were considered to be outside biological safe limits. In particular, European hake (*Merluccius merluccius*) was found to be the most exploited species in the Mediterranean Sea, and current measures (minimum landing size, mesh size, etc.) were found to have been ineffective for reducing the over-exploitation. The over-exploitation of fishery resources is also affecting the biodiversity in relation to discards as well as to sensitive habitats (e.g. *Posidonia* meadows, coralligenous communities). The majority of the fisheries operating in the MPAs of the Alboran Sea use small-scale gears, although medium bottom trawl vessels and some purse seiners and trammel nets are illegally operating on some algae and *Posidonia* meadows of these MPAs, impacting these communities and the stability of the ecosystems. Small-scale fisheries are considered the most appropriate methods to be substantial and to extract fishery resources, and management plans of the MPAs have to include the local fishing communities. The idea is the implementation of strategies of adaptive management based on the application of (a) regulatory measures and fleet management, with well-defined objectives and with sufficient and continued funding; (b) Integrated Coastal Zone Management; and (c) an ecosystem approach in relation to the biology and life cycle of commercial and threatened species and interactions among them, effects of climate change on stocks and fisheries and relationships between coastal and deep-sea stocks that define appropriate biological units of management, among others (Robles 2010). For example, in Al Hoceima National Park (Morocco), innovative and effective strategies have been incorporated such as a funding system for the conversion of some fishing gears or diversification of fishermen's income (fishing tourism, whale watching, etc.), establishment of the Observatory of Al Hoceima (ODYSSEA) and the adoption and implementation of the EU Marine Strategy Framework Directive (MSFD) (Nibani 2019).

In summary, the fundamental weakness that prevents an improvement of fisheries is the lack of the real implementation of the important regulatory measures, together with a lack of integration in co-management schemes at all levels (national, regional and especially at a more local level) (Robles 2010).

An interesting way for controlling illegal fishing inside the MPAs, as well as productivity of some fishes (e.g. groupers), is the use of artificial reefs whose purpose is, on the one hand, to exercise passive surveillance against illegal fishing and, on the other hand, to provide shelter and protection for marine fauna. For example, some MPAs of the northern Alboran Sea (e.g. Natural Park of Cabo de Gata-Níjar or Paraje Natural de Acantilados Maro-Cerro Gordo) deployed artificial reefs and detected promising results on the fish communities as well as in the number of illegal fishing lines and nets entangled in these reefs (Junta de Andalucía 2008–2019). The artificial reefs are a very valuable tool for passive surveillance. In this sense, there is also a need for more collaboration between organisms in order to have more complete and effective reefs and not only for fishing purposes. The installation of artificial reefs around all MPAs of the Alboran Sea could be a way for supplying the lack of surveillance systems, especially for those MPAs from Morocco and Algeria coast.

Generally speaking, the tourism system is based on mass tourism and, sometimes, has limited impact on the local economy. These tourism activities are environmentally unsustainable because they bring with them economic (income fall, overconstruction of infrastructures, etc.), environmental (loss of natural areas, decrease/disappearance of species, etc.) and socio-cultural problems (loss of cultural identity, increased illegal activities, etc.) (Robles 2010). This kind of tourism should be reconsidered in the MPAs.

Pollution (e.g. sewage, oil spills, litter) is still one of the most important threats for some habitats (e.g. vegetated habitats) and species, particularly the derivative from dangerous substances or outdated chemicals. The number of waste water plants and the effective treatment of these waste water plants should be improved, as well as regulations that minimize the use of non-degradable plastics. However, the high concentration of PCBs and DDTs found in the population of common dolphin is another important indicator (Robles 2010). In the southern Alboran Sea, more waste water treatment plants are also urgently needed (Colloca et al. 2003).

Invasive species represent a recent main threat for MPAs-KBAs of the Alboran Sea, and some of these species are increasing due to the global change and deterioration of the ecosystems. For example the recent expansion of the exotic invasive algae *Rugulopteryx okamurae*, (see Flores-Moya et al. 2021, Chap. 8 in this book) throughout the northern and southern sectors of Alboran Sea, has generated huge problems by displacing native macroalgae species (with further effects on the ecosystem), producing important losses to the artisanal fishermen and finally affecting the native biota associated to photophilous bottoms. The tourism has also suffered consequences because hundreds of tons of the alga upset the beaches, and even the underwater system used by the desalination plant in Marbella (Spain) had troubles due to the massive growth of this brown algae. The main way of introduction of these invasive species seems to be due to maritime traffic (commercial and recreational). It is essential to provide the necessary elements for the control of the introduction and/or reintroduction of invasive alien species by adopting a specific code of conduct according to the Code of Practices (1995) of the International Council for the Exploration of the Sea, the lines of action (1994) of the International Maritime Organization on ballast water and fouling and the precautionary approach of FAO in 1996 (Robles 2010).

