Impact of Plastic Pollution on Marine Life in the Mediterranean Sea

Aikaterini Anastasopoulou and Tomaso Fortibuoni

Contents

Abstract Marine litter is an environmental problem of global concern with well-documented impacts on marine biodiversity and ecosystems. At a global scale, marine litter is mainly composed of plastic. Plastics can affect marine organisms mainly through ingestion and entanglement but also through the facilitation of transport of organisms via rafting or the provision of new habitats for colonization. Impacts vary according to the type and size of the plastics and can occur at different levels of biological organization in a wide variety of habitats. In this chapter, we reviewed and synthesized literature in order to describe the impact of litter on marine

---

Anastasopoulou Aikaterini and Fortibuoni Tomaso contributed equally.

A. Anastasopoulou (✉)
Hellenic Centre for Marine Research, Institute of Marine Biological Resources and Inland Waters, Attica, Greece
e-mail: kanast@hcmr.gr

T. Fortibuoni
Italian National Institute for Environmental Protection and Research, Ozzano dell'Emilia, Italy

National Institute of Oceanography and Applied Geophysics, Trieste, Italy
e-mail: tomaso.fortibuoni@isprambiente.it

Friederike Stock, Georg Reifferscheid, Nicole Brennholt, and Evgeniia Kostianaia (eds.),
Plastics in the Aquatic Environment - Part I: Current Status and Challenges,
Hdb Env Chem (2022) 111: 135–196, DOI 10.1007/698_2019_421,

life in the Mediterranean sensitive ecosystem. The review focused on the following impact categories: ingestion, entanglement and other effects (e.g. colonization and rafting). In the Mediterranean, reports of ingestion were made for more than 49,454 individuals from 116 species, of which the taxonomic group with the greatest number of species impacted was Teleosts (~59%). Forty-four species were found entangled in marine litter (59% were invertebrates, mainly Cnidarians), of which the species with the highest number of entanglement records in the Mediterranean Sea was the loggerhead sea turtle (*Caretta caretta*). One hundred and seventy-eight taxa were found rafting on floating objects or using marine litter as a substratum, including Chromista and Bacteria. The most common phyla rafting on marine litter were Arthropods and Cnidarians.

Keywords Entanglement, Ingestion, Mediterranean, Plastic pollution, Rafting

1 Introduction

Marine litter has been globally recognized as a growing environmental concern, which can significantly affect wildlife, from marine worms [1] to whales [2] and potentially humans [3]. Globally, the proportion of plastic among marine litter ranges from 60 to 80%, although it has reached over 90–95% in some areas [4]. Plastics are produced in huge quantities and have become an essential part of our life mostly due to their low production costs and specific characteristics like durability and flexibility [5]. As reported by PlasticsEurope in 2017 [6], about 335 million tons of plastics were produced in 2016. Up to 5% of plastics produced each year ends up in the sea [7], where it persists, accumulates and fragments into smaller pieces (e.g. microplastics) by UV radiation, waves and mechanical forces [8], increasing the potential for ingestion by organisms [9]. The colour, density, shape, size and abundance of these tiny plastic particles may affect their potential availability to marine organisms [1, 10]. Jovanović [11] reported that, in the relatively near future, the abundance of plastic micro- and nanoparticles will be greater than the count of plankton. Plastics, including microplastics, contaminate habitats from shallow water to the deep sea and from the poles to the equator. They are present on shorelines, in the water column, on the seafloor, in sediments and in organisms (e.g. [12, 13]).

The Mediterranean Sea is the largest and deepest enclosed sea on Earth [14]. It constitutes 1 of the 25 biodiversity centres that are recognized on a planetary scale, and it is considered a biodiversity hotspot by exceptionally high levels of endemism [15]. Moreover, the Mediterranean is a popular touristic destination with high pressures from anthropogenic activities (e.g. intense shipping, fishing, aquaculture, coastal urbanization) that take place in its waters and around its coastlines, factors that increase the input of marine litter into the basin [16, 17]. The Mediterranean is experiencing a deterioration of habitats, related to various human-origin activities, including global warming, uncontrolled urbanization and coastal development, fish farming, pollution and unsustainable fishing [15].

Plastic pollution in the Mediterranean has been well-documented: litter was found from shallow waters down to 4,500 m, as well as in surface waters where plastic concentration in some areas is comparable to that of the subtropical gyres (e.g. [16, 18, 19]). Several studies have demonstrated that plastics are ingested by marine organisms (e.g. [10, 20, 21]) and the number of reports on the impacts of plastics on marine organisms has increased over time. The high amount of plastics in the Mediterranean exposes its marine biodiversity to a direct threat [22].

Several reviews of the impacts of litter on marine life have been published (e.g. [8, 20, 21, 23, 24]). Marine litter impacts on the Mediterranean marine biodiversity were reviewed by Deudero and Alomar [25], who provided a list of 134 species affected by marine litter. More recently, Fossi et al. [26] provided a list of Mediterranean species known to ingest marine litter. This chapter provides the current state of knowledge about the impact of litter on marine organisms in the Mediterranean Sea based on the relevant literature (peer-reviewed scientific literature, grey literature, web sites and reports) published so far. We considered the effects of all kinds of marine litter, even if the great majority of records were referred to plastic litter, in particular as concerns ingestion.

The reviews published by Laist [20], Kühn et al. [23], Kiessling et al. [27], Deudero and Alomar [25] and Fossi et al. [26] were used as the starting point for this review. Web of Science, Scopus and Google Scholar scientific databases were used to search for the keywords: "plastics, marine litter, debris, microplastics, impact, ingestion, entanglement, rafting, hitch-hiking, ghost-fishing, entrapment, bioindicators, Mediterranean Sea, marine organisms, invertebrates, fish, marine mammals, turtles, seabirds, cetaceans, molluscs, crustaceans", appropriately combined. We further consulted the web sites Litterbase (https://litterbase.awi.de) and "Marine litter and biodiversity interactions in the Mediterranean Sea" (https://panaceacatalogue.adabyron.uma.es/gvsigonline/core/public_project_load/marinelitter/). No laboratory/experimental studies were included in the review. The bibliographic search was closed in August 2019. Our literature search spanned records from 1980 to 2019. Taxonomic information and species names were updated using the World Register of Marine Species (WoRMS) database (www.marinespecies.org). Species habitat information was based on several databases (FishBase, www.fishbase.org; SeaLifeBase, www.sealifebase.org; the Reptile Database, www.reptile-database.org; the World Cetacea Database, www.marinespecies.org/cetacea/). The species' conservation status was retrieved from the International Union for Conservation of Nature (IUCN) database (www.iucnredlist.org), referring to the Mediterranean subpopulation when specific information was available. Species were arranged into taxonomic groups (bacteria, plankton, marine plants, invertebrates, tunicates, teleosts, elasmobranchs, marine mammals, sea turtles and seabirds), and areas were grouped into Mediterranean subregions, as defined by the Marine Strategy Framework Directive (MSFD) (Western Mediterranean Sea, Ionian Sea and the Central Mediterranean Sea, Adriatic Sea and Aegean-Levantine Sea). It should be noted that a study was considered for all subregions if it covered two or more subregions. This work focuses mainly on ingestion and entanglement since they constitute the most common impacts of anthropogenic litter on marine organisms [23]. However, evidence of other kinds of impacts (e.g. colonization and rafting) on Mediterranean marine life is reported.

A total of 128 documents reporting impacts of marine litter on 329 taxa of the Mediterranean life were collected; among them, 156 taxa were found affected with regard to ingestion and/or entanglement (Tables 1 and 2). Figure 1 summarizes the number of species affected by marine litter either by ingestion or by entanglement according to different subregions of the Mediterranean; Fig. 2 presents the number of documents reporting ingestion/entanglement according to different subregions.

The highest number of species documented for marine litter ingestion has been reported for the Western Mediterranean Sea ($N = 67$), followed by that of the Aegean-Levantine Sea ($N = 37$). The highest number of species affected by entanglement was also reported for the Western Mediterranean Sea ($N = 67$), followed by the Ionian Sea and the Central Mediterranean Sea ($N = 23$).

The subregions with the lowest number of published reports on the effects of marine litter on biota were the Adriatic and the Aegean-Levantine Sea, indicating a gap of knowledge for these areas (Fig. 2).

2 Ingestion

Ingestion has been defined as the main impact of litter on marine organisms according to the MSFD Criterion 10.2 “Impacts of litter on marine life”, which will be used towards the achievement of a Good Environmental Status (GES) that is reached when “Properties and quantities of marine litter do not cause harm to the coastal and marine environment” [152]. Specifically, Indicator 10.2.1 refers to “Trends in the amount and composition of litter ingested by marine animals”.

Plastic is the most common litter category ingested by marine organisms (e.g. [8, 20, 21, 23, 26, 58, 80, 153]). Plastic particles have been found in all trophic levels, from zooplanktonic species such as copepods to invertebrates like polychaetes and bivalves, as well as vertebrates like fish, birds and marine mammals (e.g. [8, 10, 23, 154]). The proportion of species ingesting plastics varies a lot among the several taxonomic groups. Litter ingestion may occur in several ways either intentionally, accidentally, as a result of secondary ingestion or through parental delivery.

Intentional plastic ingestion can occur because of misidentification of litter items as natural prey. For example, Moser and Lee [155] studied the guts of seabirds and reported that some seabirds selected specific plastic shapes and colours and mistook them for potential prey items. Additionally, Ory et al. [156] showed that the planktivorous fish *Decapterus muroadsi* (Carangidae) ingested preferentially blue microplastics resembling their copepod prey, whereas Campani et al. [81] mentioned that turtles frequently ingested plastic bags as they may have mistaken them for jellyfish, which is a common prey in their diet. Moreover, the small size of

Table 1 List of Mediterranean species that have ingested plastics and microplastics according to published literature and online sources (search closed in August 2019)

ML effect	Taxon	Phylum	Species	Habitat	IUCN status	MSFD subregion	Reference
Animalia							
	Invertebrates	Annelida					
I			*Saccocirrus papillocercus*	Benthic	NE	W Med	[28]
		Mollusca					
I			*Mytilus galloprovincialis*	Benthic	NE	Ion & C Med; W Med	[29–32]
I			*Octopus salutii*	Demersal	DD	W Med	[22]
		Cnidaria					
I			*Pelagia noctiluca*	Pelagic	NE	Ion & C Med	[33]
		Echinodermata					
I			*Holothuria (Panningothuria) forskali*	Benthic	NE	W Med	[34]
I			*Holothuria* (*Holoturia*) *tubulosa*	Benthic	NE	Ion & C Med	[35]
		Arthropoda					
I		Amphipoda	*Gammarella fucicola*	Benthic	NE	W Med	[36]
I			*Gammarus aequicauda*	Benthic	NE	W Med	[36]
I			*Melita hergensis*	Demersal	NE	W Med	[36]
I			*Nototropis guttatus*	Benthic	NE	W Med	[36]
I		Leptostraca	*Nebalia strausi*	Demersal	NE	W Med	[36]
I		Decapoda	*Aristeus antennatus*	Demersal	NE	W Med	[37]
I			*Athanas nitescens*	Demersal	NE	W Med	[36]
I			*Galathea intermedia*	Demersal	NE	W Med	[36]
I			*Liocarcinus navigator*	Benthic	NE	W Med	[36]

(continued)

Table 1 (continued)

ML effect	Taxon	Phylum	Species	Habitat	IUCN status	MSFD subregion	Reference
I			*Nephrops norvegicus*	Benthic	LC	W Med; AD; Ion & C Med, AG & LEV	[38]
I			*Palaemon xiphias*	Benthic	NE	W Med	[36]
I			*Plesionika narval*	Benthic	NE	AG & LEV	[39]
Vertebrates							
		Chordata					
I	Teleosts		*Argyrosomus regius*	Benthopelagic	LC (Med)	AG & LEV	[40]
I			*Boops boops*	Demersal	LC (Med)	W Med	[41, 42]
I			*Caranx crysos*	Reef-associated	LC	AG & LEV	[40]
I			*Cataetyx laticeps*	Benthopelagic	LC (Med)	W Med	[43]
I			*Centracanthus cirrus*	Benthopelagic	LC (Med)	W Med	[22]
I			*Chelidonichthys cuculus*	Demersal	LC (Med)	W Med	[22]
I			*Chelidonichthys lucerna*	Demersal	LC (Med)	AD; AG & LEV	[40, 44]
I			*Chelon auratus*	Pelagic	LC (Med)	AD; AG & LEV	[40, 45]
I			*Citharus linguatula*	Demersal	LC (Med)	Ion & C Med	[45]
I			*Coryphaena hippurus*	Pelagic	LC (Med)	W Med	[46]
I			*Dentex gibbosus*	Benthopelagic	DD (Med)	AG & LEV	[40]
I			*Diaphus metopoclampus*	Bathypelagic	LC (Med)	Ion & C Med	[47]
I			*Diplodus annularis*	Benthopelagic	LC (Med)	AG & LEV	[40]
I			*Electrona risso*	Bathypelagic	LC (Med)	Ion & C Med	[47]
I			*Engraulis encrasicolus*	Pelagic	LC (Med)	W Med; AD	[41, 48, 49, 60]
I			*Glossanodon leioglossus*	Bathydemersal	LC (Med)	W Med	[22]
I			*Helicolenus dactylopterus*	Bathydemersal	LC (Med)	W Med	[22]

I			*Hoplostethus mediterraneus*	Benthopelagic	LC (Med)	W Med	[22]
I			*Hygophum benoiti*	Bathypelagic	LC (Med)	Ion & C Med	[47]
I			*Lepidion lepidion*	Bathypelagic	LC (Med)	W Med	[22]
I			*Lepidopus caudatus*	Benthopelagic	LC (Med)	W Med	[50]
I			*Lepidotrigla dieuzeidei*	Demersal	LC (Med)	W Med	[22]
I			*Lithognathus mormyrus*	Demersal	LC (Med)	AG & LEV	[40]
I			*Merluccius merluccius*	Demersal	VU (Med)	AD; Ion & C Med	[44, 51, 52]
I			*Mora moro*	Bathypelagic	LC (Med)	W Med	[43]
I			*Mullus barbatus*	Demersal	LC	AD; Ion & C Med; AG & LEV; W Med	[29, 40, 44, 45, 51, 53, 54]
I			*Mullus surmuletus*	Demersal	LC	AD; AG & LEV; W Med	[40, 45, 55]
I			*Myctophum punctatum*	Bathypelagic	LC (Med)	Ion & C Med; W Med	[47, 56]
I			*Naucrates ductor*	Reef-associated	LC (Med)	W Med	[22]
I			*Nemipterus randalli*	Demersal	LC	AG & LEV	[40]
I			*Nettastoma melanurum*	Bathypelagic	LC (Med)	W Med	[43]
I			*Nezumia aequalis*	Benthopelagic	LC (Med)	W Med	[22]
I			*Notacanthus bonaparte*	Bathypelagic	LC (Med)	W Med	[57]
I			*Pagellus acarne*	Benthopelagic	LC (Med)	AG & LEV	[40]
I			*Pagellus bogaraveo*	Benthopelagic	LC (Med)	Ion & C Med	[58, 59]
I			*Pagellus erythrinus*	Benthopelagic	LC (Med)	AD; Ion & C Med; AG & LEV	[29, 40, 45, 59]
I			*Pagrus pagrus*	Benthopelagic	LC (Med)	AG & LEV	[40]
I			*Pelates quadrilineatus*	Reef-associated	NE	AG & LEV	[40]
I			*Phycis phycis*	Benthopelagic	LC (Med)	W Med	[31]
I			*Polyacanthonotus rissoanus*	Bathydemersal	LC (Med)	W Med	[57]

(continued)

Table 1 (continued)

ML effect	Taxon	Phylum	Species	Habitat	IUCN status	MSFD subregion	Reference
I			*Polyprion americanus*	Demersal	DD (Med)	W Med	[22]
I			*Pomadasys incisus*	Demersal	LC (Med)	AG & LEV	[40]
I			*Sardina pilchardus*	Pelagic	LC (Med)	AD; Ion & C Med; AG & LEV; W Med	[29, 40, 41, 44, 45, 48, 60]
I			*Saurida undosquamis*	Reef-associated	LC	AG & LEV	[40]
I			*Schedophilus ovalis*	Benthopelagic	LC (Med)	W Med	[22]
I			*Sciaena umbra*	Demersal	VU (Med)	AG & LEV	[40]
I			*Scomber japonicus*	Pelagic	LC	AD; AG & LEV	[40, 45]
I			*Scorpaena* spp.	Demersal		W Med	[31]
I			*Seriola dumerili*	Reef-associated	LC	W Med	[22]
I			*Serranus cabrilla*	Demersal	LC (Med)	AG & LEV	[40]
I			*Siganus luridus*	Reef-associated	LC	AG & LEV	[40, 61]
I			*Siganus rivulatus*	Reef-associated	LC	AG & LEV	[61]
I			*Solea solea*	Demersal	LC (Med)	AD	[45, 62]
I			*Sparus aurata*	Demersal	LC (Med)	AD; AG & LEV	[40, 45]
I			*Spondyliosoma cantharus*	Benthopelagic	LC (Med)	W Med	[31]
I			*Synchiropus phaeton*	Demersal	LC (Med)	W Med	[22]
I			*Thunnus alalunga*	Pelagic	LC (Med)	Ion & C Med	[63]
I			*Thunnus thynnus*	Pelagic	EN (Med)	Ion & C Med	[63]
I			*Trachinotus ovatus*	Pelagic	LC (Med)	Ion & C Med	[64]
I			*Trachinus draco*	Demersal	LC (Med)	W Med	[22]

I			*Trachurus mediterraneus*	Pelagic	LC	AG & LEV; W Med	[40, 41]
I			*Trachurus picturatus*	Benthopelagic	LC (Med)	W Med	[22]
I			*Trachurus trachurus*	Pelagic	LC (Med)	AD	[45]
I			*Trachyrincus scabrus*	Bathydemersal	LC (Med)	W Med	[43]
I			*Upeneus moluccensis*	Reef-associated	LC	AG & LEV	[40]
I			*Upeneus pori*	Demersal	NE	AG & LEV	[40]
I			*Uranoscopus scaber*	Demersal	LC (Med)	W Med	[31]
I			*Zeus faber*	Benthopelagic	LC (Med)	W Med	[50]
I			*Xiphias gladius*	Pelagic	NT (Med)	Ion & C Med	[63]
I	Elasmobranchs		*Centroscymnus coelolepis*	Bathydemersal	LC (Med)	W Med	[43, 65]
I			*Etmopterus spinax*	Bathydemersal	LC (Med)	Ion & C Med; W Med	[43, 55, 58, 66]
I			*Galeus melastomus*	Demersal	LC (Med)	Ion & C Med; W Med	[43, 55, 58, 65, 66]
I			*Prionace glauca*	Pelagic	CR (Med)	W Med	[67]
I			*Pteroplatytrygon violacea*	Pelagic	LC (Med)	Ion & C Med	[58]
I			*Raja clavata*	Demersal	NT (Med)	W Med	[22]
I			*Scyliorhinus canicula*	Demersal	LC (Med)	W Med	[66]
I			*Squalus acanthias*	Benthopelagic	EN (Med)	AD	[44]
I			*Squalus blainville*	Demersal	DD (Med)	Ion & C Med	[58]
I	Marine mammals		*Grampus griseus*	Pelagic	DD (Med)	AG & LEV; Ion & C Med	[68, 69]
I			*Phocoena phocoena*	Pelagic	LC	AG & LEV	[68]
I			*Physeter macrocephalus*	Pelagic	EN (Med)	AD; AG & LEV; Ion & C Med; W Med	[2, 68, 70–74]
I			*Stenella coeruleoalba*	Pelagic	VU (Med)	AD	[75]
I			*Tursiops truncatus*	Pelagic	VU (Med)	AD; AG & LEV	[76–78]
I			*Ziphius cavirostris*	Pelagic	DD (Med)	AD; Ion & C Med	[68, 79]

(continued)

Table 1 (continued)

ML effect	Taxon	Phylum	Species	Habitat	IUCN status	MSFD subregion	Reference
I	Sea turtles		*Caretta caretta*	Benthopelagic	LC (Med)	AD; Ion & C Med; AG & LEV; W Med	[80–95]
I			*Chelonia mydas*	Benthopelagic	EN	Ion & C Med; AG & LEV	[84, 90, 94, 95, 96]
I			*Dermochelys coriacea*	Benthopelagic	VU	AD; AG & LEV	[73, 97]
I			*Trionyx triunguis*	Benthopelagic	CR (Med)	AG & LEV	[90]
I	Seabirds		*Calonectris diomedea*		LC	W Med	[98]
I			*Stercorarius skua*		LC	W Med	[98]
I			*Falco eleonorae*		LC	AG & LEV	[99]
I			*Ichthyaetus audouinii*		NE	W Med	[98]
I			*Ichthyaetus melanocephalus*		NE	W Med	[98]
I			*Larus michahellis*		LC	W Med	[98]
I			*Morus bassanus*		LC	W Med	[98]
I			*Puffinus yelkouan*		VU	W Med	[98]
I			*Puffinus mauretanicus*		CR	W Med	[98]
I			*Rissa tridactyla*		VU	W Med	[98]

Study locations were grouped according to MSFD subregions (*W Med* the Western Mediterranean Sea, *Ion & C Med* the Ionian Sea and the Central Mediterranean Sea, *AD* the Adriatic Sea, *AG & LEV* the Aegean-Levantine Sea). The species conservation status according to the IUCN Red List is reported (*NE* not evaluated, *LC* least concern, *DD* data deficient, *NT* near threatened, *EN* endangered, *VU* vulnerable, *CR* critically endangered). It is reported when the assessment is specific for the Mediterranean Sea; otherwise, it is the global assessment