25.7.4 Management Measures

In 2006, the IUCN decided to start an initiative with the aim of achieving better conservation and sustainable development in the Alboran Sea. The long-term objective of this analysis was to create the conditions and to construct the basis required for the establishment of coordinated management of the Alboran Sea (Robles 2010). This initiative had the support of the Málaga Provincial Council, the Agence de Développement de l'Oriental (Morocco), Instituto Español de Oceanografía (Spain) and the Institut National de Recherche Halieutique (Morocco). Different meetings have been made in Spain (Barcelona 2008) and Morocco (Oujda 2009), as well as projects such as POCTEFEX-Alboran (Spain, Morocco and Algeria, 2012–2014) or fisheries projects such as CopeMed I–II (2009–2020). During the POCTEFEX-Alboran project, some progress was achieved for the establishment of an Alboran conservation and sustainable development technology platform (Geoportal of Alboran Sea), meetings of artisanal fishing entities (e.g. in Alhucemas in 2014), cooperative working groups (biodiversity, MPA and Integrated Coastal Zone Management) and initial assessment of the Cap des Trois Fourches, in accordance with the MSFD, among others.

Recently, two projects have promoted the implementation of the ecosystem approach (EcAp), in coherence with the MSFD and in the context of the BC (EcAp-MED I–II, 2010–2019). The first initiated the EcAp road map, especially in relation to the development of an integrated monitoring and assessment programme for the Mediterranean, whereas the second has provided assistance to the Southern Mediterranean contracting parties to the BC for implementing the EcAp (https://www.rac-spa.org/ecapmed_ii).

Significant steps with important efforts have been done, and much progress has been made in scientific knowledge about habitats, species, threats, etc. affecting the ecosystems. Nevertheless, there is still a weak coordination between national and international agencies that may result in negative effects on the conservation and management of some MPAs-KBAs, generally due to the complex existing legislation regarding competences in the marine part (e.g. Alboran Island). For such reason, further collaboration within local, regional and national governments of the countries around the Alboran Sea as well as of the different sectors exploiting its different resources (e.g. fisheries, tourism industry) is urgently needed in order to switch for an effective conservation of the Alboran Sea natural heritage.

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Appendix A: The Toponymy of the Submarine Physiographic and Morphological Features of the Alboran Sea and the Strait of Gibraltar Region

Desirée Palomino, Juan-Tomás Vázquez, Luis-Miguel Fernández-Salas, and Víctor Díaz-del-Río

A.1 Introduction

The toponymy of the main submarine physiographic and morphological features of the Alboran Sea and the Strait of Gibraltar has been compiled without taking into account the coastal places that can be obtained from standardized land cartographic bases. For this, a review of the bibliography has been carried out and the most widely used features have been recorded. Although several features previously unnamed have been added and named in this chapter. Each toponymy, either physiographic and morphological features, has been characterized with a morphological or geological type and also has been provided with the bibliographic references where its description was made. 155 toponymies have been differentiated and placed on a map, identifying them with a point located inside each morphological feature, assigning them geographical coordinates. Their locations are shown on the map in Fig. A.1 and their typologies and coordinates in Table A.1.