Table 2 List of Mediterranean species affected by marine litter (*E* entanglement, *O* other effects, such as rafting, colonization, etc.) according to published literature and online sources (search closed in August 2019)

ML effect	Taxon	Phylum	Species	Habitat	IUCN status	MSFD subregion	Reference
Plantae							
		Tracheophyta					
O			*Cymodocea nodosa*		LC (Med)	W Med	[100]
O			*Posidonia oceanica*		LC (Med)	W Med	[100]
		Rhodophyta					
O			*Hydrolithon farinosum*			W Med	[100]
Chromista							
		Ochrophyta					
O			*Achnanthes* spp.			W Med	[101, 102]
O			*Amphora* spp.			W Med	[101]
O			*Ceratoneis closterium*			W Med	[101]
O			*Cyclotella* spp.			W Med	[101]
O			*Cylindrotheca* spp.			W Med	[102]
O			*Cymbella* spp.			W Med	[101]
O			*Cystoseira* spp.			W Med	[100]
O			*Cocconeis* spp.			W Med	[101]
O			*Entomoneis* spp.			W Med	[101]
O			*Licmophora* spp.			W Med	[101]
O			*Navicula* spp.			W Med	[101, 102]
O			*Pleurosigma* spp.			W Med	[101]
O			*Thalassionema nitzschioides*			W Med	[101]
O			*Thalassionema* spp.			W Med	[102]
O			*Thalassiosira* spp.			W Med	[102]

(continued)

Table 2 (continued)

ML effect	Taxon	Phylum	Species	Habitat	IUCN status	MSFD subregion	Reference
		Myzozoa					
O			*Alexandrium taylori*			W Med	[103]
O			*Coolia monotis*			W Med	[102]
O			*Coolia* spp.			W Med	[101, 103]
O			*Dinophysis* spp.			W Med	[101]
O			*Heterocapsa* spp.			W Med	[101]
O			*Ostreopsis* spp.			W Med	[103]
O			*Prorocentrum lima*			W Med	[101]
O			*Prorocentrum minimum*			W Med	[101]
O			*Prorocentrum* spp.			W Med	[103]
O			*Pentapharsodinium tyrrhenicum*			W Med	[101]
		Haptophyta					
O			*Calcidiscus leptoporus*			W Med	[101]
O			*Coronosphaera mediterranea*			W Med	[101]
O			*Helicosphaera carteri*			W Med	[101]
O			*Syracosphaera halldalii*			W Med	[101]
O			*Syracosphaera molischii*			W Med	[101]
O			*Syracosphaera pulchra*			W Med	[101]
O			*Umbilicosphaera sibogae*			W Med	[101]
O			*Zygosphaera hellenica*			W Med	[101]

		Foraminifera					
O			*Miniacina miniacea*			Ion & C Med	[104]
O			*Tretomphaloides concinnus*			W Med	[105]
Bacteria							
		Proteobacteria					
O			*Acinetobacter junii*			AD	[106]
O			*Acinetobacter lwoffii*			AD	[106]
O			*Aeromonas bestiarum*			AD	[106]
O			*Aeromonas salmonicida*			AD	[106]
O			*Aeromonas sanarellii*			AD	[106]
O			*Aestuariibacter halophilus*			AD	[106]
O			*Aestuariibacter litoralis*			AD	[106]
O			*Alteromonas macleodii*			AD	[106]
O			*Alteromonas marina*			AD	[106]
O			*Alteromonas mediterranea*			AD	[106]
O			*Alteromonas* spp.			W Med	[107]
O			*Croceicoccus naphtovorans*			W Med	[107]
O			*Erythrobacter* spp.			W Med	[107]
O			*Erythrobacter citreus*			AD	[106]
O			*Haemophilus piscium*			AD	[106]
O			*Haliea salexigens*			AD	[106]
O			*Hyphomonas* spp.			W Med	[107]

(continued)

Table 2 (continued)

ML effect	Taxon	Phylum	Species	Habitat	IUCN status	MSFD subregion	Reference
O			*Oceanibaculum pacificum*			AD	[106]
O			*Parasphingopyxis lamellibrachiae*			AD	[106]
O			*Parvularcula oceani*			AD	[106]
O			*Pelagibacter ubique*			W Med	[107]
O			*Proteus mirabilis*			AD	[106]
O			*Pseudoruegeria sabulilitoris*			AD	[106]
O			*Roseobacter* spp.			W Med	[107]
O			*Roseovarius algicolus*			AD	[106]
O			*Shimia marina*			W Med	[107]
O			*Tepidamorphus gemmatus*			AD	[106]
O			*Thioalkalivibrio sulfidophilus*			AD	[106]
O			*Vibrio anguillarum*			W Med	[107]
O			*Vibrio harveyi*			W Med	[107]
O			*Vibrio pectinicida*			W Med	[107]
O			*Vibrio xiamenensis*			W Med	[107]
		Chloroflexi					
O			*Anaerolinea thermophila*			AD	[106]
		Planctomycetes					
O			*Bythopirellula goksoyri*			AD	[106]

O			*Croceitalea dokdonensis*			AD	[106]
O			*Rhodopirellula baltica*			AD	[106]
O			*Rhodopirellula lusitana*			AD	[106]
		Bacteroidetes					
O			*Nonlabens dokdonensis*			AD	[106]
O			*Tenacibaculum* spp.			W Med	[107]
O			*Ulvibacter litoralis*			W Med	[107]
		Cyanobacteria					
O			*Calothrix* spp.			W Med	[107]
O			*Leptolyngbya* spp.			W Med	[107]
O			*Microchaete tenera*			W Med	[107]
O			*Oscillatoria* spp.			W Med	[107]
O			*Pleurocapsa* spp.			W Med	[107]
O			*Phormidium* spp.			W Med	[107]
O			*Prochlorococcus marinus*			AD	[106]
O			*Rivularia* spp.			W Med	[107]
O			*Scytonema* spp.			W Med	[107]
O			*Synechococcus* spp.			W Med	[107]
Animalia							
	Invertebrates	Annelida					
O			*Bonellia viridis*	Benthic	NE	AG & LEV	[108]
O			*Filograna implexa*	Sessile	NE	W Med	[109]
O			*Filograna* spp.	Sessile		Ion & C Med; W Med	[104, 110]
O			*Filogranula gracilis*	Sessile	NE	Ion & C Med	[104]

(continued)

Table 2 (continued)

ML effect	Taxon	Phylum	Species	Habitat	IUCN status	MSFD subregion	Reference
O			*Filogranula* spp.	Sessile		Ion & C Med	[104]
O			*Hydroides* spp.	Sessile		AG & LEV	[111]
O			*Metavermilia multicristata*	Sessile	NE	Ion & C Med	[104]
O			*Nereis splendida*	Benthic	NE	W Med	[100]
O			*Placostegus tridentatus*	Sessile	NE	Ion & C Med	[104]
O			*Sabella pavonina*	Sessile	NE	W Med	
O			*Salmacina* spp.	Sessile		W Med	[110]
O			*Semivermilia* spp.	Sessile		Ion & C Med	[104]
O			*Semivermilia agglutinata*	Sessile	NE	Ion & C Med	[104]
O			*Serpula vermicularis*	Sessile	NE	Ion & C Med; AG & LEV	[104, 111]
O			Serpulidae	Sessile		Ion & C Med; AG & LEV	[104, 111]
O			*Spirobranchus polytrema*	Sessile	NE	W Med	[100]
O			*Spirobranchus triqueter*	Sessile	NE	AG & LEV	[111]
O			*Vermiliopsis* spp.	Sessile		Ion & C Med; W Med	[104, 112]
		Mollusca					
O			*Anomia ephippium*	Benthic	NE	AG & LEV	[111]
O			*Ascidiella aspersa*	Sessile	NE	AG & LEV	[111]
O			*Corbula gibba*	Benthic	NE	AG & LEV	[111]
O			*Diodora* spp.	Benthic		AG & LEV	[111]
O			*Doto* spp.			W Med	[100]

O			*Fiona pinnata*	Pelagic	NE	W Med	[100]
O			*Mytilus* spp.	Benthic		Ion & C Med	[113]
O			*Modiolus barbatus*	Benthic	NE	AG & LEV	[108]
O			*Musculus subpictus*	Benthic	NE	AG & LEV	[111]
O			*Neopycnodonte cochlear*	Benthic	NE	W Med; Ion & C Med; AG & LEV	[104, 111, 112]
O			*Ostrea edulis*	Benthic	NE	Ion & C Med	[113]
O			*Pedicularia sicula*	Benthic	NE	Ion & C Med	[104]
E			*Sepia officinalis*	Benthic	LC	AG & LEV	[114]
O			*Striarca lactea*	Benthic	NE	Ion & C Med	[104]
		Cnidaria					
E			*Acanthogorgia hirsuta*	Benthic	LC (Med)	Ion & C Med; W Med	[109, 110, 115]
O			*Alcyonium coralloides*	Sessile	LC (Med)	Ion & C Med	[104]
E			*Antipathella subpinnata*	Benthic	NT (Med)	Ion & C Med; W Med	[109, 110, 115–117]
E			*Antipathes dichotoma*	Demersal	NT (Med)	Ion & C Med; W Med	[109, 115, 117]
E			*Bebryce mollis*	Benthic	DD (Med)	Ion & C Med; W Med	[115, 118]
O			*Bougainvillia muscus*	Benthic	NE	AG & LEV	[111]
E			*Callogorgia verticillata*	Sessile	NT (Med)	Ion & C Med; W Med	[109, 115–120]
O			*Coenocyathus cylindricus*	Sessile	DD (Med)	Ion & C Med	[104]
E			*Corallium rubrum*	Sessile	EN (Med)	Ion & C Med; W Med	[109, 110, 115, 116]
O			Caryophylliidae	Sessile		Ion & C Med	[104]
O			*Clytia hemisphaerica*	Sessile	NE	W Med	[100]
E			*Dendrophyllia cornigera*	Reef-associated	EN (Med)	W Med	[109, 117]

(continued)

Table 2 (continued)

ML effect	Taxon	Phylum	Species	Habitat	IUCN status	MSFD subregion	Reference
E			*Dendrophyllia ramea*	Reef-associated	VU (Med)	W Med; AG & LEV	[110, 121]
O			*Desmophyllum dianthus*	Reef-associated	EN (Med)	W Med; Ion & C Med	[104, 122]
E, O			*Desmophyllum pertusum*	Sessile	NE	W Med; Ion & C Med	[104, 120, 123]
O			*Errina aspera*	Sessile	NE	Ion & C Med	[104]
O			*Eudendrium* spp.			W Med	[100]
E			*Eunicella cavolini*	Benthic	NT (Med)	Ion & C Med; W Med	[109, 110, 115, 116, 118, 124, 125]
E			*Eunicella singularis*	Benthic	NT (Med)	Ion & C Med; W Med	[110, 115]
E			*Eunicella verrucosa*	Sessile	NT (Med)	Ion & C Med; W Med	[110, 115]
O			*Gonothyraea loveni*	Pelagic	NE	W Med	[100]
O			Hydrozoa	Sessile		Ion & C Med	[104]
O			*Laomedea angulata*	Pelagic	NE	W Med	[100]
E			*Leiopathes glaberrima*	Reef-associated	EN (Med)	Ion & C Med; W Med	[109, 115, 117, 119, 126]
E, O			*Madrepora oculata*	Sessile	EN (Med)	Ion & C Med; W Med	[104, 109, 112, 120, 123, 127, 128]
O			*Obelia dichotoma*	Sessile	NE	W Med	[100]
O			*Oculina patagonica*	Sessile	LC (Med)	W Med	[129]
E			*Paramuricea clavata*	Sessile	VU (Med)	Ion & C Med; W Med; AD	[109, 110, 115–118, 130, 131]
E			*Paramuricea macrospina*	Benthic	DD (Med)	Ion & C Med	[115]
E			*Parantipathes larix*	Benthic	NT (Med)	Ion & C Med; W Med	[109, 115, 124]
E			*Savalia savaglia*	Benthic	NT (Med)	Ion & C Med; W Med	[115, 116]

O			*Sertularella* spp.	Sessile		Ion & C Med	[104]
O			Sertulariidae	Sessile		Ion & C Med	[104]
E			*Swiftia dubia*	Sessile	NE	Ion & C Med	[132]
E			*Viminella flagellum*	Benthic	NT (Med)	Ion & C Med; W Med	[109, 115, 116]
		Echinodermata					
O			*Arbacia lixula*	Benthic	NE	W Med	[100]
E			*Cidaris cidaris*	Benthic	NE	Ion & C Med	[132]
		Porifera					
O			*Haliclona* (*Reniera*) spp.	Sessile		W Med	[112]
E			*Geodia cydonium*	Sessile	NE	AD	[133]
E			*Pachastrella monilifera*	Sessile	NE	W Med	[134]
E			*Poecillastra compressa*	Sessile	NE	W Med	[134]
E			*Raspailia* (*Raspailia*) *viminalis*	Sessile	NE	Ion & C Med	[115]
O			*Sycon raphanus*	Sessile	NE	Ion & C Med	[104]
		Bryozoa					
O			*Amathia gracilis*	Sessile	NE	W Med	[100]
O			*Callopora lineata*	Sessile	NE	W Med	[100]
O			*Cellaria salicornioides*	Sessile	NE	Ion & C Med	[104]
O			*Cellepora* spp.	Benthic		Ion & C Med	[104]
O			*Celleporina* spp.	Sessile		Ion & C Med	[104]
O			Cheilostomatida	Sessile		Ion & C Med	[104]
O			Cyclostomatida	Sessile		Ion & C Med	[104]
O			*Electra posidoniae*	Benthic	NE	W Med	[100]
O			*Haplopoma* spp.	Sessile		Ion & C Med	[104]

(continued)

Table 2 (continued)

ML effect	Taxon	Phylum	Species	Habitat	IUCN status	MSFD subregion	Reference
O			*Membranipora membranacea*	Sessile	NE	W Med	[100]
O			*Puellina gattyae*	Sessile	NE	Ion & C Med	[104]
O			*Puellina* spp.	Sessile		Ion & C Med	[104]
		Brachiopoda					
O			*Gryphus vitreus*	Benthic	NE	W Med	[135]
		Arthropoda					
O		Amphipoda	*Caprella andreae*	Benthic	NE	W Med	[136]
O			*Caprella hirsuta*	Benthic	NE	W Med	[136]
O			*Elasmopus brasiliensis*	Benthic	NE	W Med	[136]
O			*Hyale grimaldii*	Benthic	NE	W Med	[136]
O			*Jassa cadetta*	Benthic	NE	W Med	[136]
O			*Phtisica marina*	Pelagic	NE	W Med	[100]
O		Lepadiformes	*Lepas* (*Anatifa*) *anatifera*	Sessile	NE	W Med; AG & LEV	[111, 136]
O			*Lepas* (*Anatifa*) *pectinata*	Sessile	NE	W Med	[100]
O			*Lepas* spp.	Sessile		Ion & C Med	[113]
O		Isopoda	*Idotea balthica*	Benthic	NE	Mediterranean	[137]
O			*Idotea metallica*	Pelagic	NE	Mediterranean; W Med	[100, 136–139]
O		Sessilia	*Adna anglica*	Sessile	NE	Ion & C Med	[104]
O			*Austrominius modestus*	Sessile	NE	W Med	[140]
O			*Chelonibia testudinaria*	Sessile	NE	Ion & C Med	[113]
O			*Hesperibalanus fallax*	Sessile	NE	W Med	[140]

O			*Megabalanus tulipiformis*	Sessile	NE	W Med; Ion & C Med	[104, 140]
O			*Octolasmis* spp.	Sessile		Ion & C Med	[104]
O			*Perforatus perforatus*	Sessile	NE	W Med; AG & LEV	[111, 140]
O			*Pachylasma giganteum*	Sessile	NE	Ion & C Med	[104]
E		Decapoda	*Geryon trispinosus*	Benthic	NE	W Med	[141]
O			*Liocarcinus navigator*	Benthic	NE	AD	[142]
E			*Maja squinado*	Benthic	NE	W Med	[143]
E, O			*Paromola cuvieri*	Demersal	NE	W Med	[122, 134]
O			*Planes minutus*	Pelagic	NE	AD	[142]
Vertebrates							
		Chordata					
O	Tunicates		*Phallusia mammillata*	Sessile	NE	AG & LEV	[111]
O			*Ciona intestinalis*	Sessile	NE	AG & LEV	[111]
O			*Styela* spp.	Sessile	NE	AG & LEV	[111]
E	Teleosts		*Conger conger*	Demersal	LC	W Med	[143]
E			*Epinephelus aeneus*	Demersal	NT (Med)	AG & LEV	[114]
E			*Scorpaena notata*	Demersal	LC (Med)	W Med	[143]
E			*Scorpaena porcus*	Demersal	LC (Med)	W Med	[143]
E			*Scorpaena scrofa*	Demersal	LC (Med)	W Med; AG & LEV	[114, 143]
E	Elasmobranchs		*Mobula mobular*	Pelagic	EN (Med)	W Med	[143]
E			*Prionace glauca*	Pelagic	CR (Med)	W Med	[144]
E			*Scyliorhinus* spp.	Demersal		AD	[145]
E	Marine mammals		*Monachus monachus*	Bathydemersal	CR (Med)	Mediterranean	[20]
E	Sea turtles		*Caretta caretta*	Benthopelagic	LC (Med)	AD; Ion & C Med; AG & LEV; W Med	[84, 90, 93, 94, 146–148]

(continued)

Table 2 (continued)

ML effect	Taxon	Phylum	Species	Habitat	IUCN status	MSFD subregion	Reference
E			*Chelonia mydas*	Benthopelagic	EN	AG & LEV	[90, 149]
E	Seabirds		*Charadrius alexandrinus*		LC	W Med	[150]
E			*Charadrius hiaticula*		LC	W Med	[150]
E			*Larus michahellis*		LC	W Med	[150]
O			*Morus bassanus*		LC	W Med	[151]
E			*Phoenicurus ochruros*		LC	W Med	[150]

Study locations were grouped according to MSFD subregions (*W Med* the Western Mediterranean Sea, *Ion & C Med* the Ionian Sea and the Central Mediterranean Sea, *AD* the Adriatic Sea, *AG & LEV* the Aegean-Levantine Sea). The species conservation status according to the IUCN Red List is reported (*NE* not evaluated, *LC* least concern, *DD* data deficient, *NT* near threatened, *EN* endangered, *VU* vulnerable, *CR* critically endangered). It is reported when the assessment is specific for the Mediterranean Sea; otherwise, it is the global assessment

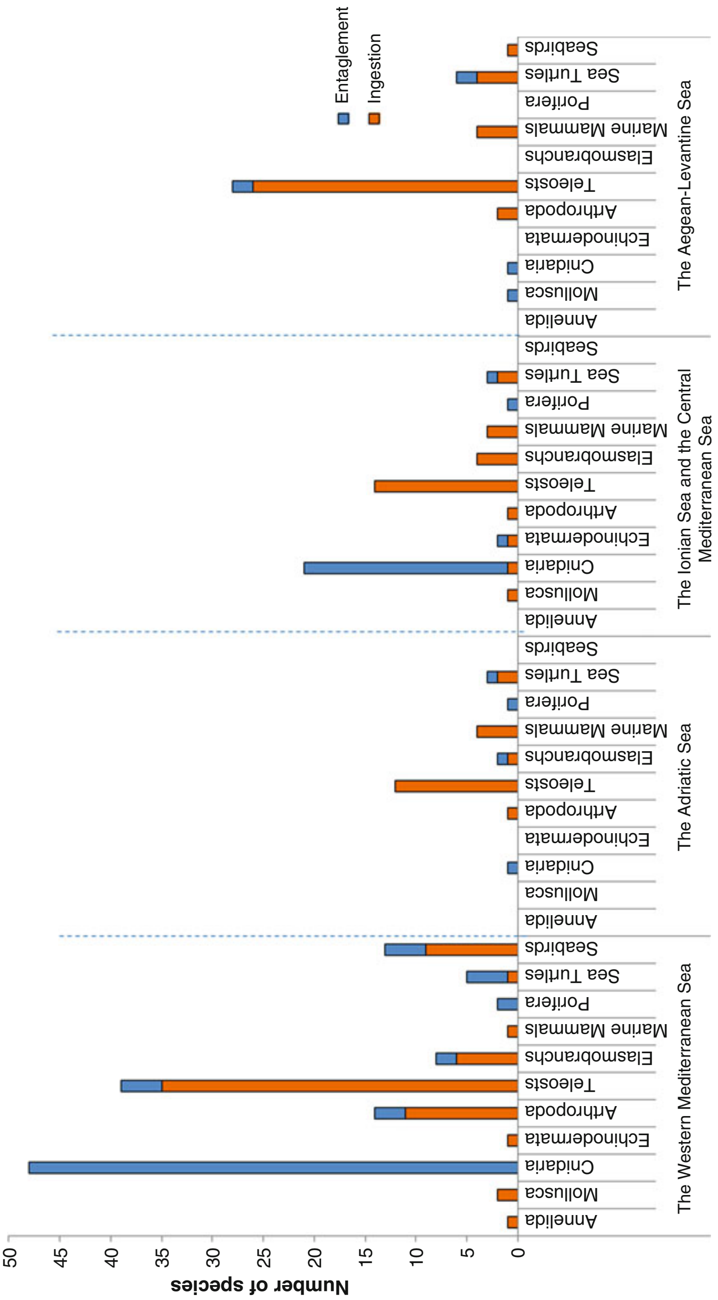

Fig. 1 Number of species affected by marine litter ingestion and entanglement in the Mediterranean subregions