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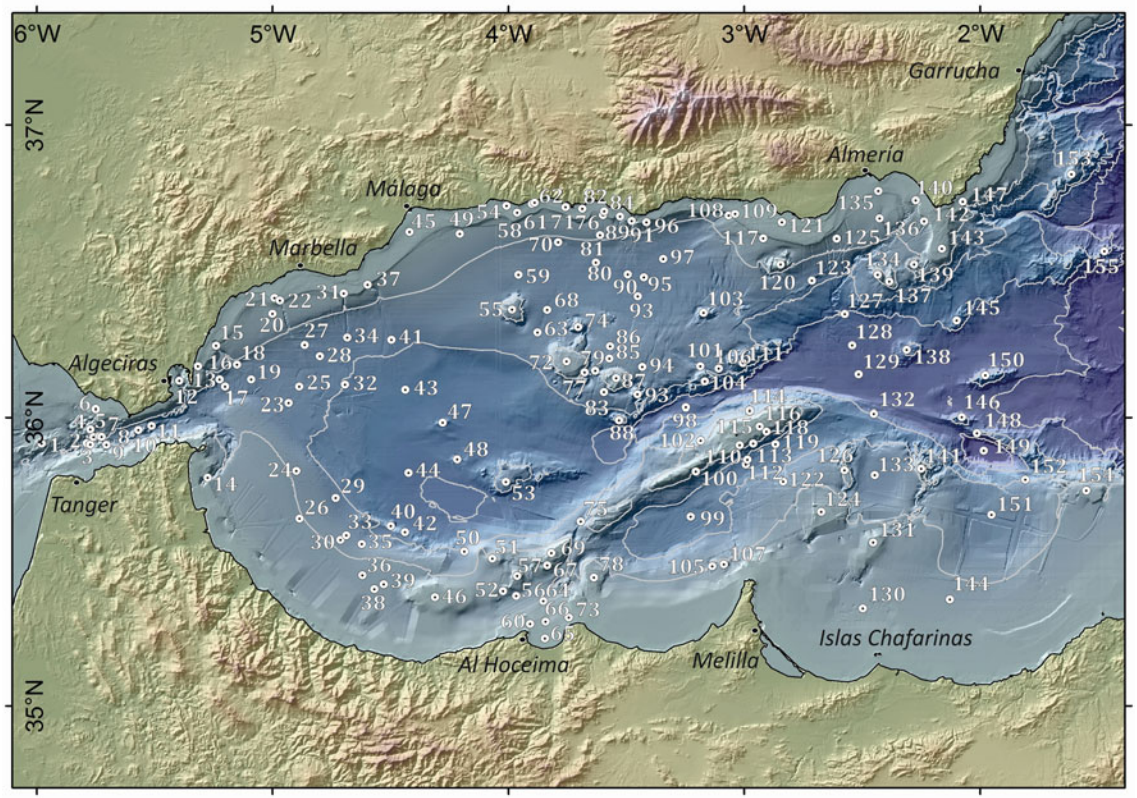

Fig. A.1 Map of the toponymy of the physiographic and morphological features of the Alboran Sea and the Strait of Gibraltar. Numbers correspond to features of Table A.1 and they have been order from East to West. Bathymetric data have been obtained from EMODnet Bathymetry Consortium (2018). https://doi.org/10.12770/18ff0d48-b203-4a65-94a9-5fd8b0ec35f6. Contours are shown every 500 m

Table A.1 Main submarine physiographic and morphological features of the Alboran Sea and the Strait of Gibraltar, where the type, name, coordinates and the reference are shown

N°	Type	Toponymy	Longitude	Latitude	Ref.
1	Seamount	Majuan Ridge	5° 58′ 41″ W	35° 54′ 38″ N	Sanz et al. (1991)
2	Depression	Poniente Pool (Tanger Basin)	5° 47′ 13″ W	35° 54′ 41″ N	Sanz et al. (1991)
3	Seamount	Malabata Seamount	5° 46′ 21″ W	35° 54′ 26″ N	Díaz del Río et al. (2009)
4	Seamount	Seco Seamount	5° 46′ 18″ W	35° 57′ 32″ N	Sanz et al. (1991)
5	Seamount	Tartesos Seamount	5° 45′ 29″ W	35° 55′ 58″ N	Sanz et al. (1991)
6	Seamount	El Puerco Bank	5° 44′ 59″ W	36° 01′ 42″ N	Esteras et al. (2000)
7	Depression	Levante Pool (Tarifa Basin)	5° 44′ 03″ W	35° 56′ 11″ N	Sanz et al. (1991)
8	Ridge	Hispalis Crests	5° 43′ 27″ W	35° 56′ 03″ N	Sanz et al. (1991)
9	Ridge	Kmara Crest	5° 42′ 12″ W	35° 54′ 21″ N	Sanz et al. (1991)
10	Seamount	Hespérides Seamount	5° 34′ 07″ W	35° 57′ 24″ N	Sanz et al. (1991)
11	Seamount	Hérculas Seamount	5° 30′ 43″ W	35° 58′ 16″ N	Sanz et al. (1991)
12	Canyon	Algeciras Canyon	5° 23′ 40″ W	36° 07′ 30″ N	Sanz et al. (1991)
13	Canyon	La Línea Canyon	5° 18′ 56″ W	36° 10′ 28″ N	Hernández-Molina (1993)
14	Canyon	Ceuta Canyon	5° 16′ 30″ W	35° 47′ 35″ N	Tesson et al. (1987)
15	Canyon	Guadiaro Canyon	5° 14′ 21″ W	36° 14′ 46″ N	Hernández-Molina (1993)
16	Turbidite channel	La Línea Turbidite Channel	5° 13′ 26″ W	36° 07′ 44″ N	Díaz del Río et al. (2009)
17	Fan	La Línea Fan	5° 12′ 03″ W	36° 06′ 17″ N	Díaz del Río et al. (2009)
18	Turbidite channel	Guadiaro Turbidite Channel	5° 09′ 02″ W	36° 10′ 48″ N	Díaz del Río et al. (2009)
19	Fan	Guadiaro Fan	5° 05′ 27″ W	36° 07′ 45″ N	Alonso and Ercilla (2003)
20	Mound field	Alcántara carbonate mound field	5° 00′ 00″ W	36° 21′ 17″ N	Sánchez-Guillamón et al. (2018)
21	Placer	Bóvedas Placer	4° 59′ 30″ W	36° 24′ 32″ N	Carta Naútica (n.d.)
22	Canyon	Guadalmina or Baños Canyon	4° 58′ 07″ W	36° 24′ 00″ N	Hernández-Molina et al. (1994)
23	Mud Volcano	Kalinin Mud Volcano	4° 55′ 53″ W	36° 02′ 53″ N	Comas et al. (2003)
24	Pockmark field	Ceuta Pockmark field	4° 53′ 57″ W	35° 48′ 58″ N	Somoza et al. (2010)
25	Mud Volcano	Perejil Mud Volcano	4° 53′ 12″ W	36° 06′ 17″ N	Comas et al. (2003)

(continued)

Table A.1 (continued)

N°	Type	Toponymy	Longitude	Latitude	Ref.
26	Contourite Drift	Ceuta Contourite Drift	4° 53′ 07″ W	35° 39′ 04″ N	Ercilla et al. (2002)
27	Turbidite channel	Guadalmina or Baños Turbidite Channel	4° 51′ 46″ W	36° 14′ 52″ N	Hernández-Molina et al. (1994)
28	Fan	Guadalmina or Baños Fan	4° 47′ 55″ W	36° 12′ 31″ N	Hernández-Molina et al. (1994)
29	Mud Volcano	Carmen Mud Volcano	4° 43′ 56″ W	35° 43′ 19″ N	Blinova et al. (2003)
30	Mud Volcano	Ceuta Mud Volcano	4° 42′ 43″ W	35° 34′ 39″ N	Somoza et al. (2010)
31	Canyon	Torrenueva Canyon	4° 41′ 52″ W	36° 25′ 31″ N	Ercilla et al. (1994)
32	Fan	Torrenueva Fan	4° 41′ 34″ W	36° 06′ 43″ N	Pérez Belzuz and Alonso (2000)
33	Mud Volcano	Tarifa Mud Volcano	4° 41′ 11″ W	35° 35′ 36″ N	Somoza et al. (2010)
34	Turbidite channel	Torrenueva Turbidite Channel	4° 40′ 56″ W	36° 16′ 24″ N	Pérez Belzuz and Alonso (2000)
35	Mud Volcano	Granada Mud Volcano	4° 37′ 18″ W	35° 33′ 45″ N	Sautkin et al. (2003)
36	Mud Volcano	Maya Mud Volcano	4° 37′ 08″ W	35° 27′ 16″ N	Sautkin et al. (2003)
37	Canyon	Fuengirola Canyon	4° 35′ 46″ W	36° 27′ 16″ N	Hernández-Molina et al. (1994)
38	Mud Volcano	Mulhacen Mud Volcano	4° 34′ 05″ W	35° 24′ 22″ N	Comas et al. (2003)
39	Mud Volcano	Dhaka Mud Volcano	4° 31′ 44″ W	35° 25′ 22″ N	Sautkin et al. (2003)
40	Mud Volcano	Marrakech Mud Volcano	4° 29′ 54″ W	35° 37′ 33″ N	Sautkin et al. (2003)
41	Turbidite channel	Fuengirola Turbidite Channel	4° 29′ 44″ W	36° 15′ 55″ N	Hernández-Molina et al. (1994)
42	Escarpment	Ceuta Escarpment	4° 26′ 18″ W	35° 36′ 15″ N	Rodriguez et al. (2017)
43	Fan	Fuengirola Fan	4° 26′ 12″ W	36° 05′ 37″ N	Hernández-Molina et al. (1994)
44	Basin	Western Alboran Basin	4° 25′ 22″ W	35° 48′ 35″ N	Ryan et al. (1973)
45	Prodelta	Guadalhorce Prodelta	4° 25′ 10″ W	36° 38′ 09″ N	Fernández-Salas et al. (2003)
46	Seamount	Xauen Bank	4° 18′ 41″ W	35° 22′ 43″ N	Vázquez (2001)
47	Seamount	El Segoviano High	4° 16′ 41″ W	35° 58′ 59″ N	Ercilla et al. (2012)
48	Seamount	Maria del Carmen High	4° 12′ 59″ W	35° 51′ 20″ N	Juan et al. (2016)