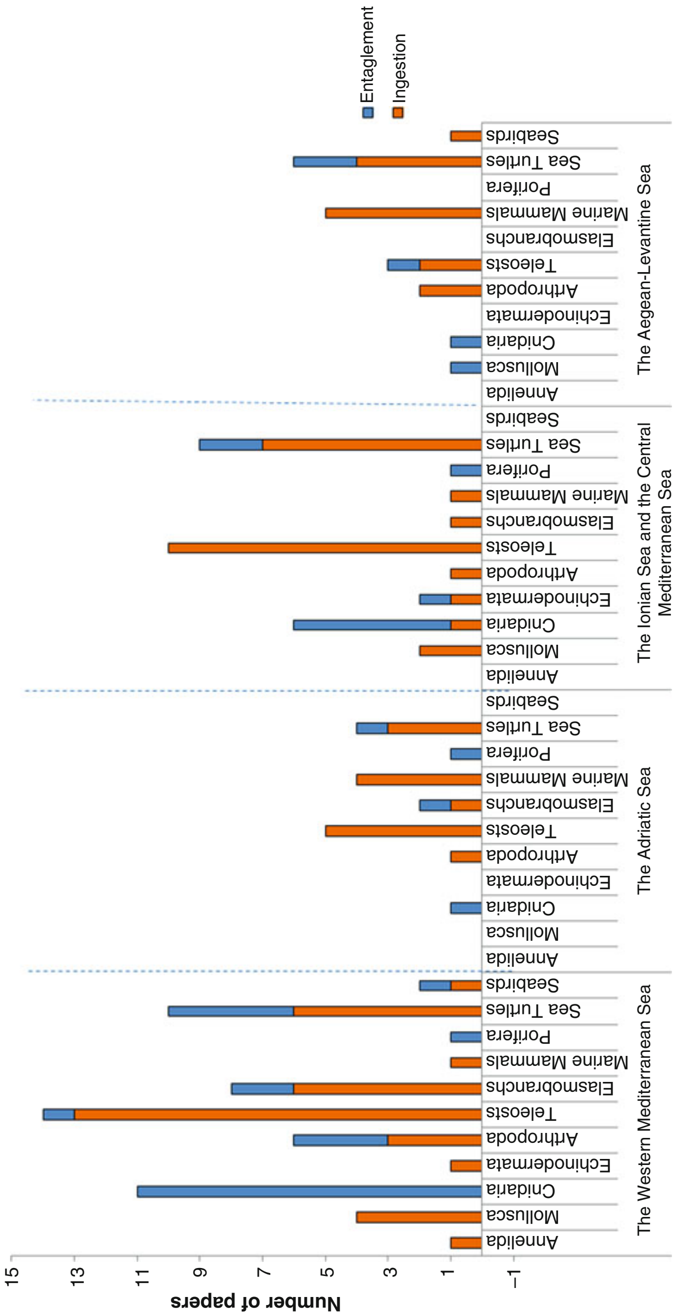

Fig. 2 Number of reports on marine litter ingestion and entanglement in the Mediterranean subregions

microplastics can make them indistinguishable from natural prey items (same size fraction of some planktonic organisms), increasing their availability to a wide range of planktivorous feeders ([10] and references therein). McCord and Campana [157] supposed that the consumption of anthropogenic material by blue sharks is related to the species opportunistic predator behaviour. Anastasopoulou et al. [58] reported that the sharks' ability to consume virtually anything of appropriate size during their feeding activity might be the reason of the plastic consumption by the species *Etmopterus spinax*, *Galeus melastomus* and *Squalus blainvillei* in the deep waters of the Eastern Ionian Sea. Finally, considering plastics as curious/attractive objects ([23] and references therein; [158]), Moss [159] reported that elasmobranchs might consume metal objects because they are attracted by their electric field.

Accidental ingestion usually occurs through passive predation or by filter-feeding activity. Filter-feeding organisms ingest plastics and microplastics by filtering large volumes of water containing them. Uptake of plastics and microplastics may also occur accidentally by passive ingestion of sediments (if plastics are of the same size fraction as sediments) when deposit or detritivores organisms are feeding (e.g. [10] and references therein; [1, 29, 39]).

Litter uptake can also occur as a result of secondary ingestion (through prey that has already ingested plastic) (e.g. [160, 161]). Predatory organisms may indirectly accumulate plastics during the ingestion of contaminated prey, which may lead to bioaccumulation at upper trophic levels. Possatto et al. [161] mentioned that some fish species (e.g. *Cynoscion acoupa*, *Centropomus undecimalis* and *Dasyatis guttata*) prey on smaller fish that have been previously contaminated by plastics. Eriksson and Burton [160] found small plastic particles in the faeces of fur seals, which were attributed to secondary ingestion through the consumption of myctophid species contaminated with plastics. The fact that many small plastics have been found in myctophid species, a common prey for large predators as tunas, supports the hypothesis of secondary ingestion ([23] and references therein). There is evidence also from laboratory studies that microplastics can be transferred from prey to predator [162] and this is therefore very likely in the environment when contaminated organisms are ingested as a whole.

Another way of litter uptake can occur through parental delivery in seabirds [164]. Adult seabirds collect plastic pieces at sea, together with food items, and bring them to feed the fledgeling chicks. Acampora et al. [165] found more plastic in the chicks than adult birds and mentioned that young birds are prone to be fed with plastic particles by their parents before fledging.

Ingested plastics are believed to have a variety of consequences for the consuming organism. The most serious effect is the direct mortality that can occur when stomachs or intestines become completely blocked or internally injured by sharp plastic objects ([8] and references therein). Other harmful effects include the blockage of the digestive tract, false feeling of satiation, reduced fitness, diminished predator avoidance, blockage of gastric enzyme production, diminished feeding stimulus, nutrient dilution, reduced growth rates, lowered steroid hormone levels, delayed ovulation and reproductive failure and absorption of toxins (e.g. [8, 10, 23, 97]). Furthermore, microplastic ingestion may cause several biochemical responses and impacts at the cellular level as cellular necrosis, oxidative stress, neurotoxic effects, liver toxicity, cancer, impaired reproductive activity, decreased immune response and malformation in animals and humans [166, 167]. Large amounts of ingested plastic might also affect an animal's buoyancy, either directly through its low density or by impairing digestive function leading to gas buildup. This may be a serious problem for turtles, potentially impairing their ability to dive and consequently leading them to starvation [168]. Additionally, plastics are liable to carry chemicals of a small molecular size as hydrophobic persistent organic pollutants (POPs) that are absorbed from the surrounding seawater (e.g. PCBs and DDT) and additives/plasticisers monomers or oligomers (e.g. flame retardants and antimicrobial agents, phthalates, bisphenol A, nonylphenols, polybrominated diphenyl ethers) of their component molecules, which were added during the manufacturing of plastics. All the above chemicals are known for their biological consequences (e.g. oestrogenic effects, testosterone reduction) on the organisms [169]. Plastics, when ingested, may also serve as indirect vehicles for the transport of pathogens via the trophic web in wild marine organisms [10]. However, further research is needed in order to understand if and to what extent microplastics pose an actual risk to wildlife and consequently to human health [170].

The extent of the harm posed by plastics on marine animals varies among species [8], and little is known about the factors influencing litter ingestion. Marine organisms feeding in different marine habitats would be exposed to different plastic abundances and consequently to different plastic availability. Few studies have examined this hypothesis. Van Franeker et al. [171, 172] provided evidence that plastic abundance in fulmars' stomachs reflected local or regional pollution levels. According to these authors, fulmars in Arctic Canada experienced lower debris ingestion rates than those in the North Sea, a difference that may result from relatively cleaner seas in Arctic Canada [171]. Anastasopoulou et al. [45], analysing several fish species from the Adriatic-Ionian macroregion, reported that the higher number of macrolitter found in the guts of the pelagic species sampled in the Adriatic Sea may be related with the higher average density of floating macrolitter found in the coastal Adriatic waters than that of the NE Ionian Sea [173]. Nevertheless, this hypothesis is not easy to be verified as many other parameters (e.g. atmospheric and oceanographic conditions) that may alter the plastic abundance at different temporal scales are involved. Differences in plastic ingestion among different locations may also reflect differences in the sampling and processing methodologies followed by each work team and not represent actual local differences in the plastic density. Moreover, different species inhabiting the same geographic area may utilize different feeding strategies, exploit differing habitats, and target different preys and may, therefore, vary in the amount of plastic ingestion. Some authors (e.g. [29, 40]) showed that pelagic fish ingest more microplastics than fish living in other habitats and exhibit higher frequencies of microplastic ingestion than demersal fish. Conversely, there are studies that reported no differences in the frequency of microplastic ingestion between pelagic and demersal fishes (e.g. [174, 175]). Anastasopoulou et al. [45] found higher macroplastic ingestion by pelagic than demersal and mesopelagic fish species, but no difference in microplastic ingestion among them.

Additionally, some organisms are subjected to ontogenetic habitat and feeding strategy shifts, and consequently, the type and number of plastics ingested by a species may vary during its different life stages. For example, juvenile birds have been reported to ingest significantly more pieces of litter than adults [165, 176]. The higher number of ingested plastics in young dolphins found by Denuncio et al. [177] was attributed to the juvenile inexperience to eat the appropriate prey. Bessa et al. [178] found a high amount of microplastics in young specimens (about 120 mm size) of *Diplodus vulgaris*; the young specimens of this species usually find shelter in estuarine waters, which are under strong influence of tidal movements and more sensitive to plastic availability. Their presence in these environments along with their opportunistic behaviour may be linked to a higher likelihood of microplastic ingestion.

First reports of plastic ingestion by marine animals date back to the early 1960s [179, 180], and successively both the number of individuals and the number of species known to ingest litter increased. However, until the 1980s the number of documents reporting ingestion did not significantly change [181]. Laist [20] reported 177 species to have been impacted by plastic ingestion worldwide, whereas Kühn et al. [23] increased this number to 331 species worldwide.

In the Mediterranean, Fossi et al. [26] documented 91 marine species having ingested marine litter, as reported in 48 papers. Our bibliographic research resulted in 76 papers documenting litter ingestion by 116 species, belonging to the taxa annelids, molluscs, cnidarians, echinoderms, arthropods, teleosts, elasmobranchs, marine mammals, sea turtles and seabirds, in a period of 31 years. Thus, a 58% increase in the number of papers was observed after Fossi et al. [26] publication. Despite the high increase in the number of published papers, the number of species increased only by 27.7%. Most of the studies were conducted in the Western Mediterranean Sea and the Ionian Sea and the Central Mediterranean Sea subregions, whereas the Adriatic and Aegean-Levantine Sea subregions were less investigated. With regard to the number of species, the higher number was observed in the Western Mediterranean Sea subregion, while the lower in the Adriatic Sea subregion.

The first study of litter ingestion in the Mediterranean was published in 1988 by Gramentz [82] for the species *Caretta caretta* and was carried out in 1986. In the last decade, the number of publications documenting litter ingestion in marine wildlife increased at an accelerating rate (79% of the collected papers were published in the last decade, from 2010 till August 2019). The low number of published works reporting litter ingestion in the past can be explained by the fact that they were mainly part of diet studies ([58] and references therein). Moreover, Carson [182] reported that this might be because many fishes that consume plastic are able to pass it through their digestive system or that past studies on stomach contents did not note/report any plastic that was encountered. In the last years, the growing recognition and concern of the marine litter problem by the media, by regional and global organizations and by the European Union that have launched several initiatives and legislative tools (e.g. MSFD) to protect the marine environment, have pushed the scientific community to pay more attention in recording and investigating litter ingestion by marine organisms and the potential risk to human consumption.

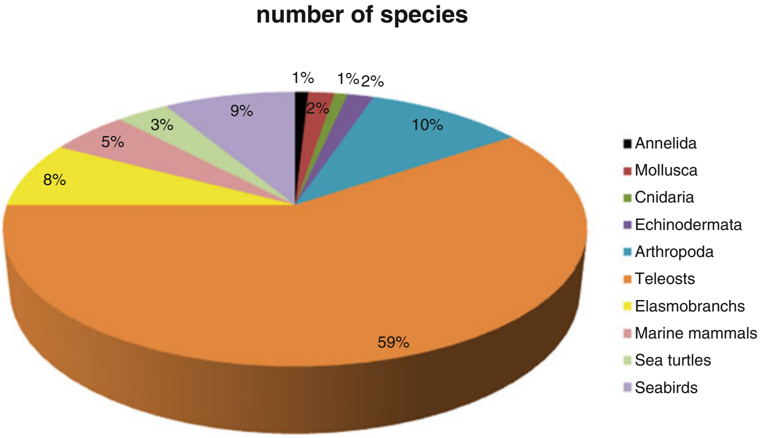

Fig. 3 Percentage of species known to have ingested litter by the taxonomic group from 1988 to August 2019 in the Mediterranean Sea

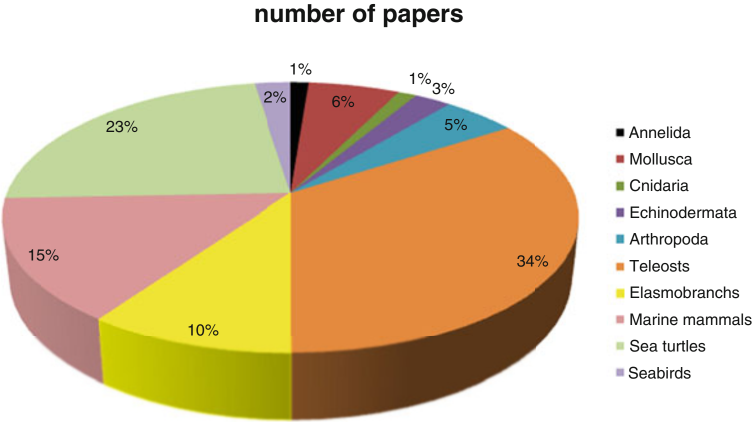

Fig. 4 Percentage of papers documenting the ingestion of marine litter by the taxonomic group from 1988 to August 2019 in the Mediterranean Sea

Teleosts were the taxonomic group with the higher number of species (59%) known to ingest plastics, followed by arthropods (12%), seabirds (10%) and elasmobranchs (9%) (Fig. 3). The number of species belonging to the other taxa was very low (<4%). Accordingly, the majority (34%) of papers reporting litter ingestion by Mediterranean marine life regarded Teleosts (Fig. 4). This could derive from the fact firstly that fish constitutes an important food source for humans and secondly that they are easy to be collected and subsequently be monitored during experimental trawl fishery surveys.

2.1 Invertebrates

In the Mediterranean, ingestion of plastics was verified in annelids (1 species), molluscs (2 species), cnidarians (1 species), echinoderms (2 species) and arthropods (12 species). The small size of microplastics makes them available for ingestion to a variety of invertebrates. Information for annelids was only available from Gusmão et al. [28]. The microfibres identified in the guts of the annelid *Saccocirrus pussicus* collected in Sardinia (Italy) were probably related to the feeding behaviour (nonselective particle feeders) of the species, which may increase the probability of accidental capture and ingestion of microfibres. No indication of physical damage due to the passage of microfibres through their gut and no mortality were detected.

Microplastic ingestion by *Mytilus galloprovincialis* was evidenced in the Mediterranean by [29–32]. Mussels are filter feeders and thus process relatively large amounts of water during feeding. This maximizes their exposure to any harmful material within the water column and can result in the accumulation of chemical pollutants and microplastics available in the environment. According to Digka et al. [29], the majority of ingested microplastics in *M. galloprovincialis* examined were fragments, in accordance with microplastics in seawater in the study area (Northern Ionian Sea). Polyethene was the most frequent polymer type found. The presence of microplastics in wild or cultured mussels [32, 183] sold for human consumption has raised a concern about whether the ingestion of litter by these organisms can cause impact on human health. The risk for human health may derive from the fact that mussels are consumed as a whole, including the gut [3]. However, recent work [184] suggests that microplastics in shellfish pose negligible risk to human health when compared to fibre exposure during a meal via dust fallout in a household. Although it is evident that humans are exposed to microplastics through their diet, there are still a lot of uncertainties around the direct connection between the ingested microplastics and the food targeted for human consumption [3, 183]. Litter ingestion has also been reported for another mollusc, the spider octopus (*Octopus salutii*), in the Western Mediterranean Sea [22].

Marine litter was found in the gastrovascular cavity of *Pelagia noctiluca* specimens in the Tyrrhenian Sea [33]. The authors mentioned that these plastic fragments were probably actively ingested by the jellyfish that wrongly recognized them as food.

Microplastic ingestion was found to occur in two Holothurian species [34, 35]. Renzi et al. [35] found consistency between the types of ingested plastics and those observed in the sediments in the studied areas, supporting the hypothesis of direct ingestion of the plastic litter from the sediment. Holothurians are benthic organisms, which ingest a large volume of sediments. Two opposite hypotheses have been proposed for plastic ingestion by Holothurians related to their feeding strategies: random (the animals had to forage on contaminated sediment to encounter plastic particles) and selective (once encountered, plastic is separated from the sediment and eaten) feeding methods [10].

Litter was also detected in crustaceans and more specifically in amphipods, leptostraca and decapods. Remy et al. [36] investigated litter in four amphipod, one leptostraca and four decapod species in the Western Mediterranean Sea and found many artificial fibres like cellulose or viscose fibres by the textile industry. Information on the presence of plastics in the guts of decapods intended for human consumption is still limited. Evidence of plastic material was reported in the stomachs of *Nephrops norvegicus* by Cristo and Cartes [38], which was attributed to the low selectivity of the species in its feeding activities. Carreras-Colom et al. [37] found that 39.2% of the individuals of blue and red shrimp *Aristeus antennatus*, a species of high commercial interest, sampled in the deep waters of the Western Mediterranean Sea, contained microplastics in their stomachs. Microplastics were mainly fibres but also tightly tangled balls of plastic strands. The uptake of plastics may occur accidentally during species normal feeding activity that occurs in a close relationship with the substrate when the species preys on endobenthic and epibenthic invertebrates, exposing shrimps to the microplastics accumulated in the seabed. Carreras-Colom et al. [37] mentioned that it is also possible that *A. antennatus* actively preys upon microplastic fibres (as balls) because they can be similar in size to small polychaetes, an important diet prey of the species. However, no clear effects on the condition or diet of the species were observed. Finally, plastics were found in another high-value commercial shrimp species, Narwal shrimp (*Plesionika narval*) in the Aegean Sea [39]. Plastics were found in approximately 6% of the stomachs of this species and were identified as nylon related to fishing activities. The plastics were mainly in the form of fibres or tangled together (balls of plastics) as a loose knot occupying the entire stomach content. Approximately 15% of the examined stomachs with ingested plastics from both sexes were empty, especially those with ball plastics, indicating a possible blockage of their digestive system. The low values of the repletion index found in shrimps with ingested plastics further support this hypothesis [39]. The presence of plastics in the stomachs of *P. narval* may be related to the feeding behaviour of the species, which is a scavenger and detritivorous feeder. The simultaneous presence of plant remains is another evidence of the passive ingestion of plastics with sediments [39].

2.2 Teleosts

Plastic ingestion has been observed in a relatively large number of fish species (69) belonging to 13 orders. The most affected species were found to be the demersal ones (30.4%), followed by benthopelagic (24.6%), pelagic (15.9%), bathypelagic and reef-associated (11.6% for each category) and bathydemersal (5.8%) fish.

Most of the demersal species are used for human consumption (e.g. *Mullus surmuletus*, *M. barbatus*, *Merluccius merluccius*, *Polyprion americanus*, *Solea solea* and *Sparus aurata*). Among demersal species, the incidence of plastics in *S. solea* was found to be very high in the Adriatic Sea, where 95% of the specimens examined had microplastics in their gastrointestinal tract [62]. Plastics in the guts of

M. barbatus, a species of high commercial value, were studied by Avio et al. [185], Bellas et al. [53], Güven et al. [40], Anastasopoulou et al. [45], Digka et al. [29], Piccardo et al. [54] and Giani et al. [51]; plastic percentage ingestion ranged from 8 to 92%. Similarly, the percentage of plastic ingestion for *M. surmuletus* ranged between 27.3 and 70% [45, 186] for the Western Mediterranean and the Adriatic Sea, respectively. Anastasopoulou et al. [45] evidenced for the first time the occurrence of litter in the stomach of spotted flounder (*Citharus linguatula*). The high variability (from 8.3 to 100%) in the presence of plastics in the guts of *M. merluccius* among the different studies conducted in the Mediterranean [51, 52, 185] could be explained by the different environmental characteristics of the areas studied and by the different number of individuals examined (in some cases the number of individuals was very low). Moreover, regurgitation of the stomach content during the fishing due to the expansion of gas in the swim bladder, which is common for this species, may result in an underestimation of the presence of plastics [51]. Demersal species live in close association with the seafloor; thus, they are more exposed to settled plastics than other species. Only one single specimen of *Sciaena umbra*, a species characterized as vulnerable in the Mediterranean by IUCN Red List, was found with microplastics in its gut in the Levantine Sea [40].