(continued)

Table A.1 (continued)

N°	Type	Toponymy	Longitude	Latitude	Ref.
49	Mound field	Málaga carbonate mound field	4° 12′ 21″ W	36° 37′ 43″ N	Sánchez-Guillamón et al. (2018)
50	Slide	Xauen-Tofiño Slide	4° 11′ 14″ W	35° 32′ 13″ N	Rodriguez et al. (2017)
51	Seamount	Ramón Margalef Seamount	4° 04′ 02″ W	35° 30′ 44″ N	Palomino et al. (2015)
52	Seamount	Petit Xauen Seamount	4° 01′ 21″ W	35° 24′ 00″ N	Palomino et al. (2015)
53	Seamount	Ibn-Batouta Bank	4° 00′ 36″ W	35° 46′ 39″ N	Vázquez (2001)
54	Prodelta	Güi Prodelta	4° 00′ 29″ W	36° 43′ 27″ N	Bárcenas et al. (2015)
55	Seamount	Avempace or Algarrobo Bank	3° 59′ 02″ W	36° 22′ 09″ N	Vázquez (2001)
56	Valley	Al-Hoceima Valley	3° 57′ 59″ W	35° 22′ 58″ N	Vázquez (2001)
57	Seamount	Tofiño Bank	3° 57′ 45″ W	35 °27′ 09″ N	Vázquez (2001)
58	Prodelta	Torrox Prodelta	3° 57′ 44″ W	36° 42′ 04″ N	Bárcenas et al. (2015)
59	Pockmark field	Avempace Pockmark field	3° 57′ 24″ W	36° 29′ 18″ N	Palomino et al. (2012)
60	Fault trace	Bokkoya Fault	3° 54′ 29″ W	35° 17′ 09″ N	d'Acremont et al. (2014)
61	Prodelta	Seco Prodelta	3° 53′ 58″ W	36° 43′ 51″ N	Bárcenas et al. (2015)
62	Prodelta	Chillar Prodelta	3° 53′ 21″ W	36° 44′ 10″ N	Bárcenas et al. (2015)
63	Passage	Herradura Sound	3° 52′ 37″ W	36° 17′ 28″ N	Díaz del Río et al. (2009)
64	Basin	Al-Hoceima or Nekor Basin	3° 51′ 07″ W	35° 21′ 53″ N	Vázquez (2001)
65	Prodelta	Nekor-Rhis prodelta	3° 50′ 41″ W	35° 14′ 07″ N	Lafosse et al. (2018)
66	Canyon	Nekor Canyon	3° 50′ 34″ W	35° 17′ 36″ N	Ercilla et al. (2019)
67	Seamount	Eurofleets Seamount	3° 50′ 10″ W	35° 29′ 20″ N	Palomino et al. (2015)
68	Fault trace	Calahonda Sound Fault	3° 50′ 09″ W	36° 22′ 07″ N	Vázquez et al. (2018)
69	Seamount	Francesc Pagés bank	3° 58′ 08″ W	35° 27′ 17″ N	d'Acremont et al. (2014)
70	Slide	Baraza Slide	3° 47′ 19″ W	36° 36′ 00″ N	Ercilla et al. (2009)
71	Prodelta	Jate Prodelta	3° 45′ 26″ W	36° 43′ 14″ N	Bárcenas et al. (2015)
72	Seamount	Herradura Bank	3° 45′ 11″ W	36° 11′ 29″ N	Vázquez (2001)

(continued)

Table A.1 (continued)