Eleven pelagic fish species were found to be affected by plastic ingestion in the Mediterranean. The highest proportion of individuals with microplastics in their guts belonged to the pelagic species *Sardina pilchardus*, which showed a highly variable incidence (0.09–96%) in different studies [29, 40, 41, 45, 48, 60, 185]. The highest value (96%) was reported in the Adriatic Sea [48]. Renzi et al. [48] found also high microplastic ingestion (91% of analysed specimens) in the pelagic species *Engraulis encrasicolus*. The authors mentioned that this high plastic incidence may be due to "net feeding", as has been reported in another study in the North Pacific zone [187]. Renzi et al. [48] suggested that the uptake of microplastics by *S. pilchardus* derived from fish's prey and not directly from the water column filtration. This was not the case for *E. encrasicolus*, which seemed to actively select microplastics through their feeding mechanisms. Female anchovies ingested on average more items (8 items/ind) than males (5 items/ind) especially during the spawning period [48]. The higher litter occurrence in guts of *S. pilchardus* compared to those of *E. encrasicolus* has been attributed to their filtration system; the larger filtration area and the smaller gap between gill rakers may allow the first species to ingest litter more likely ([41] and references therein) than the latter. Romeo et al. [63] reported that about 18% of large pelagic fishes in the Mediterranean (*Xiphias gladius*, *Thunnus thynnus* and *T. alalunga*) had plastic litter in their stomachs. The uptake of plastics by *T. thynnus*, a species characterized as endangered according to the IUCN Red List for threatened species, could be explained by the opportunistic feeding strategy of this species. Conversely, *T. alalunga* is a specialist feeder. Romeo et al. [63] provided several possible explanations for these high rates of litter ingestion. Firstly, tuna often chase prey schools to shallow water where they are more easily caught, but where plastic fragments are more abundant (given their buoyancy); secondly, feeding on aggregated preys may increase the ingestion of unwanted particles, as the predator is not focusing on a single large prey, but on several small ones; thirdly, secondary ingestion cannot be excluded. The same hypothesis has also been suggested for swordfish *X. gladius* [63]. The fact that the majority of preys in the diet of swordfish [188] are fish species known to ingest plastics, e.g. *S. pilchardus*, *E. encrasicolus* and *Boops boops* [29, 40–42, 45, 48, 49, 60, 185], enhances the hypothesis of secondary ingestion. Massutí et al. [46] found 12% of *Coryphaena hippurus* specimens, a top predator species in the Western Mediterranean pelagic ecosystem, with nonfood material, grouped as miscellaneous items, in their stomachs. The authors suggested that this phenomenon might indicate a nonselective predator activity, although unusual for the species. However, some additional reasons could be the secondary ingestion (the diet of the species is based on other fishes, crustaceans, cnidarians and cephalopods that may ingest plastics) or the fact that the species has been reported to be associated with floating debris ([46] and references therein). Moreover, the adult specimens analysed were caught with longlines around Majorca (Spain, Western Mediterranean Sea) [46], and they remained alive in the gear for many hours, which can increase the bias from "net feeding". Other pelagic fish species have also been investigated for plastics in the Mediterranean. *Scomber japonicus* has been studied from two locations: 43% of individuals from South Adriatic and 57% from the Levantine Sea were found to contain macro- and microplastics, respectively [40, 45]. *Trachurus mediterraneus* has been studied in the Aegean-Levantine Sea and the West Mediterranean Sea: 48% and 42.5% of the individuals respectively were found with ingested litter [40, 41]. Rios-Fuster et al. [41] reported that the species showed the highest level of ingested anthropogenic particles compared to the rest of the examined species. Pelagic planktivorous/filter feeder fish plays a key role in pelagic food webs, representing a central link for larger predators [26]. Moreover, their diel vertical migrations may act as a biological pump, transferring plastic litter from surface waters to mesopelagic waters and from low trophic levels of the food web to top predators [174].

The occurrence of macroplastics and microplastics was studied in several benthopelagic species in the Mediterranean. Macroplastic occurrence in *Pagellus erythrinus* from the Ionian and the Central Mediterranean Sea and the Adriatic Sea was found to be 2% and 3.3%, respectively [45]. Macroplastic occurrence in the species *Pagellus bogaraveo* and *Cataetyx laticeps* was 1.7% and 10% for the Ionian and the Central Mediterranean and the Western Mediterranean subregions, respectively [43, 58]. The microplastic occurrence in benthopelagic fishes showed a high variability ranging from 6.7 to 100%. Avio et al. [31] reported that all specimens of the benthopelagic species *Spondyliosoma cantharus* and *Phycis phycis* studied in Giglio Island (Tyrrhenian Sea) had microplastics in their stomachs. According to the authors, these values may reflect the elevated levels of microplastics in the Tyrrhenian basin, as well as the close proximity to the shoreline, which is an important sink compartment for microplastics, particularly in highly touristic or anthropized areas. Presumably, another cause for these values could be the low number of specimens analysed for both species (five and eight individuals, respectively). The commercial species *P. erythrinus* was studied in several areas in the Mediterranean [29, 40, 45, 59]. The proportion of *P. erythrinus* with microplastics in the Tyrrhenian Sea was 6.7% [59], a value higher than those reported by Anastasopoulou et al. [45] for the presence of macroplastics in the North Adriatic and North-East Ionian Sea (3.3% and 2%, respectively) and lower than those reported for the coastal waters of Turkey (22%) [40]. Significantly higher frequency of microplastic ingestion (42.1% for the Ionian and the Central Mediterranean Sea and 50% for the Adriatic Sea subregions) by the same species was mentioned by Digka et al. [29] and Anastasopoulou et al. [45]. Other benthopelagic species investigated in the Mediterranean were *Argyrosomus regius*, *Diplodus annularis*, *Dentex gibbosus*, *Centracanthus cirrus*, *Hoplostethus mediterraneus*, *Lepidopus caudatus*, *Nezumia aequalis*, *Schedophilus ovalis*, *Trachurus picturatus*, *Zeus faber*, *Pagrus pagrus* and *Trisopterus luscus* (Table 1), with the latter presenting the lowest incidence of litter occurrence (0.03%).

The occurrence of plastics in bathypelagic species ranged from 0.3 to 11.8%. The lowest occurrence of plastics was observed in *Diaphus metopoclampus* (0.3%) [47], whereas the highest one (11.8%) was observed in *Notacanthus bonaparte*, which seems consistent with the species diet, which is based on benthos [57].

Reef-associated (*Caranx crysos*, *Pelates quadrilineatus*, *Saurida undosquamis*, *Siganus luridus*, *Siganus rivulatus* and *Upeneus moluccensis*) species were studied in the Aegean-Levantine Sea by Güven et al. [40] and van der Hal et al. [61] whereas the species (*Naucrates ductor*, *Seriola dumerili*) in the Western Mediterranean Sea by Compa et al. [22]. The authors did not find any correlation between the number of ingested litter and the trophic level of species. Individuals with plastics in their guts ranged between 28 and 60% depending on the species, and fish that ingested a higher number of microplastic particles originated from the sites that also had a higher particle count in the seawater and sediment.

The last category is bathydemersal species. Cartes et al. [43] found that 33.3% of the specimens of *Trachyrincus scabrus* analysed, the largest macrourid fish inhabiting the deep waters of the Western Mediterranean Sea, have ingested macroplastics. This species preys upon other fishes, and the uptake of plastics could be a result of secondary ingestion. Plastic threads occurred in 3.7% of *Polyacanthonotus rissoanus* specimens in the Western Mediterranean Sea [57]. Litter ingestion has also been reported for the species *Glossanodon leioglossus* and *Helicolenus dactylopterus* in the Western Mediterranean Sea [22].

2.3 Elasmobranchs

In the Mediterranean, plastic ingestion has been reported in nine elasmobranch species (Table 1).

Anastasopoulou et al. [58] found that 5 out of 26 examined species from the deep waters of the Eastern Ionian Sea ingested litter. They examined 1,502 individuals, and 28 of them contained debris (~2%). The incidence of plastic in the stomachs of elasmobranchs was much greater than that of Teleosts: 4 (*Galeus melastomus*, *Pteroplatytrygon violacea*, *Squalus blainville*, *Etmopterus spinax*) out of 9 elasmobranch species were found with plastics in their stomachs, while only 1 out of

17 Teleost species examined contained plastics. The authors suggested that the types of litter ingested were related to the feeding behaviour of elasmobranch species. For instance, *G. melastomus*, a nektobenthic opportunistic feeder, swallowed all types of litter, the pelagic and bathypelagic/demersal feeders *P. violacea* and *S. blainville* ingested only pieces of plastic bags, whereas *E. spinax*, which has bathybenthic/bathydemersal feeding habits, mainly ingested hard plastics ([58] and references therein).

Similarly, Cartes et al. [43] studied three elasmobranch species (*G. melastomus*, *E. spinax* and *Centroscymnus coelolepis*) in the deep waters of the Western Mediterranean Sea. The authors mentioned a variety of allochthonous items in the diets of deep-sea elasmobranchs, including threads/fibres, remains of bags or sacks, cartoon remains, coal fragments of unknown origin and organic remains originating from human activities.

Microplastics were identified in 21 of 125 individuals of *G. melastomus* in the Western Mediterranean Sea [55]. The authors suggested that the higher values of microplastic ingestion in Western Mediterranean compared to that reported for the Eastern Ionian Sea [58] might reflect the general patterns of availability and large-scale distribution of marine litter in the Mediterranean. Indeed, litter densities from trawl surveys in continental slopes were higher in the Western Mediterranean (4.0 ± 1.8 kg/ha) compared to the central (0.6 ± 0.4 kg/ha) and eastern (1.1 ± 0.3 kg/ha) region [19]. Also in deep areas, higher values have been reported in western areas (1.8 ± 1.5 kg/ha) than in central (1.7 ± 0.6 kg/ha) and eastern areas (1.2 ± 0.3 kg/ha) [19]. Valente et al. [66] found very high litter frequency of occurrence values in three deepwater elasmobranch species (*G. melastomus*, *E. spinax* and *Scyliorhinus canicula*) studied in the Tyrrhenian Sea, which may coincide with the high litter densities recorded for the continental slopes in the Western Mediterranean and the wide anthropogenic pressure insisting on the area.

The first record of marine plastic litter in the stomachs of blue sharks (*Prionace glauca*) in the Mediterranean Sea was reported by Bernardini et al. [67]. According to these authors, 24 out of 95 specimens analysed were found with plastic litter in their stomachs, and juvenile blue sharks showed a significantly higher occurrence of ingested plastics than adults did. They proposed several explanations for the high uptake of plastics by the blue sharks. Firstly, blue sharks are pelagic species and feed on the surface to >600 m depth following the prey distribution in mesopelagic waters. Secondly, they are opportunistic feeders, playing the role of scavengers. Thirdly, their position at the top of the Mediterranean food web could increase the probability of exposure to secondary plastic ingestion. Fourthly, the colour of plastics could trick the predators ([67] and references therein). It is worth mentioning that blue shark Mediterranean subpopulation is characterized as critically endangered according to the IUCN Red List for threatened species, and the population is decreasing mainly due to fishing. Plastic ingestion may represent a further threat for the species in the Mediterranean.

Avio et al. [185] documented the presence of plastics in spiny dogfish *Squalus acanthias* in the Adriatic Sea. The Mediterranean subpopulation of *S. acanthias* is considered endangered by IUCN, and plastic can result in a further threat to the species in the area.

2.4 Marine Mammals

Litter ingestion by marine mammals in the Mediterranean Sea is less documented in the scientific literature than for other organisms (e.g. fish, marine birds and sea turtles) [68], although several cases have been reported worldwide [70]. So far, the existing information regarding interactions between large marine mammals and marine litter is related more to entanglement rather than ingestion [70]. Most of the available record of litter ingestion by mammals collected from small sample sizes provided by stranded animals, presenting only a snapshot of the impacts occurring unseen at sea [189]. Litter ingestion in singly stranded animals, although offers important information to researchers [71], may not be representative of mammals' populations and therefore may not provide accurate results [97].

One individual of a sperm whale (*Physeter macrocephalus*), the largest of the toothed whales, was found dead in a Spanish coastal area (Western Mediterranean Sea subregion) in 2012, without evidence of entanglement scars or other injuries. De Stephanis et al. [70] reported ingestion of various plastic items, such as plastic cover material, burlap plastic bags, flower pots, hosepipes and ropes, which originated from the local greenhouse agriculture. Another individual of *P. macrocephalus* that had ingested plastic was reported in the southwest of Crete Island (Aegean-Levantine Sea subregion). A small square piece of rigid plastic mesh 10 × 10 cm was found inside the stomach of the whale, which was most likely to be litter disposed of at sea [2]. In the south Adriatic Sea, seven sperm whales were found stranded in 2009. Pieces of fishing gears and hooks, ropes and plastic objects were found in 74% of the individuals examined [72]. Marine litter was found in the stomach of 10 out of 13 sperm whales (77%) stranded along the Italian coast (Western Mediterranean Sea subregion) between the period from 2009 to 2013, and it was composed mostly of plastic [71]. Similarly, marine litter found in the stomachs of six out of ten sperm whales stranded along the Ionian and Aegean Seas from 1993 to 2014; the majority of litter was plastics except only one metal wire tied at the top of a plastic bag [68]. According to the authors, the high percentage of plastic sheets in the stomachs of sperm whales is probably linked with the high abundance of plastic bags and packaging in both the water column and the seafloor. The sperm whale Mediterranean subpopulation is classified as endangered according to the IUCN Red List, and plastic ingestion could result in additional mortality for the species.

Two Cuvier's beaked whales (*Ziphius cavirostris*), which were found stranded along the Croatian coast (the Adriatic Sea subregion), contained four plastic bags (two of them were shopping bags from soft plastic, and the other two were made of more solid plastics). According to the authors, the cause of death was probably the direct result of ingesting plastic bags [79]. Plastics were found in the stomach of one Cuvier's beaked whale stranded along the Greek Ionian Sea coasts (the Ionian Sea and the Central Mediterranean Sea subregion), and its death may be caused by gastric blockage [68].

Dolphins have been reported to ingest marine litter quite often as well. Shoham-Frider [69] documented ingestion of pieces of plastic bags by a stranded Risso's dolphin (*Grampus griseus*) along the Mediterranean coast of Israel (Aegean-Levantine subregion). The pieces of plastic bags found in its stomach contributed to the dolphin's poor physical condition. Alexiadou et al. [68] mentioned plastic ingestion by a Risso's dolphin stranded along the Greek Ionian Sea coasts (the Ionian Sea and the Central Mediterranean Sea subregion), the death of which may have been caused by gastric blockage. Levy et al. [76] reported ingestion of nylon filaments and nets by a common bottlenose dolphin (*Tursiops truncatus*) in 2002 in the Port of Haifa, Israel. Gomerčić et al. [77] examined 120 stranded bottlenose dolphins along the Croatian coasts of the Adriatic Sea in the period from 1990 to 2008. Almost 10% of these dolphins had from 1 to 13 pieces of gill-net parts in their forestomachs depending on the specimen. Two of these animals had heavy forestomach and oesophagal ulcerations. Probably, these dolphins had torn off a part of the gill nets while feeding on fish entangled in the fishing nets [77]. The authors mentioned that this hypothesis was supported by the fact that dolphins with gill-net parts in their stomachs were found without larynx strangulation. Interaction of marine mammals with fishing nets as part of their feeding strategy is well-known [77]. An individual of striped dolphin (*Stenella coeruleoalba*) was found dead near the SW coast of the island Krk, in the North Adriatic Sea, in 1998. The cause of death was that the entire volume of the stomach was occluded by different kinds of plastic material (garbage bags, rubber gloves, cellophane wrappings). The blubber layer was extraordinarily thin, indicating starvation [75].

Finally, Alexiadou et al. [68] reported the first evidence of plastic ingestion for harbour porpoise *Phocoena phocoena* in the Mediterranean. Ingestion of plastic by harbour porpoises is well-known in the North Sea [190].

2.5 Sea Turtles

The Mediterranean loggerhead sea turtle (*Caretta caretta*), green sea turtle (*Chelonia mydas*), African softshell turtle (*Trionyx triunguis*) and leatherback turtle (*Dermochelys coriacea*) have been found to be affected by litter ingestion (Table 1). The threat from plastic ingestion is well-documented for *C. caretta* (e.g. [80–92, 96]). The species was indeed selected in the framework of the MSFD as the target species for monitoring the amount and composition of litter ingested by marine animals in the Mediterranean. The loggerhead sea turtle has also been recommended by the expert group of the Barcelona Convention LBS protocol as the main target species regarding "Common Indicator 18E: Trends in the amount of litter ingested by or entangling marine organisms" [89]. Conversely, only three papers [84, 90, 96] reported the presence of marine litter in *C. mydas* and just one [90] in *T. triunguis* and *D. coriacea* [97].

Gramentz [82] examined sea turtles *C. caretta* incidentally caught by Maltese fishermen while fishing for *Xiphias gladius* and *Coryphaena hippurus*. Most plastics found in the guts of these specimens were transparent, milky (translucent) or white pieces of polystyrol, styrofoam and PVC, which were considered by the author as strongly indicative that these materials were ingested, being mistaken for jellyfish. Moreover, Gramentz [81] suggested that the pieces of aluminium foil found in the gut of another individual were indicative that the animal was attracted by the silvery reflections of metals, probably mistaking them for fish. Different types of litter appeared in the gastrointestinal tract of 43 loggerhead sea turtles (79.6%) caught illegally by fishermen in Spanish Mediterranean waters, with plastics being the most frequent type (75.9%). Similar results of high plastic ingestion by loggerhead were reported by [80, 85, 87, 89, 91, 93], for other areas of the Western Mediterranean Sea; by Casale et al. [92] for the Ionian Sea and the Central Mediterranean Sea; by Lazar and Gračan [80] for the Adriatic Sea; and by Sönmez [90] for the Aegean-Levantine Sea. The high occurrence of ingested plastics might be explained by the ubiquity of soft floating debris in the marine ecosystem and by the high attraction of loggerheads for this litter type [80, 81, 92]. Tomás et al. [83] mentioned that no lethal effect and neither clear evidence of digestive tract blockage were observed during the necropsies of *C. caretta* captured in the Western Mediterranean Sea. Conversely, this was not the case for seven loggerhead turtles caught in Sicily, in which intestinal occlusions, caused by the ingestion of foreign bodies of various nature, such as pumice stones, pieces of wood and plastics, fragments of electrical wires, candy wrappings, newspaper bits, tar and cellophane, were observed [84]. Campani et al. [81] reported that the presence of plastics principally in the last sections of intestines indicates that probably most of the plastics pass through the gastrointestinal tract of the *C. caretta* are excreted. Matiddi et al. [89] found the marine litter mainly in the intestine of the *C. caretta* specimens examined in the Western Mediterranean, followed by the stomach, while the oesophagus was the least affected part of the gastrointestinal tract. Moreover, Camedda et al. [87] reported that in studies of dead specimens, 70% of the litter was found in the intestines and only 30% in the stomachs.

Similar to the results reported for loggerhead sea turtles, plastics were also the most commonly ingested type of litter in *C. mydas*, *T. triunguis* and *D. coriacea* [84, 90, 96, 97]. These species have been listed as endangered (global population) and critically endangered (Mediterranean subpopulation), respectively, by the IUCN Red List mainly due to fisheries by-catch, and plastic ingestion may represent a significant further threat to these species [96].

2.6 Seabirds

On a global scale, reports of seabird plastic ingestion have been increasing since the 1960s, and they have stabilized over time [23, 153]. However, in the Mediterranean Sea, there is a lack of information on marine litter ingestion by seabirds [99]. Only two papers [98, 99] provided some information on litter ingestion by different seabird species.

Codina-García et al. [98] examined nine seabird species accidentally caught by longliners in the Western Mediterranean Sea from 2003 to 2010. Among them, Scopoli's shearwater (*Calonectris diomedea*), yelkouan shearwater (*Puffinus yelkouan*) and Balearic shearwater (*P. mauretanicus*) presented the highest occurrence of litter ingestion (96%, 71% and 70%, respectively). According to these authors, this result is of conservation concern, since *P. yelkouan* is considered vulnerable by IUCN, while *P. mauretanicus* is considered critically endangered. *C. diomedea*, although characterized as least concern at a global scale by IUCN, in the Spanish national catalogue is listed as vulnerable. The other species (*Ichthyaetus audouinii*, *I. melanocephalus*, *Larus michahellis*, *Rissa tridactyla*, *Stercorarius skua* and *Morus bassanus*) were less affected (13–50%), although the number of specimens examined was low. The highest mean number of items/ind (49.3 ± 77.7) was observed in Audouin's gull (*L. audouinii*). Plastic items found in this study could be classified mostly as microlitter, that is, most of them were smaller than 5 mm [98].

Steen et al. [99] observed, through a camera trap placed in a nest situated in the eastern region of the Aegean Sea, a parental female Eleonora's falcon (*Falco eleonorae*) arriving at the nest with plastic waste (a snack wrapper) and feeding the nestlings. The female bird probably mistook the plastic waste for a small bird or large insect during hunting [99].

3 Entanglement

Entanglement of seabirds, marine mammals, sea turtles and fish in marine debris is the most known and visible effect of plastic pollution on marine organisms [23]. However, many species vulnerable to entanglement are scattered across wide ocean areas and individuals that become entangled and die may quickly sink or be consumed by predators at sea without being detected [20]. Thus, the estimated mortality rates and the effects of entanglement on the population dynamics of many species are probably underestimated [97]. Many marine species interact with marine debris as a result of their normal behaviour patterns: drifting debris attracts fish and invertebrates, and thus marine mammals, seabirds and turtles could be attracted to debris by its associated prey species [20].

Entanglement is the second main impact (following ingestion) to be considered when dealing with criteria 10.2. "Impacts of litter on marine life" of the MSFD [191]. However, no indicator related to entanglement has been defined to date for long-term monitoring programmes due to the difficulties in detecting it (see [192] for a thorough discussion on this issue).