N°	Type	Toponymy	Longitude	Latitude	Ref.
73	Fault trace	Trougout Falt	3° 44′ 39″ W	35° 18′ 26″ N	d'Acremont et al. (2014)
74	Seamount	La Herradura Spur Seamount	3° 42′ 14″ W	36° 18′ 34″ N	Palomino et al. (2011)
75	Fault trace	Al-Idrissi fault	3° 41′ 34″ W	35° 38′ 29″ N	d'Acremont et al. (2014)
76	Prodelta	Verde Prodelta	3° 41′ 09″ W	36° 42′ 53″ N	Bárcenas et al. (2015)
77	Slide	Navarro Slide	3° 40′ 34″ W	36° 09′ 14″ N	Palomino et al. (2009)
78	Ridge	Ras Tarf Ridge	3° 38′ 13″ W	35° 26′ 50″ N	Galindo-Zaldivar et al. (2018)
79	Passage	Calahonda Sound	3° 37′ 56″ W	36° 09′ 33″ N	Díaz del Río et al. (2009)
80	Fan	Salobreña Fan	3° 37′ 44″ W	36° 31′ 51″ N	Ercilla et al. (2016)
81	Gullies	Salobreña Gullies	3° 36′ 41″ W	36° 37′ 30″ N	García et al. (2006)
82	Gullies	Almuñecar Gullies	3° 35′ 54″ W	36° 41′ 33″ N	Vázquez et al. (2015)
83	Contourite Drift	Djibouti Ville Contourite Drift	3° 35′ 43″ W	36° 05′ 09″ N	López-González et al. (2019)
84	Prodelta	Guadalfeo Prodelta	3° 35′ 36″ W	36° 42′ 21″ N	Lobo et al. (2006)
85	Fault trace	La Herradura Sound Fault	3° 34′ 20″ W	36° 12′ 04″ N	Vázquez et al. (2018)
86	Marginal Plateau	Motril-Djibouti Marginal Plateau	3° 34′ 06″ W	36° 14′ 37″ N	Vázquez (2001)
87	Seamount	Djibouti Ville Bank	3° 32′ 35″ W	36° 08′ 00″ N	Vázquez (2001)
88	Seamount	Ibn Babirol Seamount	3° 31′ 51″ W	35° 59′ 26″ N	This chapter
89	Canyon	Motril Canyon	3° 31′ 36″ W	36° 41′ 16″ N	León and Somoza (1999)
90	Fan	Motril Fan	3° 29′ 36″ W	36° 29′ 24″ N	Pérez Belzuz et al. (2000)
91	Canyon	Sacratif or Carchuna Canyon	3° 28′ 37″ W	36° 40′ 21″ N	Pérez Belzuz and Alonso (2000)
92	Seamount	Al-Idrissi Seamount	3° 27′ 11″ W	36° 04′ 40″ N	This chapter
93	Basin	Motril Basin	3° 27′ 03″ W	36° 24′ 51″ N	Vázquez (2001)
94	Fault trace	Djibouti Sound Fault	3° 25′ 55″ W	36° 10′ 20″ N	This chapter
95	Fan	Sacratif or Carchuna Fan	3° 25′ 31″ W	36° 28′ 47″ N	Pérez Belzuz and Alonso (2000)
96	Canyon	Calahonda Canyon	3° 24′ 52″ W	36° 40′ 08″ N	Vázquez et al. (2015)

(continued)

Table A.1 (continued)

N°	Type	Toponymy	Longitude	Latitude	Ref.
97	Fan	Calahonda Fan	3° 20′ 37″ W	36° 32′ 36″ N	Ercilla et al. (2016)
98	Passage	Alboran Trough	3° 14′ 53″ W	36° 02′ 01″ N	Farmer and Armi (1988)
99	Basin	Southern Alboran (Almohades) Basin	3° 13′ 38″ W	35° 39′ 28″ N	Ryan et al. (1973)
100	Slide	Juan de la Cosa Slide	3° 12′ 19″ W	35° 48′ 48″ N	Bárcenas (2002)
101	Fault trace	Averroes fault	3° 11′ 10″ W	36° 10′ 28″ N	Estrada et al. (2014)
102	Slide	Antares Slide	3° 11′ 05″ W	35° 55′ 13″ N	Bárcenas (2002)
103	Seamount	Jose Medialdea Seamount	3° 10′ 22″ W	36° 21′ 30″ N	Vázquez et al. (2021)
104	Ridge	South Adra Ridge	3° 10′ 03″ W	36° 07′ 21″ N	Perea et al. (2018)
105	Seamount	Palomas Seamount	3° 08′ 05″ W	35° 29′ 14″ N	This chapter
106	Contourite Channel	Adra Contourite Channel	3° 06′ 28″ W	36° 09′ 59″ N	Vázquez (2001)
107	Mound field	West Melilla carbonate mounds	3° 05′ 09″ W	35° 29′ 35″ N	Lo Iacono et al. (2014)
108	Canyon	Adra Canyon	3° 03′ 55″ W	36° 41′ 29″ N	Vázquez et al. (2015)
109	Prodelta	Adra Prodelta	3° 02′ 20″ W	36° 41′ 50″ N	Jabaloy-Sánchez et al. (2010)
110	Canyon	Al Borani Canyon	3° 01′ 10″ W	35° 54′ 19″ N	Bárcenas et al. (2000)
111	Ridge	Adra North or Averroes Ridge	3° 00′ 21″ W	36° 11′ 10″ N	Vázquez (2001)
112	Fan	Al Borani Fan	2° 59′ 38″ W	35° 50′ 18″ N	Bárcenas et al. (2000)
113	Turbidite channel	Al Borani Turbidite Channel	2° 59′ 13″ W	35° 51′ 18″ N	Bárcenas et al. (2000)
114	Gullies	Castor Gullies	2° 58′ 39″ W	36° 01′ 21″ N	Vázquez et al. (2015)
115	Slide	Los Bolos Slide	2° 57′ 44″ W	35° 54′ 37″ N	Bárcenas (2002)
116	Ridge	Alboran Ridge	2° 56′ 04″ W	35° 58′ 09″ N	Vázquez (2001)
117	Mound field	Aceitunas carbonate mound field	2° 55′ 12″ W	36° 36′ 47″ N	Sánchez-Guillamón et al. (2018)
118	Canyon	Piedra Escuela Canyon	2° 54′ 20″ W	35° 57′ 06″ N	Bárcenas et al. (2000)
119	Fan	Piedra Escuela Fan	2° 52′ 02″ W	35° 54′ 32″ N	Bárcenas et al. (2000)
120	Seamount	Chella Bank/Seco de los Olivos bank	2° 50′ 43″ W	36° 31′ 27″ N	Duggen et al. (2004)
121	Fault trace	Balanegra fault	2° 50′ 27″ W	36° 40′ 07″ N	Marín-Lechado et al. (2005)

(continued)

Table A.1 (continued)

N°	Type	Toponymy	Longitude	Latitude	Ref.
122	Slide	Montera Slide	2° 50′ 05″ W	35° 46′ 46″ N	Casas et al. (2015)
123	Fault trace	Serrata-Carboneras Fault	2° 42′ 48″ W	36° 28′ 07″ N	Ballesteros et al. (2008)
124	Ridge	Tres Forcas Ridge	2° 40′ 27″ W	35° 40′ 28″ N	Vázquez (2001)
125	Gullies	Campo de Dalías Gullies System	2° 36′ 27″ W	36° 36′ 45″ N	García et al. (2006)
126	Seamount	Catifas Bank or West Cabliers	2° 34′ 33″ W	35° 49′ 04″ N	Vázquez (2001)
127	Turbidite channel	Almería Turbidite Channel	2° 34′ 28″ W	36° 21′ 15″ N	Estrada et al. (1997)
128	Fan	Almería Fan	2° 32′ 33″ W	36° 14′ 48″ N	Estrada et al. (1997)
129	Basin	Eastern Alboran Basin	2° 30′ 56″ W	36° 08′ 50″ N	Ryan et al. (1973)
130	Mound field	Melilla Carbonate Mound Field	2° 29′ 51″ W	35° 20′ 23″ N	Comas and Pinheiro (2007)
131	Seamount	Provençaux Bank	2° 27′ 13″ W	35° 34′ 08″ N	Vázquez (2001)
132	Escarpment	Yusuf Escarpment	2° 27′ 01″ W	36° 00′ 47″ N	Vázquez (2001)
133	Basin	Pytheas or Caldeira Basin	2° 26′ 50″ W	35° 48′ 04″ N	Vázquez (2001)
134	Seamount	Avenzoar or Western Sabinar Banks	2° 26′ 03″ W	36° 29′ 21″ N	Vázquez (2001)
135	Prodelta	Andarax Prodelta	2° 25′ 56″ W	36° 46′ 32″ N	García et al. (2006)
136	Gullies	Andarax Gullies	2° 25′ 36″ W	36° 40′ 55″ N	Vázquez (2001)
137	Seamount	Sabinar Bank (or Eastern Sabinar)	2° 23′ 05″ W	36° 27′ 57″ N	This chapter
138	Seamount	Maimonides Seamount	2° 18′ 39″ W	36° 13′ 52″ N	Vázquez (2001)
139	Seamount	Pollux Bank	2° 16′ 47″ W	36° 31′ 26″ N	Duggen et al. (2004)
140	Canyon	Almería Canyon	2° 16′ 25″ W	36° 44′ 34″ N	Ercilla (1992)
141	Seamount	East Cabliers Bank	2° 15′ 02″ W	35° 49′ 26″ N	Vázquez (2001)
142	Gullies	Gata Gullies	2° 14′ 15″ W	36° 40′ 17″ N	Vázquez et al. (2015)
143	Spur	Cabo de Gata Spur	2° 09′ 47″ W	36° 34′ 40″ N	Alonso and Maldonado (1992)
144	Marginal Plateau	Moulouya Marginal Plateau	2° 07′ 40″ W	35° 22′ 13″ N	El Robrini (1992)
145	Ridge	Maimonides Ridge	2° 05′ 56″ W	36° 19′ 56″ N	Vázquez (2001)
146	Ridge	Yusuf Ridge	2° 04′ 42″ W	36° 00′ 06″ N	Vázquez (2001)
147	Canyon	Gata Canyon	2° 04′ 25″ W	36° 44′ 22″ N	Pérez-Hernández et al. (2014)
148	Fault trace	Yusuf fault	2° 00′ 50″ W	35° 56′ 44″ N	Vázquez (2001)