Entanglement of marine life occurs in all ecosystems around the world and affects a wide range of species, including whales, sea turtles, fur seals, seabirds, octopuses, corals, crabs, fish, etc. (for a global review, see [23]). Entanglement can cause wounds and entrapment, hindering animals ability to move, reproduce, feed and escape from predators, and potentially lead to death from starvation, suffocation, strangulation or drowning [20, 23]. Moreover, entanglement could cause lacerations and infections from the abrasive or cutting action of attached debris, and entangled animals may exhibit altered behaviour patterns potentially hampering their survival [97]. Whales and dolphins are usually entangled around their neck, flippers and flukes by fishing gear (e.g. [193]). Seals can become entangled in fishing gear, packing straps or other loop-shaped items that encircle the neck at a young age and create problems during growth [194]. As summarized by Kühn et al. [23], seabirds may become entangled around the bill, wings and feet with rope-like materials, which constrains their ability to fly or forage; marine turtles are prone to entanglement by floating debris, while hatchlings may be entangled in beach debris on their way to the sea; crabs, octopuses, fishes and a wide range of smaller marine biota can be caught in derelict traps and nets on the seafloor where they could die from starvation and serve as bait, attracting new victims. Derelict fishing lines and nets may cause direct physical damage to benthic sessile organisms such as sponges and corals, breaking them or causing a progressive removal of their tissues, making them more vulnerable to parasites or bacterial infections [134].

Most records of entanglement around the world involve fishing gears, six-pack plastic rings and packing strapping bands [97]. As regards fishing gear, generally it is not straightforward determining if the animal became entangled in an active gear (by-catch) or in an abandoned, lost or otherwise discarded fishing gear (ghost fishing) [20, 26]. Indeed, “ghost fishing” refers to derelict fishing gear that continues to catch marine animals, inducing mortality without human control [195]. Moreover, larger vertebrates may continue to travel after becoming entangled in nets, hence transforming active fishing gear into marine debris [196]. For these reasons, the MSFD monitoring criteria for biota considered entanglement as a secondary criterion, and each member state has to decide for its implementation [197]. In this review, we considered as entanglement by marine debris only those cases where the authors explicitly refer to it. Reports in which the gear was identified as likely having been operational at the time of entanglement were excluded (e.g. [78]).

In the Mediterranean Sea, the first documented record of a marine animal entangled in anthropogenic debris dates back to 1979, when a small turtle with a large piece of a plastic sheet wrapped around its shell was observed attempting to swim in the Eastern Mediterranean [146]. The author did not specify the species, but it could probably be the loggerhead sea turtle (*C. caretta*) since it is the most common sea turtle in the Mediterranean [147].

According to the present review, *C. caretta* is the species with the highest number of entanglement records in the Mediterranean Sea. The species resulted impacted both by land-based sources, such as plastic bags and sheets, and by sea-based sources, like fishing aggregating devices (FADs) and fishing lines. During their juvenile pelagic phase, sea turtles are dependent on driftlines for their food supply and shelter [97]. The currents that form driftlines and transport hatchlings to oceanic convergence zones also concentrate floating anthropogenic debris, resulting in a trap for these young turtles, whether it be through ingestion or entanglement [148]. We identified four papers reporting loggerhead entanglement in marine debris in Italian waters (mainly in the Tyrrhenian Sea) and one in Turkey (Aegean-Levantine Sea) (Table 2). Casale et al. [147] reported entangled loggerhead in the South Tyrrhenian

Sea, Ionian Sea, Strait of Sicily and North Adriatic Sea between 2000 and 2008. Even though the authors reported that the entanglement of analysed specimens was due to anthropogenic material that could not be ascribed with certainty to operating or abandoned fishing gear, they concluded that entanglement in ghost gear or in other anthropogenic debris affects high numbers of turtles in the Mediterranean. In 1994, a juvenile loggerhead turtle was found close to the Island of Panarea (South Tyrrhenian Sea, Sicily; Western Mediterranean Sea subregion) trapped in a bundle of polyethene packaging twine; a piece of cord had been swallowed and extended out of the animal's mouth for a length of 20 cm, and it was removed through an endoscopy, as reported in the Marine Turtle Newsletter 71:5, http://www.seaturtle.org/mtn/archives/mtn71/mtn71p5.shtml. Blasi et al. [94] reported loggerhead individuals entangled in anchored illegal FADs and in floating debris (nylon and debris from FADs or land-based sources) near the Aeolian Archipelago (South Tyrrhenian Sea, Sicily; Western Mediterranean Sea subregion) in a study conducted between 2011 and 2014. Turtles became entangled or injured in the anchoring lines and debris of FADs at the neck, flippers and posterior limbs. These entanglements produced injuries and hampered the ability to swim and dive and were responsible for a general state of undernutrition probably due to the inability of turtles to successfully capture preys.

Marine pollution, intended, for example, as entanglement in rope and net, cloth sack or nylon bag, as well as the presence of these substances in the digestive system, was identified as the main cause of death of stranded green turtles (*C. mydas*) found on Samandağ beach (Turkey, Aegean-Levantine Sea subregion) between 2009 and 2017 [90]. Rope entanglement represented the main problem for green turtles at the oceanic stage. *C. mydas* is an endangered species because of the extensive subpopulation declines in all the major ocean basins over the last three generations. The main causes for this decline are the overexploitation of eggs and adult females at nesting beaches, juveniles and adults in foraging areas and, to a lesser extent, incidental mortality relating to marine fisheries and degradation of marine and nesting habitats. For this reason, green turtles are subjected to legislative protection under a number of treaties and laws (e.g. Annex II of the SPAW Protocol to the Cartagena Convention; Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora; Appendices I and II of the Convention on Migratory Species (CMS)). On the same beach, marine pollution was identified as the third cause of death for loggerhead, following fishing activities and intentional killing [90]. Özdilek et al. [149] found that solid waste accumulations on beaches along the Samandağ coast negatively affect green turtle hatchlings trying to reach the sea. The authors observed that litter represented an obstacle for the rushing hatchlings, and when they hang on the litter, they were easily hunted by ghost crabs living there.

Through in situ experiments using some of the most common items found on beaches (plastic bottles, styrofoam cups, plastic canisters and fishing nets), Triessnig et al. [198] showed that most sea turtle hatchlings were permanently entrapped in cups and canisters or entangled in nets. The study was conducted in the Gulf of Fethiye (southwest Turkey) in the Aegean-Levantine Sea subregion. Turkey is one of the main contributors to marine plastic debris in the Mediterranean [7], and at the same time, it hosts the main nesting concentrations of loggerhead [199], resulting in a high risk for the species since nesting beaches are extremely important habitats for marine turtles [200].

In the first global review ever published on the entanglement of marine life, Laist [20] reported only one species from the Mediterranean, i.e. the Mediterranean monk seal (*Monachus monachus*). The author reported that the animal was entangled in derelict fishing gear and a rubber hoop. Further evidence of entanglement of Mediterranean monk seals was reported in the Western Mediterranean Sea, the Ionian Sea and the Central Mediterranean Sea and the Aegean-Levantine Sea [201], but it is not clear if these were cases of by-catch or ghost fishing, and thus they were not considered in this review. Caution is needed when attributing entanglement to marine debris. Kühn et al. [23], for instance, attributed to plastic litter the entanglement of an individual of monk seal reported in [201]. However, in the article, it is clearly described that it was a case of by-catch.[1]

Other marine mammals threatened by marine litter (and in particular fishing gear), in terms of entanglement, are cetaceans [189]. However, we did not find in the literature any reference for the Mediterranean Sea clearly distinguishing cases of cetaceans' entanglement due to by-catch from cases due to ghost fishing. Even if some marine mammals, especially juveniles, may attempt to rest on the debris, may want to investigate it by curiosity or even play with it, risking their entanglement, most cases of entanglement records of cetaceans are related to active fishing gear [97]. Entanglement in fishing gear was observed for the endangered sperm whale (*P. macrocephalus*) in the Southern Tyrrhenian Sea [203] and in the Greek Seas [204]; for the vulnerable common bottlenose dolphin (*T. truncatus*) in the Adriatic Sea [77] and Greek Seas [204]; and for Risso's dolphin (*G. griseus*) in the Greek Seas [204].

As regards seabirds, the only entanglement records found for the Mediterranean were anecdotal evidence on accidental entrapments by fishing lines on a beach along the Tyrrhenian coast of central Italy: one adult of *Charadrius hiaticula* (Fig. 5), an adult male of *Phoenicurus ochruros*, an adult female *Charadrius alexandrinus* and an adult of *Larus michahellis* [150]. It is worth noting that *C. alexandrinus* is an endangered species in Italy [205] that breeds locally and is included in Annex 1 of 147/2009 "Birds" EU Directive as threatened species.

Three elasmobranch species subjected to entanglement in marine debris in the Mediterranean Sea were identified in the literature. However, the number of sharks and rays that become entangled and die undetected could be much greater than those reported since they will invariably die at sea and very likely be rapidly consumed

---

[1] "A hungry seal raids a fishing net but suddenly finds itself ensnared. In its desperation, it bites and tears and struggles until the net is reduced to shreds. The harder it struggles to escape, the tighter the surviving rope and mesh entwines it. In the end it lies at the water's surface, gasping, exhausted, the remnants of the net wound tight around its throat. The following morning, the unfortunate owner of the tattered nets set out from the little fishing village of Komi on Chios to bring in his night's catch, only to discover the seal still struggling to liberate itself" [202].

Fig. 5 An adult individual of *Charadrius hiaticula* entrapped by fishing line with the hook [150]

[145]. An individual of giant devil ray (*Mobula mobular*) was found dead entrapped in a ghost net in 2011 in the Port-Cros National Park (Western Mediterranean Sea, France) [143]. According to IUCN, it is an endangered species, and its geographic range is limited to the Mediterranean Sea and possibly adjoining North Atlantic waters. *M*. *mobular* is also included in Annex II "List of endangered or threatened species" to the Protocol concerning Special Protected Areas and Biological Diversity in the Mediterranean of the Barcelona Convention and in Annex II "Strictly protected fauna species" to the Bern Convention. In 2016, a juvenile female of blue shark *Prionace glauca*, with a yellow plastic polyolefin strapping band collar surrounding its gill area, was captured by a commercial longline boat in the North-Western Mediterranean Sea (Fig. 6). The ring encircled the gill region causing damage to the tissue of this area and in the front part of the right pectoral fin, and the fifth-gill slit was obstructed, which could cause breathing problems [144]. The investigative behaviour of sharks in relation to inanimate objects is probably the main cause of such encircling by debris [97]. Entanglement is more frequent in juveniles [20] since they are attracted to floating debris by curiosity and thus plastic loops can easily slip onto their body. A plastic collar around a shark's gill slits or body can cause traumatic cutting into tissue and chronic infection; it may compromise its ability to feed and grow and cause its death by strangulation [145]. Finally, in a report by Butterworth et al. [145] a picture of a deceased catshark (*Scyliorhinus* spp.) entangled in a fishing net in Croatia (Adriatic Sea) is shown, but it is not possible to identify the species.

Fig. 6 Lateral view of the head of the *Prionace glauca* specimen showing damage on the gill region and the pectoral fin by a plastic debris collar [144]

Only two documented cases of teleost species entanglement in marine debris were found in the literature for the Mediterranean Sea. Houard et al. [143] reported ghost fishing for red scorpionfish (*Scorpaena scrofa*), small red scorpionfish (*Scorpaena notata*), black scorpionfish (*Scorpaena porcus*) and European conger (*Conger conger*) in the Port-Cros National Park (Western Mediterranean Sea, France). Furthermore, Ayaz et al. [114] reported ghost fishing for red scorpionfish (*S. scrofa*), as well as for white grouper (*Epinephelus aeneus*) in the Gökova Special Environmental Protection Area (Aegean Sea, Turkey); all specimens were found dead. However, entanglement for teleosts is probably underreported because of the difficulties in its observation at sea, due, for instance, to considerable scavenging pressure on entrapped fish [206], and because information about the number of fishing gears lost or for how long such gears continue to fish is limited [207]. Potentially, a wide range of teleost species may be affected by ghost fishing. Ayaz et al. [208], for instance, performed an experimental study of ghost fishing in southwest Izmir Bay, Turkey (Aegean-Levantine Sea subregion): 29 species (22 fish, 5 crustacea, 1 cephalopod and 1 gastropod) were captured by the ghost gillnets.

Entanglement can also occur in invertebrate benthic/sessile species, such as cnidarians and sponges, which can suffer broken parts, necrosis, progressive removal of the tissues and wounds susceptible to infections [116]. Marine debris may act as a significant stressor for coral reefs, causing suffocation, shading, tissue abrasion and mortality of corals [209]. Rock habitats support dense aggregations of tridimensional complex sessile fauna called “marine animal forests”, which have been proposed as indicators to monitor the temporal and spatial trends of entanglement by marine litter. Indeed, they are vulnerable to damage due to their slow growth rate, they are widely distributed from shallow waters to the deep sea, and they are immobile enabling the precise location of the entanglement event and reducing the risk of misinterpretation due to possible interaction with active fishing gears [209].

In the Mediterranean Sea, 20 cnidarian species were found to be affected by entanglement in marine litter (Table 2), representing the taxon with the highest number of species showing this kind of impact. Most cases of entanglement were due to fishing lines and nets. The largest number of cnidarian species subjected to entanglement was found in the Ionian Sea and Central Mediterranean Sea and

Western Mediterranean Sea subregions (19 species). Only one species (*Paramuricea clavata*) was found in the Adriatic Sea subregion and one species (*Dendrophyllia ramea*) in the Aegean-Levantine Sea subregion. Endangered species in the Mediterranean *Dendrophyllia cornigera*, *Leiopathes glaberrima*, *Corallium rubrum* and *Madrepora oculata* were included in the list of species entangled by marine litter. The latter is considered critically endangered in Italian Seas, where it was found in the Ionian Sea stuck by plastic litter [127]. Moreover, nine near threatened species and two vulnerable species were found to be impacted by entanglement in the Mediterranean. The likelihood of diseases increased 20-fold once a coral is entangled in plastic [210]. For instance, Bavestrello et al. [130] found along the Portofino Promontory (Ligurian Sea, Italy) that severe damage to gorgonians (*P. clavata*) was caused by lost fishing gear (mostly monofilament lines) affecting tens of colonies through a continuing abrasive action. The stretched lines, under the action of sea currents, mechanically excoriated the coenenchyme. The authors concluded that the major cause of mortality in *P. clavata* facies along the Portofino Promontory was due to damage by fishing lines, followed by the attachment of several epibionts in the damaged surface [130]. Indeed, if injuries are of minor intensity, gorgonians are able to rapidly healing the wound by coenenchyme regeneration. Conversely, pioneering species such as hydroids may settle on the damaged surface and are soon replaced by stronger competitors like bryozoans, macroalgae, serpulids or sponges, which can no longer be removed by the newly growing coenenchyme.

Four species belonging to the taxon Porifera were found entangled in marine litter in the Mediterranean Sea, i.e. *Geodia cydonium* in the North Adriatic Sea [133], *Pachastrella monilifera* and *Poecillastra compressa* in the Ligurian Sea (Western Mediterranean Sea) [134] and *Raspailia* (*Raspailia*) *viminalis* in the Strait of Sicily. Most entanglement records involved fishing nets and lines.

Finally, two crustaceans (spinous spider crab *Maja squinado* and three-spined Geryon *Geryon trispinosus*; Fig. 7), one mollusc (common cuttlefish *Sepia officinalis*) and one echinoderm (pencil urchin *Cidaris cidaris*) were found entangled in marine litter (mainly fishing nets) in the Mediterranean Sea (Table 2). Ramirez-

Fig. 7 Ghost fishing of *Geryon trispinosus* by a discarded/lost net recovered from 1,200 m depth in the Western Mediterranean Sea [135]

Llodra et al. [135] reported evidence of ghost fishing in one sample from 1,200 m in the Western Mediterranean, where several Geryon crabs were observed dead or moribund in a broken fishing net (Fig. 7). Indeed, benthic organisms entangled in derelict fishing gear or other litter items on the seafloor can eventually die because of starvation [209].

4 Other Impacts

Marine litter may have an impact on marine life indirectly by offering available substrates for rafting species and facilitating species dispersal [27]. A wide range of sessile and motile marine organisms colonize floating litter (also called hitch-hikers, [211]), including bivalves, barnacles, algae, foraminifera and a rich microbial community that forms biofilms known as the "Plastisphere" [212]. The composition of the microbial community has been found to significantly differ from the surrounding seawater suggesting that plastic litter forms a novel habitat for microbiota [212]. Many species may extend their distribution range through transport by floating rafts: several taxa, including potential invaders, were already found on marine litter far beyond their natural dispersal range [27]. Passive transport can last for years, with marine current-driven journeys covering vast distances across the oceans [213]. Floating natural debris (e.g. plants, trunks, pumice) has always acted as a dispersal vector for marine organisms, but since the quantities of synthetic and non-biodegradable materials in marine debris have increased manifold over the last decades in the Mediterranean Sea [214], the dispersal has probably been accelerated [211]. Abundant floating marine litter may facilitate the spread of invasive and pathogenic species [27].

We found 29 papers describing the effects of marine litter on the biota in the Mediterranean Sea other than ingestion and entanglement, impacting bacteria, algae, marine plants, invertebrates, tunicates and seabirds (Table 2). Most of these species use marine litter as a substratum, but marine litter can also be used instead of sponges by the crab *Paromola cuvieri* to cover its carapace [122, 134] (Fig. 8). Overall, the most common phyla rafting on or encrusting marine litter were Bacteria, Algae, Arthropods and Cnidarians. Most taxa were associated with plastic litter.

The most comprehensive study on hitch-hikers in the Mediterranean Sea was published in 2003 by Aliani and Molcard [100], who found 21 species rafting on plastic floating litter (mainly plastic bags, bottles and styrofoam) in the Ligurian and Tyrrhenian Sea (Western Mediterranean Sea) (Table 2). The most common species found were the barnacle *Lepas* (*Anatifa*) *pectinata* and the isopod *Idotea metallica*, but many other species were identified, including coralline algae (e.g. *Hydrolithon farinosum*), seagrass species (e.g. *Cymodocea nodosa*), hydrozoans (e.g. *Obelia dichotoma*), polychaetes (e.g. *Nereis splendida*), nudibranchs (e.g. *Doto* spp.), etc. No alien species was found. *I. metallica* is an obligate rafter without benthic populations and was found hitch-hiking on marine litter also along the Catalan coast [138] and in the Alboran Sea [136]. This species is adapted to the rafting life-style and has low food requirements compared to its congener *I. baltica* that

Fig. 8 The crustacean *Paramola cuvieri* carries plastic on its exoskeleton, instead of usual sponges (470 m depth) [134]

predominantly colonizes algal rafts, which are rapidly consumed by this voracious herbivore [27]. Gutow and Franke [139] observed that specimens of *I. metallica* found rafting on floating litter in the Mediterranean represented not just ephemeral assemblages but persistent local populations.

Two papers analysed the bacterial films in the Mediterranean Sea [106, 107]. The authors identified 50 bacterial species on the microplastics sampled in the Northern Adriatic Sea and Western Mediterranean Sea (Table 2). Some of them were hydrocarbon-degrading bacterial species, able to degrade various types of plastics through the secretion of specific extracellular enzymes. The bacteria *Aeromonas salmonicida* was also identified for the first time on microplastics, which is responsible for bacterial diseases in fishes. The risk associated with microplastic pollution for the spreading of diseases should be evaluated taking into account the occurrence of pathogenic bacteria in other environmental matrices, like water and other floating objects. Dussud et al. [107] found that some putative pathogens were particularly abundant on plastic marine debris and rather rare in free-living and organic particle-attached bacteria, such as the fish pathogen *Tenacibaculum* spp. or the crustacean and invertebrate pathogens *Phormidium* spp. and *Leptolyngbya* spp. This result suggests that microplastics may serve as a vector of pathogenic bacterial species in the marine environment, although this issue has been little studied [103].

Another notable example of hitch-hiker in the Mediterranean Sea includes the Arch-fronted swimming crab (*Liocarcinus navigator*), reported for the first time ever rafting on floating marine litter in the Adriatic Sea [142]. The authors also observed two specimens of Columbus crab (*Planes minutus*) jumping from one to another piece of floating plastic marine debris (a plastic sandal and a sports shoe).

Marine litter can also serve as a substratum for cnidarians, including the alien species *Oculina patagonica* found in the Alicante harbour (Spain) inhabiting plastic bags and cans, and the potentially harmful dinoflagellates *Coolia* spp. and *Ostreopsis* spp. found on plastic that littered the waterfront of La Fosca beach (Costa Brava, Catalan coast). Plastic is used as a substratum also by sessile annelids like *Filograna implexa* [109], *Placostegus tridentatus* [104] and *Spirobranchus triqueter* [111].

Fig. 9 The northern gannets plastic nest of Porto Venere (La Spezia Gulf), built over the deck of a boat [151]

Battaglia et al. [104] reported evidence of colonization of rafting floats in expanded PVC from abandoned, lost or derelict fishing gears by 3,014 deepwater organisms belonging to 38 taxa of macro-invertebrates (Arthropoda, Cnidaria, Mollusca, Porifera, Bryozoa and Foraminifera) in the Strait of Messina (Ionian Sea). Four of these species are protected: the three deepwater corals *Errina aspera*, *Desmophyllum pertusum* and *Madrepora oculata* as well as the deep-sea cirripede crustacean *Pachylasma giganteum*. The authors speculated that the hydrodynamism of the Strait of Messina produces a continuous and strong frictional stress on the abandoned, lost or derelict fishing gears laying on the bottom. This causes the breakage of ropes and nets releasing the fishing floats, which may emerge and strand on the shore or follow the course of currents and disperse far from the point of release.

Finally, marine litter can be used by seabirds to build their nests. Indeed, plastic lightness and flexibility make it attracting to birds for the construction of nests, but it can easily twist around the body of new-borns or even of adults, damaging them and possibly causing their death [215]. Merlino et al. [151] found that northern gannets (*Morus bassanus*) in the La Spezia Gulf (Ligurian Sea, Italy; Western Mediterranean Sea subregion) build their nests using more anthropogenic objects than natural ones, in particular fragments of nets made with polypropylene and polyethene that are used for mussel farming (Fig. 9). The study concluded that the prevalent productive activities of the area (mussel farming) are responsible for the problem of marine and coastal pollution and pose a danger for the local fauna.