(continued)

Table A.1 (continued)

N°	Type	Toponymy	Longitude	Latitude	Ref.
149	Basin	Yusuf Basin	1° 59′ 06″ W	35° 53′ 08″ N	Mauffret et al. (1987)
150	Seamount	Al Mansour Seamount	1° 58′ 39″ W	36° 08′ 36″ N	Vázquez (2001)
151	Basin	Habibas Basin	1° 57′ 06″ W	35° 39′ 53″ N	Vázquez (2001)
152	Escarpment	Habibas Escarpment	1° 48′ 29″ W	35° 47′ 10″ N	Vázquez (2001)
153	Seamount	La Polacra high	1° 36′ 49″ W	36° 49′ 56″ N	Duggen et al. (2008)
154	Seamount	Alidade Bank	1° 33′ 02″ W	35° 44′ 53″ N	Ammar et al. (2007)
155	Ridge	Los Genoveses Ridge	1° 28′ 23″ W	36° 34′ 10″ N	Duggen et al. (2008)

A.2 Glossary

The different submarine morphological types that have been differentiated in the Alboran Sea and the Strait of Gibraltar region are described briefly below in alphabetical order.

Basin: A depression, relatively flat and of variable extent that represent the deep marine environment below the continental margin.

Canyon: An elongated, narrow, erosive steep-sided depression in the continental margin that generally deepens down-slope.

Contourite Channel: erosive and elongated depressions mainly produced by the action of the contour bottom currents.

Contourite Drift: Sediment deposited or substantially reworked by the persistent action of contour bottom currents.

Depression: Area morphologically depressed with respect to the surrounding reliefs.

Escarpment: An elongated, characteristically linear, steep slope separating horizontal or gently sloping areas of the seafloor.

Fan: A relatively smooth, depositional feature continuously deepening away from a sediment source commonly located at the lower termination of a canyon or canyon system.

Fault trace: Fracture affecting the seafloor surface along whose trace occur a relative displacement of the two blocks into which the affected sedimentary units are divided. Along this type of feature, the trace of the fault is marked by several secondary morphological features as linear scarps, depressions or ridges.

Gullies: Narrow valley with steep walls, excavated by erosion of ephemeral or weak flows that generally deepens down-slope.

Marginal Plateau: A large, relatively flat elevation that is higher than the surrounding relief with one or more relatively steep sides located on the continental slope.

Mound: Elevation with a rounded profile, commonly formed by the expulsion of fluids or by coral reef development, sedimentation and (bio)erosion, with less than 100 m of height.

Mound field: A distinct group of mounds.

Mud Volcano: A cone-shaped elevation formed by mud breccia sediments accumulation related to the expulsion of non-magmatic gasses and sediments.

Passage: A long depression generally wide and flat bottomed with symmetrical and parallel sides usually emplaced between two high reliefs.

Placer: Accumulation of sediments, usually sands, with minerals resistant to erosion, of high density formed by the action of the gravity on moving particles.

Pockmark field: A group of cone-shaped, circular or elliptical crater-like depressions formed in the seafloor by the expulsion of fluids.

Prodelta: The furthest offshore portion of a delta, lying at the toe of the delta front, and characterized by a relatively slow rate of fine-grained deposition.

Ridge: An elongated elevation of varying complexity and size, generally having steep sides.

Seamount: A distinct elevation above the surrounding relief commonly found on the continental margin. Usually with a circular or subcircular base and a relief up to 100 m height.

Slide: Gravitational mass movement of a significant volume of sediment, through a sliding plane. It has been considered both erosive and/or depositional characteristics of these type of feature.

Spur: A subordinate ridge protruding from a larger feature.

Turbidite Channel: An elongated, meandering depression, occurring on a gentle sloping plain or fan usually at the end of a submarine canyon by the action of turbiditic currents.

Valley: An elongated depression that generally widens and deepens down-slope.

A.3 Submarine Features Data Base

The physiographic and morphologic submarine features differentiated in the Alboran Sea and the Strait of Gibraltar region are presented ordered from west to east (Table A.1).

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[1] The number is related to the submarine feature in Table A.1.

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