5 Conclusions

Our review demonstrates that the impact of plastic pollution on Mediterranean marine life, including a number of commercially important species, is a widespread and pervasive phenomenon. This is not surprising, since the Mediterranean Sea is both a crucial biodiversity hotspot and a critically polluted area, and it has been described as one of the areas most affected by marine litter in the world [26]. Evidence of plastic impact on marine life is accumulating fast because ocean plastic is a contemporary focal point of concern for the marine environment. Consequently, even if this is the most up-to-date collection of information on the impact of plastic pollution on marine life in the Mediterranean Sea, the number of species known to be impacted by plastic is deemed to increase along with growing scientific literature. A variety of direct and indirect effects of plastic pollution on marine biota has been described, including ingestion; entanglement; substrate for the dispersal of some organisms, e.g. bacteria; vectors for exposure to potential pathogens; and much more.

Plastic ingestion is the most studied impact in the region. There is scientific evidence that a large number of Mediterranean species, across multiple habitats and trophic levels, ingest plastics, mainly microplastics. It is documented that macroplastics are also regularly uptaken and retained by a variety of marine animals including fish, birds, turtles and cetaceans. The consequences of microplastic ingestion for marine organisms are still largely unknown, but generally considered as a lower risk than ingestion of larger plastic items. For instance, direct mortality in wild fish caused by ingested microplastics has not yet been described in the published literature [24]. Conversely, ingestion of and entanglement in the plastic waste can cause the suffering and death of seabirds, turtles and cetaceans. For instance, gastric blockage from plastic can be lethal for marine mammals [68]. Nevertheless, the population effects of these deaths are still largely unknown [216].

From this review, it emerges that the literature regarding seabirds for the Mediterranean is scarce. Seabirds are among the animals the most impacted by marine litter worldwide, with 165 species of the 367 species (45%, but limiting the analysis to species actually checked for plastic, the proportion is 78%) that have been recorded to ingest plastics [168]. Since seabird ingestion rates scale with plastic exposure [217], the high densities of plastic litter in the Mediterranean allow expecting ingestion rates by seabirds to increase proportionately. Thus, much research effort is needed in order to evaluate the impact of marine litter on Mediterranean seabirds.

Commercially important fish species contaminated with microplastics represent a potential source of these particles and the chemicals they contain for human consumers [218]. Many commercially important species for Mediterranean fisheries, such as European anchovy, sardine and common sole, have been found with microplastics in their guts. However, recently different scientists have denounced that the risk deriving from microplastics is probably overstated since their quantity in the marine environment is generally so low that they do not represent an environmental risk [219, 220]. It is worth noting that Katsanevakis [97] affirmed in 2008 that “The impact of microscopic plastic particles on marine fauna and the marine food web is largely unknown”, and 10 years later Markic et al. [24] still recognize that “Plastic ingestion is of special concern, as its magnitude and consequences for marine organisms and potentially humans are still largely unknown”. Also, a recent report by the Food and Agriculture Organization (FAO) stated that “Despite the increasing literature on marine plastic contamination, there is very little information on its effects at ecosystem, habitat, population or even individual level" [154]. Thus, further research is needed to investigate the effects of plastic particles on marine biota in the wild as well as those of their additives and adhering contaminants.

The presence of microplastics in lower trophic levels raises the possibility that microplastics and/or their contaminants may be transferred through the food web. However, the number of studies reporting trophic transfer remains limited. To date there is only initial evidence that suggests the potential of trophic transfer of microplastic in wild-caught organisms [221]. For this reason, further studies are needed in order to better understand the effects of plastics on the Mediterranean food webs and ecosystem.

Concluding, according to the reviewed literature, it seems that ingestion and entanglement can have dramatic consequences on marine life at the individual level. Conversely, it is unlikely to occur frequently enough to have adverse demographic impacts in the Mediterranean, with the possible exception of some marine turtles [168]. However, it must be noted that the available literature generally pertains to individuals rather than on a population level. Studies at the population level are indeed hindered by multiple environmental and human-induced stressors to which wild animals are subjected, which may mask the possible role played by microplastics [154].

References

1. Van Cauwenberghe L, Claessens M, Vandegehuchte MB, Janssen CR (2015) Microplastics are taken up by mussels (*Mytilus edulis*) and lugworms (*Arenicola marina*) living in natural habitats. Environ Pollut 199:10–17. https://doi.org/10.1016/j.envpol.2015.01.008.
2. Roberts SM (2003) Examination of the stomach contents from a Mediterranean sperm whale found south of Crete, Greece. J Mar Biol Assoc UK 83:667–670. https://doi.org/10.1017/S0025315403007628h
3. Rochman CM, Tahir A, Williams SL, Baxa DV, Lam R, Miller JT, Teh F-C, Werorilangi S, Teh SJ (2015) Anthropogenic debris in seafood: plastic debris and fibers from textiles in fish and bivalves sold for human consumption. Sci Rep 5:14340. https://doi.org/10.1038/srep14340
4. Moore CJ (2008) Synthetic polymers in the marine environment: a rapidly increasing, long-term threat. Environ Res 108:131–139. https://doi.org/10.1016/j.envres.2008.07.025
5. Worm B, Lotze HK, Jubinville I, Wilcox C, Jambeck J (2017) Plastic as a persistent marine pollutant. Annu Rev Environ Resour 42:1–26. https://doi.org/10.1146/annurev-environ-102016-060700
6. PlasticsEurope, Plastics – the Facts (2017) An analysis of European plastics production, demand and waste data, 2017. https://doi.org/10.1016/j.marpolbul.2013.01.015
7. Jambeck JR, Geyer R, Wilcox C, Siegler TR, Perryman M, Andrady A, Narayan R, Law KL (2015) Plastic waste inputs from land into the ocean. Science 347:768–771
8. Derraik JGB (2002) The pollution of the marine environment by plastic debris: a review. Mar Pollut Bull 44:842–852. https://doi.org/10.1016/S0025-326X(02)00220-5
9. Boerger CM, Lattin GL, Moore SL, Moore CJ (2010) Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre. Mar Pollut Bull 60:2275–2278. https://doi.org/10.1016/j.marpolbul.2010.08.007

10. Wright SL, Thompson RC, Galloway TS (2013) The physical impacts of microplastics on marine organisms: a review. Environ Pollut 178:483–492. https://doi.org/10.1016/j.envpol.2013.02.031
11. Jovanović B (2017) Ingestion of microplastics by fish and its potential consequences from a physical perspective. Int Environ Assess Manag 13:510–515. https://doi.org/10.1002/ieam.1913
12. Barnes DKA, Galgani F, Thompson RC, Barlaz M (2009) Accumulation and fragmentation of plastic debris in global environments. Philos Trans R Soc B Biol Sci 364:1985–1998. https://doi.org/10.1098/rstb.2008.0205
13. Law KL, Thompson RC (2014) Microplastics in the seas. Nature 345:144–145. https://doi.org/10.1002/2014EF000240/polymer
14. Coll M, Piroddi C, Steenbeek J, Kaschner K, Lasram FBR, Aguzzi J, Ballesteros E, Bianchi CN, Corbera J, Dailianis T, Danovaro R, Estrada M, Froglia C, Galil BS, Gasol JM, Gertwage R, Gil J, Guilhaumon F, Kesner-Reyes K, Kitsos MS, Koukouras A, Lampadariou N, Laxamana E, de la Cuadra CMLF, Lotze HK, Martin D, Mouillot D, Oro D, Raicevich S, Rius-Barile J, Saiz-Salinas JI, Vicente CS, Somot S, Templado J, Turon X, Vafidis D, Villanueva R, Voultsiadou E (2010) The biodiversity of the Mediterranean Sea: estimates, patterns, and threats. PLoS One 5:e11842. https://doi.org/10.1371/journal.pone.0011842
15. UNEP-MAP RAC/SPA (2010) The Mediterranean Sea biodiversity: state of the ecosystems, pressures, impacts and future priorities
16. Cózar A, Sanz-Martín M, Martí E, González-Gordillo JI, Ubeda B, Gálvez JÁ, Irigoien X, Duarte CM (2015) Plastic accumulation in the Mediterranean Sea. PLoS One 10:1–12. https://doi.org/10.1371/journal.pone.0121762
17. Liubartseva S, Coppini G, Lecci R, Clementi E (2018) Tracking plastics in the Mediterranean: 2D Lagrangian model. Mar Pollut Bull 129:151–162. https://doi.org/10.1016/j.marpolbul.2018.02.019
18. Pham CK, Ramirez-Llodra E, Alt CHS, Amaro T, Bergmann M, Canals M, Company JB, Davies J, Duineveld G, Galgani F, Howell KL, Huvenne VAI, Isidro E, Jones DOB, Lastras G, Morato T, Gomes-Pereira JN, Purser A, Stewart H, Tojeira I, Tubau X, van Rooij D, Tyler PA (2014) Marine litter distribution and density in European seas, from the shelves to deep basins. PLoS One 9:e95839. https://doi.org/10.1371/journal.pone.0095839
19. Suaria G, Avio CG, Mineo A, Lattin GL, Magaldi MG, Belmonte G, Moore CJ, Regoli F, Aliani S (2016) The Mediterranean plastic soup: synthetic polymers in Mediterranean surface waters. Sci Rep 6:1–10. https://doi.org/10.1038/srep37551
20. Laist DW (1997) Impacts of marine debris: entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records. In: Coe JM, Rogers DB (eds) Marine debris. Sources, impacts solution. Springer, New York, pp 99–413. https://doi.org/10.1007/978-1-4613-8486-1
21. Gall SC, Thompson RC (2015) The impact of debris on marine life. Mar Pollut Bull 92:170–179. https://doi.org/10.1016/j.marpolbul.2014.12.041
22. Compa M, Alomar C, Wilcox C, van Sebille E, Lebreton L, Hardesty BD, Deudero S (2019) Risk assessment of plastic pollution on marine diversity in the Mediterranean Sea. Sci Total Environ 678:188–196. https://doi.org/10.1016/j.scitotenv.2019.04.355
23. Kühn S, Bravo Rebolledo EL, van Franeker JA (2015) Deleterious effects of litter on marine life. In: Bergmann M, Gutow L, Klages M (eds) Marine anthropogenic litter. Springer, Cham, pp 75–116. https://doi.org/10.1007/978-3-319-16510-3_4
24. Markic A, Gaertner J-C, Gaertner-Mazouni N, Koelmans AA (2019) Plastic ingestion by marine fish in the wild. Crit Rev Environ Sci Technol:1–41. https://doi.org/10.1080/10643389.2019.1631990
25. Deudero S, Alomar C (2015) Mediterranean marine biodiversity under threat: reviewing influence of marine litter on species. Mar Pollut Bull 98:58–68. https://doi.org/10.1016/j.marpolbul.2015.07.012

26. Fossi MC, Pedà C, Compa M, Tsangaris C, Alomar C, Claro F, Ioakeimidis C, Galgani F, Hema T, Deudero S, Romeo T, Battaglia P, Andaloro F, Caliani I, Casini S, Panti C, Baini M (2018) Bioindicators for monitoring marine litter ingestion and its impacts on Mediterranean biodiversity. Environ Pollut 237:1023–1040. https://doi.org/10.1016/j.envpol.2017.11.019
27. Kiessling T, Gutow L, Thiel M (2015) Marine litter as habitat and dispersal vector. In: Marine anthropogenic litter, pp 141–181. https://doi.org/10.1007/978-3-319-16510-3
28. Gusmão F, Di Domenico M, Amaral ACZ, Martínez A, Gonzalez BC, Worsaae K, Ivar do Sul JA, da Cunha Lana P (2016) In situ ingestion of microfibres by meiofauna from sandy beaches. Environ Pollut 216:584–590. https://doi.org/10.1016/j.envpol.2016.06.015
29. Digka N, Tsangaris C, Torre M, Anastasopoulou A, Zeri C (2018) Microplastics in mussels and fish from the Northern Ionian Sea. Mar Pollut Bull 135:30–40. https://doi.org/10.1016/j.marpolbul.2018.06.063
30. Vandermeersch G, van Cauwenberghe L, Janssen CR, Marques A, Granby K, Fait G, Kotterman MJJ, Diogène J, Bekaert K, Robbens J, Devriese L (2015) A critical view on microplastic quantification in aquatic organisms. Environ Res 143:46–55. https://doi.org/10.1016/j.envres.2015.07.016
31. Avio CG, Cardelli LR, Gorbi S, Pellegrini D, Regoli F (2017) Microplastics pollution after the removal of the Costa Concordia wreck: first evidences from a biomonitoring case study. Environ Pollut 227:207–214. https://doi.org/10.1016/j.envpol.2017.04.066
32. Renzi M, Guerranti C, Blašković A (2018) Microplastic contents from maricultured and natural mussels. Mar Pollut Bull 131:248–251. https://doi.org/10.1016/j.marpolbul.2018.04.035
33. Macali A, Semenov A, Venuti V, Crupi V, D'Amico F, Rossi B, Corsi I, Bergami E (2018) Episodic records of jellyfish ingestion of plastic items reveal a novel pathway for trophic transference of marine litter. Sci Rep 8:6105. https://doi.org/10.1038/s41598-018-24427-7
34. Alomar C, Estarellas F, Deudero S (2016) Microplastics in the Mediterranean Sea: deposition in coastal shallow sediments, spatial variation and preferential grain size. Mar Environ Res 115:1–10. https://doi.org/10.1016/j.marenvres.2016.01.005
35. Renzi M, Blašković A, Bernardi G, Russo GF (2018) Plastic litter transfer from sediments towards marine trophic webs: a case study on holothurians. Mar Pollut Bull 135:376–385. https://doi.org/10.1016/j.marpolbul.2018.07.038
36. Remy F, Collard F, Gilbert B, Compère P, Eppe G, Lepoint G (2015) When microplastic is not plastic: the ingestion of artificial cellulose fibers by macrofauna living in seagrass macrophytodetritus. Environ Sci Technol 49:11158–11166. https://doi.org/10.1021/acs.est.5b02005
37. Carreras-Colom E, Constenla M, Soler-Membrives A, Cartes JE, Baeza M, Padrós F, Carrassón M (2018) Spatial occurrence and effects of microplastic ingestion on the deep-water shrimp *Aristeus antennatus*. Mar Pollut Bull 133:44–52. https://doi.org/10.1016/j.marpolbul.2018.05.012
38. Cristo M, Cartes JE (1998) A comparative study of the feeding ecology of *Nephrops norvegicus* (L.), (Decapoda: Nephropidae) in the bathyal Mediterranean and adjacent Atlantic. Sci Mar 62:81–90. https://doi.org/10.3989/scimar.1998.62s181
39. Bordbar L, Kapiris K, Kalogirou S, Anastasopoulou A (2018) First evidence of ingested plastics by a high commercial shrimp species (*Plesionika narval*) in the eastern Mediterranean. Mar Pollut Bull 136:472–476. https://doi.org/10.1016/j.marpolbul.2018.09.030
40. Güven O, Gökdağ K, Jovanović B, Kıdeyş AE (2017) Microplastic litter composition of the Turkish territorial waters of the Mediterranean Sea, and its occurrence in the gastrointestinal tract of fish. Environ Pollut 223:286–294. https://doi.org/10.1016/j.envpol.2017.01.025
41. Rios-Fuster B, Alomar C, Compa M, Guijarro B, Deudero S (2019) Anthropogenic particles ingestion in fish species from two areas of the western Mediterranean Sea. Mar Pollut Bull 144:325–333. https://doi.org/10.1016/j.marpolbul.2019.04.064
42. Nadal MA, Alomar C, Deudero S (2016) High levels of microplastic ingestion by the semipelagic fish Bogue *Boops boops* (L.) around the Balearic Islands. Environ Pollut 214:517–523. https://doi.org/10.1016/j.envpol.2016.04.054

43. Cartes JE, Soler-Membrives A, Stefanescu C, Lombarte A, Carrassón M (2016) Contributions of allochthonous inputs of food to the diets of benthopelagic fish over the Northwest Mediterranean slope (to 2300 m). Deep-Sea Res I Oceanogr Res Pap 109:123–136. https://doi.org/10.1016/j.dsr.2015.11.001
44. Avio CG, Gorbi S, Regoli F (2015) Experimental development of a new protocol for extraction and characterization of microplastics in fish tissues: first observations in commercial species from Adriatic Sea. Mar Environ Res 111:18–26. https://doi.org/10.1016/j.marenvres.2015.06.014
45. Anastasopoulou A, Kova M, Bojani D, Digka N, Fortibuoni T, Koren Š, Mandi M, Mytilineou C, Pe A, Ronchi F, Jasna Š, Torre M, Tsangaris C, Tutman P (2018) Assessment on marine litter ingested by fish in the Adriatic and NE Ionian Sea macro-region (Mediterranean). Mar Pollut Bull 133:841–851. https://doi.org/10.1016/j.marpolbul.2018.06.050
46. Massutí E, Deudero S, Sánchez P, Morales-Nin B (1998) Diet and feeding of dolphin (*Coryphaena hippurus*) in Western Mediterranean waters. Bull Mar Sci 63:329–341
47. Romeo T, Pedà C, Battaglia P, Fossi MC, Andaloro F (2016) First record of plastic debris in the stomach of Mediterranean lanternfishes. Acta Adriat 57:115–124
48. Renzi M, Specchiulli A, Blašković A, Manzo C, Mancinelli G, Cilenti L (2019) Marine litter in stomach content of small pelagic fishes from the Adriatic Sea: sardines (*Sardina pilchardus*) and anchovies (*Engraulis encrasicolus*). Environ Sci Pollut Res 26:2771–2781. https://doi.org/10.1007/s11356-018-3762-8
49. Collard F, Gilbert B, Eppe G, Parmentier E, Das K (2015) Detection of anthropogenic particles in fish stomachs: an isolation method adapted to identification by Raman spectroscopy. Arch Environ Contam Toxicol 69:331–339. https://doi.org/10.1007/s00244-015-0221-0
50. Bottari T, Savoca S, Mancuso M, Capillo G, Panarello G, Bonsignore M, Crupi R, Sanfilippo M, D'Urso L, Compagnini G, Neri F, Romeo T, Luna GM, Spanò N, Fazio E (2019) Plastics occurrence in the gastrointestinal tract of *Zeus faber* and *Lepidopus caudatus* from the Tyrrhenian Sea. Mar Pollut Bull 146:408–416. https://doi.org/10.1016/j.marpolbul.2019.07.003
51. Giani D, Baini M, Galli M, Casini S, Fossi MC (2019) Microplastics occurrence in edible fish species (*Mullus barbatus* and *Merluccius merluccius*) collected in three different geographical sub-areas of the Mediterranean Sea. Mar Pollut Bull 140:129–137. https://doi.org/10.1016/j.marpolbul.2019.01.005
52. Mancuso M, Savoca S, Bottari T (2019) First record of microplastics ingestion by European hake (*Merluccius merluccius*) from the Tyrrhenian Sicilian coast (Central Mediterranean Sea). J Fish Biol 94:517–519. https://doi.org/10.1111/jfb.13920
53. Bellas J, Martínez-Armental J, Martínez-Cámara A, Besada V, Martínez-Gómez C (2016) Ingestion of microplastics by demersal fish from the Spanish Atlantic and Mediterranean coasts. Mar Pollut Bull 109:55–60. https://doi.org/10.1016/j.marpolbul.2016.06.026
54. Piccardo M, Felline S, Terlizzi A (2018) Preliminary assessment of microplastic accumulation in wild Mediterranean species. In: Cocca M et al (eds) Proceedings of the international conference on microplastic pollution in the Mediterranean Sea. Springer, Cham, pp 115–120. https://doi.org/10.1007/978-3-319-71279-6_16
55. Alomar C, Deudero S (2017) Evidence of microplastic ingestion in the shark *Galeus melastomus* Rafinesque, 1810 in the continental shelf off the western Mediterranean Sea. Environ Pollut 223:223–229. https://doi.org/10.1016/j.envpol.2017.01.015
56. Collignon A, Hecq J-H, Galgani F, Voisin P, Collard F, Goffart A (2012) Neustonic microplastic and zooplankton in the North Western Mediterranean Sea. Mar Pollut Bull 64:861–864. https://doi.org/10.1016/j.marpolbul.2012.01.011
57. Romeu OR, Cartes JE, Solé M, Carrassón M (2016) To what extent can specialized species succeed in the deep sea? The biology and trophic ecology of deep-sea spiny eels (Notacanthidae) in the Mediterranean Sea. Deep-Sea Res I Oceanogr Res Pap 115:74–90. https://doi.org/10.1016/j.dsr.2016.05.006

58. Anastasopoulou A, Mytilineou C, Smith CJ, Papadopoulou KN (2013) Plastic debris ingested by deep-water fish of the Ionian Sea (Eastern Mediterranean). Deep-Sea Res I Oceanogr Res Pap 74:11–13
59. Savoca S, Capillo G, Mancuso M, Bottari T, Crupi R, Branca C, Romano V, Faggio C, D'Angelo G, Spanò N (2019) Microplastics occurrence in the tyrrhenian waters and in the gastrointestinal tract of two congener species of seabreams. Environ Toxicol Pharmacol 67:35–41. https://doi.org/10.1016/j.etap.2019.01.011
60. Compa M, Ventero A, Iglesias M, Deudero S (2018) Ingestion of microplastics and natural fibres in *Sardina pilchardus* (Walbaum, 1792) and *Engraulis encrasicolus* (Linnaeus, 1758) along the Spanish Mediterranean coast. Mar Pollut Bull 128:89–96. https://doi.org/10.1016/j.marpolbul.2018.01.009
61. van der Hal N, Yeruham E, Angel DL (2018) Dynamics in microplastic ingestion during the past six decades in herbivorous fish on the Mediterranean Israeli coast. In: Cocca M et al (eds) Proceedings of the international conference on microplastic pollution in the Mediterranean Sea. Springer, Cham. https://doi.org/10.1007/978-3-319-71279-6_21
62. Pellini G, Gomiero A, Fortibuoni T, Ferrà C, Grati F, Tassetti AN, Polidori P, Fabi G, Scarcella G (2018) Characterization of microplastic litter in the gastrointestinal tract of *Solea solea* from the Adriatic Sea. Environ Pollut 234:943–952. https://doi.org/10.1016/j.envpol.2017.12.038
63. Romeo T, Battaglia P, Pedà C, Consoli P, Andaloro F, Fossi MC (2015) First evidence of presence of plastic debris in stomach of large pelagic fish in the Mediterranean Sea. Mar Pollut Bull 95:358–361. https://doi.org/10.1016/j.marpolbul.2015.04.048
64. Battaglia P, Pedà C, Musolino S, Esposito V, Andaloro F, Romeo T (2016) Diet and first documented data on plastic ingestion of Trachinotus ovatus L. 1758 (Pisces: Carangidae) from the strait of Messina (Central Mediterranean Sea). Ital J Zool 83:121–129. https://doi.org/10.1080/11250003.2015.1114157
65. Carrassón M, Stefanescu C, Cartes JE (1992) Diets and bathymetric distributions of two bathyal sharks of the Catalan deep sea (Western Mediterranean). Mar Ecol Prog Ser 82:21–30
66. Valente T, Sbrana A, Scacco U, Jacomini C, Bianchi J, Palazzo L, de Lucia GA, Silvestri C, Matiddi M (2019) Exploring microplastic ingestion by three deep-water elasmobranch species: a case study from the Tyrrhenian Sea. Environ Pollut 253:342–350. https://doi.org/10.1016/j.envpol.2019.07.001
67. Bernardini I, Garibaldi F, Canesi L, Fossi MC, Baini M (2018) First data on plastic ingestion by blue sharks (*Prionace glauca*) from the Ligurian Sea (North-Western Mediterranean Sea). Mar Pollut Bull 135:303–310. https://doi.org/10.1016/j.marpolbul.2018.07.022
68. Alexiadou P, Foskolos I, Frantzis A (2019) Ingestion of macroplastics by odontocetes of the Greek Seas, Eastern Mediterranean: often deadly! Mar Pollut Bull 146:67–75. https://doi.org/10.1016/j.marpolbul.2019.05.055
69. Shoham-Frider E, Amiel S, Roditi-Elasar M, Kress N (2002) Risso's dolphin (*Grampus griseus*) stranding on the coast of Israel (eastern Mediterranean). Autopsy results and trace metal concentrations. Sci Total Environ 295:157–166. https://doi.org/10.1016/S0048-9697(02)00089-X
70. De Stephanis R, Giménez J, Carpinelli E, Gutierrez-Exposito C, Cañadas A (2013) As main meal for sperm whales: plastics debris. Mar Pollut Bull 69:206–214. https://doi.org/10.1016/j.marpolbul.2013.01.033
71. Panti C, Baini M, Lusher A, Hernandez-Milan G, Bravo Rebolledo EL, Unger B, Syberg K, Simmonds MP, Fossi MC (2019) Marine litter: one of the major threats for marine mammals. Outcomes from the European Cetacean Society workshop. Environ Pollut 247:72–79. https://doi.org/10.1016/j.envpol.2019.01.029
72. Mazzariol S, di Guardo G, Petrella A, Marsili L, Fossi CM, Leonzio C, Zizzo N, Vizzini S, Gaspari S, Pavan G, Podestà M, Garibaldi F, Ferrante M, Copat C, Traversa D, Marcer F, Airoldi S, Frantzis A, de Beraldo Quirós Y, Cozzi B, Fernández A (2011) Sometimes sperm whales (*Physeter macrocephalus*) cannot find their way back to the high seas: a multidisciplinary study on a mass stranding. PLoS One 6:e19417. https://doi.org/10.1371/journal.pone.0019417

73. Poppi L, Zaccaroni A, Pasotto D, Dotto G, Marcer F, Scaravelli D, Mazzariol S (2012) Post-mortem investigations on a leatherback turtle *Dermochelys coriacea* stranded along the northern Adriatic coastline. Dis Aquat Org 100:71–76. https://doi.org/10.3354/dao02479
74. Viale D, Verneau N, Tison Y (1992) Stomach obstruction in a sperm whale beached on the Lavezzi islands: macropollution in the Mediterranean. J Rech Oceanogr 16:100–102
75. Pribanic S, Holcer D, Miokovic D (1998) First report of plastic ingestion by striped dolphin (Stenella coeruleoalba) in the Croatian part of the Adriatic Sea. Eur Res Cetac 13:443–446
76. Levy AM, Brenner O, Scheinin A, Morick D, Ratner E, Goffman O, Kerem D (2009) Laryngeal snaring by ingested fishing net in a common bottlenose dolphin (*Tursiops truncatus*) off the Israeli shoreline. J Wildl Dis 45:834–838. https://doi.org/10.7589/0090-3558-45.3.834
77. Gomerčić MD, Galov A, Gomerčić T, Škrtić D, Ćurković S, Lucić H, Vuković S, Arbanasić H, Gomerčić H (2009) Bottlenose dolphin (*Tursiops truncatus*) depredation resulting in larynx strangulation with gill-net parts. Mar Mamm Sci 25:392–401. https://doi.org/10.1111/j.1748-7692.2008.00259.x
78. Milani CB, Vella A, Vidoris P, Christidis A, Koutrakis E, Frantzis A, Miliou A, Kallianiotis A (2018) Cetacean stranding and diet analyses in the North Aegean Sea (Greece). J Mar Biol Assoc UK 98:1011–1028. https://doi.org/10.1017/S0025315417000339
79. Gomerčić H, Duras Gomerčić M, Gomerčić T, Lucić H, Dalebout M, Galov A, Škrtić D, Ćurković S, Vuković S, Huber D (2006) Biological aspects of Cuvier's beaked whale (*Ziphius cavirostris*) recorded in the Croatian part of the Adriatic Sea. Eur J Wildl Res 52:182–187. https://doi.org/10.1007/s10344-006-0032-8
80. Lazar B, Gračan R (2011) Ingestion of marine debris by loggerhead sea turtles, *Caretta caretta*, in the Adriatic Sea. Mar Pollut Bull 62:43–47. https://doi.org/10.1016/j.marpolbul.2010.09.013
81. Campani T, Baini M, Giannetti M, Cancelli F, Mancusi C, Serena F, Marsili L, Casini S, Fossi MC (2013) Presence of plastic debris in loggerhead turtle stranded along the Tuscany coasts of the Pelagos Sanctuary for Mediterranean Marine Mammals (Italy). Mar Pollut Bull 74:225–230. https://doi.org/10.1016/j.marpolbul.2013.06.053
82. Gramentz D (1988) Involvement of loggerhead turtle with the plastic, metal, and hydrocarbon pollution in the Central Mediterranean. Mar Pollut Bull 19:11–13. https://doi.org/10.1016/0025-326X(88)90746-1
83. Tomás J, Guitart R, Mateo R, Raga J (2002) Marine debris ingestion in loggerhead sea turtles, *Caretta caretta*, from the Western Mediterranean. Mar Pollut Bull 44:211–216. https://doi.org/10.1016/S0025-326X(01)00236-3
84. Russo G, di Bella C, Insacco G, Palazzo P, Violani C, Zava B (2003) Notes on the influence of human activities on sea chelonians in Sicilian waters. J Mt Ecol 7:37–41
85. Revelles M, Cardona L, Aguilar A, Fernández G (2007) The diet of pelagic loggerhead sea turtles (*Caretta caretta*) off the Balearic archipelago (western Mediterranean): relevance of long-line baits. J Mar Biol Assoc UK 87:805–813. https://doi.org/10.1017/S0025315407054707
86. Casale P, Freggi D, Paduano V, Oliverio M (2016) Biases and best approaches for assessing debris ingestion in sea turtles, with a case study in the Mediterranean. Mar Pollut Bull 110:238–249. https://doi.org/10.1016/j.marpolbul.2016.06.057.
87. Camedda A, Marra S, Matiddi M, Massaro G, Coppa S, Perilli A, Ruiu A, Briguglio P, de Lucia GA (2014) Interaction between loggerhead sea turtles (*Caretta caretta*) and marine litter in Sardinia (Western Mediterranean Sea). Mar Environ Res 100:25–32. https://doi.org/10.1016/j.marenvres.2013.12.004
88. Mecozzi M, Pietroletti M, Monakhova YB (2016) FTIR spectroscopy supported by statistical techniques for the structural characterization of plastic debris in the marine environment: application to monitoring studies. Mar Pollut Bull 106:155–161. https://doi.org/10.1016/j.marpolbul.2016.03.012
89. Matiddi M, Hochsheid S, Camedda A, Baini M, Cocumelli C, Serena F, Tomassetti P, Travaglini A, Marra S, Campani T, Scholl F, Mancusi C, Amato E, Briguglio P, Maffucci F, Fossi MC, Bentivegna F, de Lucia GA (2017) Loggerhead Sea turtles (*Caretta caretta*): a target

species for monitoring litter ingested by marine organisms in the Mediterranean Sea. Environ Pollut 230:199–209. https://doi.org/10.1016/j.envpol.2017.06.054

90. Sönmez B (2018) Sixteen year (2002–2017) record of sea turtle strandings on Samandağ Beach, the Eastern Mediterranean coast of Turkey Bektaş Sönmez. Zool Stud 57:53. https://doi.org/10.6620/ZS.2018.57-53
91. Domènech F, Aznar FJ, Raga JA, Tomás J (2019) Two decades of monitoring in marine debris ingestion in loggerhead sea turtle, *Caretta caretta*, from the western Mediterranean. Environ Pollut 244:367–378. https://doi.org/10.1016/j.envpol.2018.10.047
92. Casale P, Abbate G, Freggi D, Conte N, Oliverio M, Argano R (2008) Foraging ecology of loggerhead sea turtles *Caretta caretta* in the Central Mediterranean Sea: evidence for a relaxed life history model. Mar Ecol Prog Ser 372:265–276. https://doi.org/10.3354/meps07702
93. Blasi MF, Mattei D (2017) Seasonal encounter rate, life stages and main threats to the loggerhead sea turtle (*Caretta caretta*) in the Aeolian Archipelago (southern Tyrrhenian Sea). Aquat Conserv Mar Freshwat Ecosyst 27:617–630. https://doi.org/10.1002/aqc.2723
94. Blasi MF, Roscioni F, Mattei D (2016) Interaction of loggerhead turtles (*Caretta caretta*) with traditional fish aggregating devices (FADs) in the Mediterranean Sea. Herpetol Conserv Biol 11:386–401
95. Duncan EM, Broderick AC, Fuller WJ, Galloway TS, Godfrey MH, Hamann M, Limpus CJ, Lindeque PK, Mayes AG, Omeyer LCM, Santillo D, Snape RTE, Godley B (2019) Microplastic ingestion ubiquitous in marine turtles. Glob Change Biol 25(2):744–752. https://doi.org/10.1111/gcb.14519
96. Duncan EM, Arrowsmith JA, Bain CE, Bowdery H, Broderick AC, Chalmers T, Fuller WJ, Galloway TS, Lee JH, Lindeque PK, Omeyer LCM, Snape RTE, Godley BJ (2019) Diet-related selectivity of macroplastic ingestion in green turtles (*Chelonia mydas*) in the eastern Mediterranean. Sci Rep 9:11581. https://doi.org/10.1038/s41598-019-48086-4
97. Katsanevakis S (2008) Marine debris, a growing problem: sources, distribution, composition, and impacts. In: Hofer TN (ed) Marine pollution: new research. Nova Science, New York, pp 53–100
98. Codina-García M, Militão T, Moreno J, González-Solís J (2013) Plastic debris in Mediterranean seabirds. Mar Pollut Bull 77:220–226. https://doi.org/10.1016/j.marpolbul.2013.10.002
99. Steen R, Torjussen CS, Jones DW, Tsimpidis T, Miliou A (2016) Plastic mistaken for prey by a colony-breeding Eleonora's falcon (*Falco eleonorae*) in the Mediterranean Sea, revealed by camera-trap. Mar Pollut Bull 106:200–201. https://doi.org/10.1016/j.marpolbul.2016.02.069
100. Aliani S, Molcard A (2003) Hitch-hiking on floating marine debris: macrobenthic species in the Western Mediterranean Sea. Hydrobiologia 503:59–63
101. Masó M, Fortuño JM, de Juan S, Demestre M (2016) Microfouling communities from pelagic and benthic marine plastic debris sampled across Mediterranean coastal waters. Sci Mar 80:117–127. https://doi.org/10.3989/scimar.04281.10A
102. Fortuño J, Masó M, Sáez R, de Juan S, Demestre M (2010) SEM microphotographs of biofouling organisms on floating and benthic plastic debris. In: Proceedings of CIESM congress, Venice, 10–14 May 2010, pp 7947
103. Masó M, Garcés E, Pagès F, Camp J (2003) Drifting plastic debris as a potential vector for dispersing Harmful Algal Bloom (HAB) species. Sci Mar 67:107–111. https://doi.org/10.3989/scimar.2003.67n1107
104. Battaglia P, Consoli P, Ammendolia G, D'Alessandro M, Bo M, Vicchio TM, Pedà C, Cavallaro M, Andaloro F, Romeo T (2019) Colonization of floats from submerged derelict fishing gears by four protected species of deep-sea corals and barnacles in the strait of Messina (Central Mediterranean Sea). Mar Pollut Bull 148:61–65. https://doi.org/10.1016/j.marpolbul.2019.07.073
105. Jorissen FJ (2014) Colonization by the benthic foraminifer Rosalina (Tretomphalus) concinna of Mediterranean drifting plastics. In: CIESM workshop monographs, pp 18–21

106. Viršek MK, Lovšin MN, Koren Š, Kržan A, Peterlin M (2017) Microplastics as a vector for the transport of the bacterial fish pathogen species *Aeromonas salmonicida*. Mar Pollut Bull 125:301–309. https://doi.org/10.1016/j.marpolbul.2017.08.024
107. Dussud C, Meistertzheim AL, Conan P, Pujo-Pay M, George M, Fabre P, Coudane J, Higgs P, Elineau A, Pedrotti ML, Gorsky G, Ghiglione JF (2018) Evidence of niche partitioning among bacteria living on plastics, organic particles and surrounding seawaters. Environ Pollut 236:807–816. https://doi.org/10.1016/j.envpol.2017.12.027
108. Ioakeimidis C, Papatheodorou G, Fermeli G, Streftaris N, Papathanassiou E (2015) Use of ROV for assessing marine litter on the seafloor of Saronikos Gulf (Greece): a way to fill data gaps and deliver environmental education. Springerplus 4(1):1–9. https://doi.org/10.1186/s40064-015-1248-4
109. Cau A, Alvito A, Moccia D, Canese S, Pusceddu A, Rita C, Angiolillo M, Follesa MC (2017) Submarine canyons along the upper Sardinian slope (Central Western Mediterranean) as repositories for derelict fishing gears. Mar Pollut Bull 123:357–364. https://doi.org/10.1016/j.marpolbul.2017.09.010
110. Consoli P, Romeo T, Angiolillo M, Canese S, Esposito V, Salvati E, Scotti G, Andaloro F, Tunesi L (2019) Marine litter from fishery activities in the Western Mediterranean Sea: the impact of entanglement on marine animal forests. Environ Pollut 249:472–481. https://doi.org/10.1016/j.envpol.2019.03.072
111. Gündoğdu S, Çevik C, Karaca S (2017) Fouling assemblage of benthic plastic debris collected from Mersin Bay, NE Levantine coast of Turkey. Mar Pollut Bull 124:147–154. https://doi.org/10.1016/j.marpolbul.2017.07.023.
112. Lastras G, Canals M, Ballesteros E, Gili J-M, Sanchez-Vidal A (2016) Cold-water corals and anthropogenic impacts in La Fonera submarine canyon head, northwestern Mediterranean Sea. PLoS One 11(5):e0155729. https://doi.org/10.1371/journal.pone.0155729
113. Frazier JG, Margaritoulis D (1990) The occurrence of the barnacle, *Chelonibia patula* (Ranzani, 1818), on an inanimate substratum (Cirripedia, Thoracica). Crustaceana 59 (2):213–218
114. Ayaz A, Ünal V, Acarli D, Altinagac U (2010) Fishing gear losses in the Gökova Special Environmental Protection Area (SEPA), eastern Mediterranean, Turkey. J Appl Ichthyol 26:416–419. https://doi.org/10.1111/j.1439-0426.2009.01386.x
115. Consoli P, Andaloro F, Altobelli C, Battaglia P, Campagnuolo S, Canese S, Castriota L, Cillari T, Falautano M, Pedà C, Perzia P, Sinopoli M, Vivona P, Scotti G, Esposito V, Galgani F, Romeo T (2018) Marine litter in an EBSA (Ecologically or Biologically Significant Area) of the Central Mediterranean Sea: abundance, composition, impact on benthic species and basis for monitoring entanglement. Environ Pollut 236:405–415. https://doi.org/10.1016/j.envpol.2018.01.097
116. Angiolillo M, di Lorenzo B, Farcomeni A, Bo M, Bavestrello G, Santangelo G, Cau A, Mastascusa V, Cau A, Sacco F, Canese S (2015) Distribution and assessment of marine debris in the deep Tyrrhenian Sea (NW Mediterranean Sea, Italy). Mar Pollut Bull 92:149–159. https://doi.org/10.1016/j.marpolbul.2014.12.044
117. Bo M, Bava S, Canese S, Angiolillo M, Cattaneo-Vietti R, Bavestrello G (2014) Fishing impact on deep Mediterranean rocky habitats as revealed by ROV investigation. Biol Conserv 171:167–176. https://doi.org/10.1016/j.biocon.2014.01.011
118. Bo M, Canese S, Spaggiari C, Pusceddu A, Bertolino M, Angiolillo M, Giusti M, Loreto MF, Salvati E, Greco S, Bavestrello G (2012) Deep coral oases in the South Tyrrhenian Sea. PLoS One 7(11):e49870. https://doi.org/10.1371/journal.pone.0049870
119. Bo M, Cerrano C, Canese S, Salvati E, Angiolillo M, Santangelo G, Bavestrello G (2014) The coral assemblages of an off-shore deep Mediterranean rocky bank (NW Sicily, Italy). Mar Ecol 35:332–342. https://doi.org/10.1111/maec.12089
120. Fabri MC, Pedel L, Beuck L, Galgani F, Hebbeln D, Freiwald A (2014) Megafauna of vulnerable marine ecosystems in French Mediterranean submarine canyons: spatial distribution and anthropogenic impacts. Deep-Sea Res PT II 104:184–207. https://doi.org/10.1016/j.dsr2.2013.06.016

121. Orejas C, Gori A, Jiménez C, Rivera J, Kamidis N, Abu Alhaija R, Iacono C (2019) Occurrence and distribution of the coral *Dendrophyllia ramea* in Cyprus insular shelf: environmental setting and anthropogenic impacts. Deep-Sea Res PT II 164:190–205. https://doi.org/10.1016/j.dsr2.2019.04.006
122. Taviani M, Angeletti L, Canese S, Cannas R, Cardone F, Cau AB, Cau AB, Follesa MC, Marchese F, Montagna P, Tessarolo C (2017) The "Sardinian cold-water coral province" in the context of the Mediterranean coral ecosystems. Deep Sea Res Part II Top Stud Oceanogr 145:61–78. https://doi.org/10.1016/j.dsr2.2015.12.008.
123. D'Onghia G, Calculli C, Capezzuto F, Carlucci R, Carluccio A, Grehan A, Indennidate A, Maiorano P, Mastrototaro F, Pollice A, Russo T, Savini A, Sion L, Tursi A (2017) Anthropogenic impact in the Santa Maria di Leuca cold-water coral province (Mediterranean Sea): observations and conservation straits. Deep-Sea Res PT II 145:87–101. https://doi.org/10.1016/j.dsr2.2016.02.012
124. Bo M, Canese S, Bavestrello G (2014) Discovering Mediterranean black coral forests: *Parantipathes larix* (Anthozoa: Hexacorallia) in the Tuscan Archipelago, Italy. Ital J Zool 81(1):112–125. https://doi.org/10.1080/11250003.2013.859750
125. Cánovas-Molina A, Montefalcone M, Bavestrello G, Cau A, Bianchi C, Morri N, Canese S, Bo M (2016) A new ecological index for the status of mesophotic megabenthic assemblages in the Mediterranean based on ROV photography and video footage. Cont Shelf Res 121:13–20. https://doi.org/10.1016/j.csr.2016.01.008
126. Deidun A, Andaloro F, Bavestrello G, Canese S, Consoli P, Micallef A, Romeo T, Bo M (2014) First characterisation of a *Leiopathes glaberrima* (Cnidaria: Anthozoa: Antipatharia) forest in Maltese exploited fishing grounds. Ital J Zool 82(2):1–10. https://doi.org/10.1080/11250003.2014.986544
127. Freiwald A, Beuck L, Ruggeberg A, Taviani M, Hebbeln D (2009) The white coral community in the Central Mediterranean Sea revealed by ROV surveys. Oceanography 22:27. https://www.jstor.org/stable/24860923
128. Orejas C, Gori A, Lo Iacono C, Puig P, Pili JM, Dale MRT (2009) Cold-water corals in the Cap de Creus canyon, northwestern Mediterranean: spatial distribution, density and anthropogenic impact. Mar Ecol-Prog Ser 397:37–51. https://doi.org/10.3354/meps08314
129. Fine M, Zibrowius H, Loya Y (2001) *Oculina patagonica*: a non-lessepsian scleractinian coral invading the Mediterranean Sea. Mar Biol 138(6):1195–1203. https://doi.org/10.1007/s002270100539
130. Bavestrello G, Cerrano C, Zanzi D, Cattaneo-Vietti R (1997) Damage by fishing activities to the Gorgonian coral *Paramuricea clavata* in the Ligurian Sea. Aquat Conserv Mar Freshwat Ecosyst 7:253–262. https://doi.org/10.1002/(SICI)1099-0755(199709)7:3<253::AID-AQC243>3.0.CO;2-1
131. Kipson S, Linares C, Čižmek H, Cebrián E, Ballesteros E, Bakran-Petricioli T, Garrabou J (2015) Population structure and conservation status of the red gorgonian *Paramuricea clavata* (Risso, 1826) in the Eastern Adriatic Sea. Mar Ecol 36(4):982–993. https://doi.org/10.1111/maec.12195
132. Pierdomenico M, Cardone F, Carluccio A, Casalbore D, Chiocci F, Maiorano P, D'Onghia G (2019) Megafauna distribution along active submarine canyons of the Central Mediterranean: relationships with environmental variables. Prog Oceanogr 171:49–69. https://doi.org/10.1016/j.pocean.2018.12.015
133. Melli V, Angiolillo M, Ronchi F, Canese S, Giovanardi O, Querin S, Fortibuoni T (2017) The first assessment of marine debris in a site of community importance in the North-Western Adriatic Sea (Mediterranean Sea). Mar Pollut Bull 114:821–830. https://doi.org/10.1016/j.marpolbul.2016.11.012
134. Angiolillo M (2019) Debris in deep water. In: Sheppard C (ed) World seas: an environmental evaluation. Elsevier, Amsterdam, pp 251–268. https://doi.org/10.1016/B978-0-12-805052-1.00015-2
135. Ramirez-Llodra E, de Mol B, Company JB, Coll M, Sardà F (2013) Effects of natural and anthropogenic processes in the distribution of marine litter in the deep Mediterranean Sea. Prog Oceanogr 118:273–287. https://doi.org/10.1016/j.pocean.2013.07.027

136. Cabezas MP, Navarro-Barranco C, Ros M, Guerra-García JM (2013) Long-distance dispersal, low connectivity and molecular evidence of a new cryptic species in the obligate rafter *Caprella andreae* Mayer, 1890 (Crustacea: Amphipoda: Caprellidae). Helgol Mar Res 67:483–497. https://doi.org/10.1007/s10152-012-0337-9
137. Holdway P, Maddock L (1983) A comparative survey of neuston: geographical and temporal distribution patterns. Mar Biol 76(3):263–270
138. Abello P, Guerao G, Codina M (2004) Distribution of the neustonic isopod *Idotea metallica* in relation to shelf-slope frontal structures. J Crustac Biol 24:558–566
139. Gutow L, Franke HD (2003) Metapopulation structure of the marine isopod *Idotea metallica*, a species associated with drifting habitat patches. Helgol Mar Res 56:259–264. https://doi.org/10.1007/s10152-002-0126-y
140. Southward AJ, Hiscock K, Kerckhof FO, Moyse JP, El AS (2004) Habitat and distribution of the warm-water barnacle, *Solidobalanus fallax* (Crustacea: Cirripedia). J Mar Biol Assoc UK 84:1169–1177. https://doi.org/10.1017/S0025315404010616h
141. Ramirez-Llodra E, Tyler PA, Baker MC, Bergstad OA, Clark MR, Escobar E, Levin LA, Menot L, Rowden AA, Smith CR, van Dover CL (2011) Man and the last great wilderness: human impact on the deep sea. PLoS One 6(7):e22588. https://doi.org/10.1371/journal.pone.0022588
142. Tutman P, Kapiris K, Kirinčić M, Pallaoro A (2017) Floating marine litter as a raft for drifting voyages for *Planes minutus* (Crustacea: Decapoda: Grapsidae) and *Liocarcinus navigator* (Crustacea: Decapoda: Polybiidae). Mar Pollut Bull 120:217–221. https://doi.org/10.1016/j.marpolbul.2017.04.063
143. Houard T, Boudouresque CF, Barcelo A, Cottalorda J, Formentin J, Jullian E, Kerlidou B, Pironneau E (2012) Occurrence of a lost fishing net within the marine area of the Port-Cros national park (Provence, northwestern Mediterranean Sea). Sci Rep Port-Cros Natl Park 118:109–118
144. Colmenero AI, Barría C, Broglio E, García-Barcelona S (2017) Plastic debris straps on threatened blue shark *Prionace glauca*. Mar Pollut Bull 115:436–438. https://doi.org/10.1016/j.marpolbul.2017.01.011
145. Butterworth A, Clegg I, Bass C (2012) Untangled. Marine debris: a global picture of the impact on animal welfare and of animal-focused solutions. World Society for the Protection of Animals, London
146. Morris RJ (1980) Floating plastic debris in the Mediterranean. Mar Pollut Bull 11:125. https://doi.org/10.1016/0025-326X(80)90073-9
147. Casale P, Affronte M, Insacco G, Freggi D, Vallini C, d'Astore PP, Basso R, Paolillo G, Abbate G, Argano R (2010) Sea turtle strandings reveal high anthropogenic mortality in Italian waters. Aquat Conserv Mar Freshwat Ecosyst 20:611–620. https://doi.org/10.1002/aqc.1133
148. Duncan EM, Botterell ZLR, Broderick AC, Galloway TS, Lindeque PK, Nuno A, Godley BJ (2017) A global review of marine turtle entanglement in anthropogenic debris: a baseline for further action. Endanger Species Res 34:431–448. https://doi.org/10.3354/esr00865
149. Özdilek Ş, Yalçın-Özdilek F, Ozaner S, Sönmez B (2006) Impact of accumulated beach litter on *Chelonia mydas* L. 1758 (green turtle) hatchlings of the Samandag coast, Hatay, Turkey. Fresenius Environ Bull 15:95–103
150. Battisti C, Kroha S, Kozhuharova E, De Michelis S, Fanelli G, Poeta G, Pietrelli L, Cerfolli F (2019) Fishing lines and fish hooks as neglected marine litter: first data on chemical composition, densities, and biological entrapment from a Mediterranean beach. Environ Sci Pollut Res 26:1000–1007. https://doi.org/10.1007/s11356-018-3753-9
151. Merlino S, Abbate M, Pietrelli L, Canepa P, Varella P (2018) Marine litter detection and correlation with the seabird nest content. Rend Lincei Sci Fis e Nat 29:867–875. https://doi.org/10.1007/s12210-018-0750-3
152. Galgani F, Hanke G, Werner S, De Vrees L (2013) Marine litter within the European marine strategy framework directive. ICES J Mar Sci 70:1055–1064. https://doi.org/10.1093/icesjms/fst122

153. Ryan PG, Moore CJ, Van Franeker JA, Moloney CL (2009) Monitoring the abundance of plastic debris in the marine environment. Philos Trans R Soc B Biol Sci 364:1999–2012. https://doi.org/10.1098/rstb.2008.0207
154. Lusher AL, Hollman PCH, Mendoza-Hill JJ (2017) Microplastics in fisheries and aquaculture: status of knowledge on their occurrence and implications for aquatic organisms and food safety. Food and Agriculture Organization of the United Nations, Rome
155. Moser ML, Lee DS (1992) A fourteen-year survey of plastic ingestion by Western North Atlantic Seabirds. Colon Waterbirds 15:83. https://doi.org/10.2307/1521357
156. Ory NC, Sobral P, Ferreira JL, Thiel M (2017) Amberstripe scad *Decapterus muroadsi* (Carangidae) fish ingest blue microplastics resembling their copepod prey along the coast of Rapa Nui (Easter Island) in the South Pacific subtropical gyre. Sci Total Environ 586:430–437. https://doi.org/10.1016/j.scitotenv.2017.01.175
157. McCord ME, Campana SE (2003) A quantitative assessment of the diet of the Blue Shark (*Prionace glauca*) off Nova Scotia, Canada. J Northwest Atl Fish Sci 32:57–63. https://doi.org/10.1080/01436597.2011.581058
158. Laist DW (1987) Overview of the biological effects of lost and discarded plastic debris in the marine environment. Mar Pollut Bull 18(6):319–326. https://doi.org/10.1016/S0025-326X(87)80019-X
159. Moss SA (1984) Sharks. Prentice-Hall, Englewood Cliffs
160. Eriksson C, Burton H (2003) Origins and biological accumulation of small plastic particles in fur seals from Macquarie Island. Ambio 32:380–384. https://doi.org/10.1579/0044-7447-32.6.380
161. Possatto FE, Barletta M, Costa MF, Ivar do Sul JA, Dantas DV (2011) Plastic debris ingestion by marine catfish: an unexpected fisheries impact. Mar Pollut Bull 62:1098–1102. https://doi.org/10.1016/j.marpolbul.2011.01.036.
162. Watts AJR, Urbina MA, Corr S, Lewis C, Galloway TS (2015) Ingestion of plastic microfibers by the crab *Carcinus maenas* and its effect on food consumption and energy balance. Environ Sci Technol 49:14597–14604. https://doi.org/10.1021/acs.est.5b04026
163. Carey MJ (2011) Intergenerational transfer of plastic debris by short-tailed shearwaters (*Ardenna tenuirostris*). Emu Austral Ornithol 111:229–234. https://doi.org/10.1071/MU10085
164. Rodríguez A, Rodríguez B, Nazaret Carrasco M (2012) High prevalence of parental delivery of plastic debris in Cory's shearwaters (*Calonectris diomedea*). Mar Pollut Bull 64:2219–2223. https://doi.org/10.1016/j.marpolbul.2012.06.011
165. Acampora H, Schuyler QA, Townsend KA, Hardesty BD (2014) Comparing plastic ingestion in juvenile and adult stranded short-tailed shearwaters (*Puffinus tenuirostris*) in eastern Australia. Mar Pollut Bull 78:63–68. https://doi.org/10.1016/j.marpolbul.2013.11.009
166. Law KL (2017) Plastics in the marine environment. Annu Rev Mar Sci 9:205–229. https://doi.org/10.1146/annurev-marine-010816-060409
167. Auta HS, Emenike CU, Fauziah SH (2017) Distribution and importance of microplastics in the marine environment a review of the sources, fate, effects, and potential solutions. Environ Int 102:165–176. https://doi.org/10.1016/j.envint.2017.02.013
168. Ryan PG (2016) Ingestion of plastics by marine organisms. In: Takada HKKH (ed) Hazardous chemicals associated with plastics in the marine environment. Springer, Cham
169. Teuten EL, Saquing JM, Knappe DRU, Barlaz MA, Jonsson S, Björn A, Rowland SJ, Thompson RC, Galloway TS, Yamashita R, Ochi D, Watanuki Y, Moore C, Viet PH, Tana TS, Prudente M, Boonyatumanond R, Zakaria MP, Akkhavong K, Ogata Y, Hirai H, Iwasa S, Mizukawa K, Hagino Y, Imamura A, Saha M, Takada H (2009) Transport and release of chemicals from plastics to the environment and to wildlife. Philos Trans R Soc B Biol Sci 364:2027–2045. https://doi.org/10.1098/rstb.2008.0284
170. Koelmans AA, Bakir A, Burton GA, Janssen CR (2016) Microplastic as a vector for chemicals in the aquatic environment: critical review and model-supported reinterpretation of empirical studies. Environ Sci Technol 50:3315–3326. https://doi.org/10.1021/acs.est.5b06069
171. van Franeker JA, Blaize C, Danielsen J, Fairclough K, Gollan J, Guse N, Hansen PL, Heubeck M, Jensen JK, Le Guillou G, Olsen B, Olsen KO, Pedersen J, Stienen EWM, Turner

DM (2011) Monitoring plastic ingestion by the northern fulmar *Fulmarus glacialis* in the North Sea. Environ Pollut 159:2609–2615. https://doi.org/10.1016/j.envpol.2011.06.008.

172. van Franeker JA, Law KL (2015) Seabirds, gyres and global trends in plastic pollution. Environ Pollut 203:89–96. https://doi.org/10.1016/j.envpol.2015.02.034
173. Zeri C, Adamopoulou A, Bojanić Varezić D, Fortibuoni T, Kovač Viršek M, Kržan A, Mandic M, Mazziotti C, Palatinus A, Peterlin M, Prvan M, Ronchi F, Siljic J, Tutman P, Vlachogianni T (2018) Floating plastics in Adriatic waters (Mediterranean Sea): from the macro- to the micro-scale. Mar Pollut Bull 136:341–350. https://doi.org/10.1016/j.marpolbul.2018.09.016
174. Lusher AL, O'Donnell C, Officer R, O'Connor I (2016) Microplastic interactions with North Atlantic mesopelagic fish. ICES J Mar Sci 73:1214–1225. https://doi.org/10.1093/icesjms/fsv241
175. Neves D, Sobral P, Ferreira JL, Pereira T (2015) Ingestion of microplastics by commercial fish off the Portuguese coast. Mar Pollut Bull 101:119–126. https://doi.org/10.1016/j.marpolbul.2015.11.008
176. Donnely-Greenan E, Hyrenbach D, Beck J, Fitzgerald S, Nevins H, Hester M (2018) First quantification of plastic ingestion by short-tailed albatross *Phoebastria albatrus*. Mar Ornithol 46:79–84
177. Denuncio P, Bastida R, Dassis M, Giardino G, Gerpe M, Rodríguez D (2011) Plastic ingestion in Franciscana dolphins, *Pontoporia blainvillei* (Gervais and d'Orbigny, 1844), from Argentina. Mar Pollut Bull 62:1836–1841. https://doi.org/10.1016/j.marpolbul.2011.05.003
178. Bessa F, Barr P, Neto JM, Frias PGL, Otero V, Sobral P, Marques JC (2018) Occurrence of microplastics in juvenile fish from an estuarine environment. Mar Pollut Bull 128:131–135. https://doi.org/10.1007/978-3-319-71279-6
179. Brongersma LD (1968) Notes upon some turtles from the Canary Islands and from Madeira. Proc K Ned Akad van Wet 71:128–136
180. Caldwell MC, Caldwell DK, Siebenaler JB (1965) Observations on captive and wild Atlantic bottlenosed dolphins, Tursiops truncatus, in the northeastern Gulf of Mexico. Contributions in science. Los Angeles City Museum, Los Angeles, pp 1–10
181. Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel – GEF (2012) Impacts of marine debris on biodiversity – current status and possible solutions. Technical Series No. 67
182. Carson HS (2013) The incidence of plastic ingestion by fishes: from the prey's perspective. Mar Pollut Bull 74:170–174. https://doi.org/10.1016/j.marpolbul.2013.07.008
183. van Cauwenberghe L, Janssen CR (2014) Microplastics in bivalves cultured for human consumption. Environ Pollut 193:65–70. https://doi.org/10.1016/j.envpol.2014.06.010
184. Catarino AI, Macchia V, Sanderson WG, Thompson RC, Henry TB (2018) Low levels of microplastics (MP) in wild mussels indicate that MP ingestion by humans is minimal compared to exposure via household fibres fallout during a meal. Environ Pollut 237:675–684. https://doi.org/10.1016/j.envpol.2018.02.069
185. Avio CG, Gorbi S, Milan M, Benedetti M, Fattorini D, D'Errico G, Pauletto M, Bargelloni L, Regoli F (2015) Pollutants bioavailability and toxicological risk from microplastics to marine mussels. Environ Pollut 198:211–222. https://doi.org/10.1016/j.envpol.2014.12.021
186. Alomar C, Sureda A, Capó X, Guijarro B, Tejada S, Deudero S (2017) Microplastic ingestion by *Mullus surmuletus* Linnaeus, 1758 fish and its potential for causing oxidative stress. Environ Res 159:135–142. https://doi.org/10.1016/j.envres.2017.07.043
187. Davison P, Asch RG (2011) Plastic ingestion by mesopelagic fishes in the North Pacific subtropical gyre. Mar Ecol Prog Ser 432:173–180. https://doi.org/10.3354/meps09142
188. Salman A (2004) The role of cephalopods in the diet of swordfish (*Xiphias gladius* Linnaeus, 1758) in the Aegean Sea (Eastern Mediterranean). Bull Mar Sci 74:21–29
189. Baulch S, Perry C (2014) Evaluating the impacts of marine debris on cetaceans. Mar Pollut Bull 80:210–221. https://doi.org/10.1016/j.marpolbul.2013.12.050
190. van Franeker JA, Bravo Rebolledo EL, Hesse E, Ijsseldijk LL, Kühn S, Leopold M, Mielke L (2018) Plastic ingestion by harbour porpoises *Phocoena phocoena* in the Netherlands:

establishing a standardised method. Ambio 47:387–397. https://doi.org/10.1007/s13280-017-1002-y
191. MSFD Technical Subgroup on Marine Litter (2013) Guidance on Monitoring of Marine Litter in European Seas. https://doi.org/10.2788/99475
192. Claro F, Fossi MC, Ioakeimidis C, Baini M, Lusher AL, Mc Fee W, McIntosh RR, Pelamatti T, Sorce M, Galgani F, Hardesty BD (2019) Tools and constraints in monitoring interactions between marine litter and megafauna: insights from case studies around the world. Mar Pollut Bull 141:147–160. https://doi.org/10.1016/j.marpolbul.2019.01.018
193. van der Hoop J, Moore M, Fahlman A, Bocconcelli A, George C, Jackson K, Miller C, Morin D, Pitchford T, Rowles T, Smith J, Zoodsma B (2014) Behavioral impacts of disentanglement of a right whale under sedation and the energetic cost of entanglement. Mar Mamm Sci 30:282–307. https://doi.org/10.1111/mms.12042
194. Allen R, Jarvis D, Sayer S, Mills C (2012) Entanglement of grey seals, *Halichoerus grypus*, at a haul out site in Cornwall, UK. Mar Pollut Bull 64:2815–2819
195. Matsuoka T, Nakashima T, Nagasawa N (2005) A review of ghost fishing: scientific approaches to evaluation and solutions. Fish Sci 71:691–702
196. Galgani F, Claro F, Depledge M, Fossi C (2014) Monitoring the impact of litter in large vertebrates in the Mediterranean Sea within the European Marine Strategy Framework Directive (MSFD): constraints, specificities and recommendations. Mar Environ Res 100:3–9. https://doi.org/10.1016/j.marenvres.2014.02.003
197. European Commission, Commission Decision (EU) 2017/848 (2017). http://eur-lex.europa.eu/pri/en/oj/dat/2003/l_285/l_28520031101en00330037.pdf
198. Triessnig P, Roetzer A, Stachowitsch M (2012) Beach condition and marine debris: new hurdles for sea turtle hatchling survival. Chelonian Conserv Biol 11:68–77. https://doi.org/10.2744/CCB-0899.1
199. Broderick AC, Glen F, Godley BJ, Hays GC (2002) Estimating the number of green and loggerhead turtles nesting annually in the Mediterranean. Oryx 36:227–235. https://doi.org/10.1017/S0030605302000431
200. Nelms SE, Duncan EM, Broderick AC, Galloway TS, Godfrey MH, Hamann M, Lindeque PK, Godley BJ (2016) Plastic and marine turtles: a review and call for research. ICES J Mar Sci 73:165–181. https://doi.org/10.1093/icesjms/fsv165
201. Karamanlidis AA, Androukaki E, Adamantopoulou S, Chatzispyrou A, Johnson WM, Kotomatas S, Papadopoulos A, Paravas V, Paximadis G, Pires R, Tounta E, Dendrinos P (2008) Assessing accidental entanglement as a threat to the Mediterranean monk seal *Monachus monachus*. Endanger Species Res 5:205–213. https://doi.org/10.3354/esr00092
202. Johnson WM, Karamanlidis AA (2000) When fishermen save seals. Monachus Guard 3:18–22
203. Pace DS, Miragliuolo A, Mussi B (2008) Behaviour of a social unit of sperm whales (*Physeter macrocephalus*) entangled in a driftnet off Capo Palinuro (Southern Tyrrhenian Sea, Italy). J Cetacean Res Manag 10:131–135. https://doi.org/10.1016/j.soilbio.2013.12.006
204. Frantzis A (2007) Fisheries interactions with cetacean species in Hellas. In: State of Hellenic fisheries. Hellenic Centre for Marine Research, Athens, pp 274–278
205. Peronace V, Cecere JG, Gustin M, Rondinini C (2012) Lista rossa 2011 degli uccelli nidificanti in Italia. Avocetta 36:11–58
206. Brown J, Macfadyen G, Huntington T, Magnus J, Tumilty J, Ghost Fishing by Lost Fishing Gear (2005) Final report to DG fisheries and maritime affairs of the European Commission. Fish/2004/20. Institute for European Environmental Policy/Poseidon Aquatic Resource Management Ltd joint report
207. Baeta F, Costa MJ, Cabral H (2009) Trammel nets' ghost fishing off the Portuguese central coast. Fish Res 98:33–39. https://doi.org/10.1016/j.fishres.2009.03.009
208. Ayaz A, Acarli D, Altinagac U, Ozekinci U, Kara A, Ozen O (2006) Ghost fishing by monofilament and multifilament gillnets in Izmir Bay, Turkey. Fish Res 79:267–271. https://doi.org/10.1016/j.fishres.2006.03.029.

209. Galgani F, Pham CK, Claro F, Consoli P (2018) Marine animal forests as useful indicators of entanglement by marine litter. Mar Pollut Bull 135:735–738. https://doi.org/10.1016/j.marpolbul.2018.08.004
210. Lamb JB, Willis BL, Fiorenza EA, Couch CS, Howard R, Rader DN, True JD, Kelly LA, Ahmad A, Jompa J, Harvell CD (2018) Plastic waste associated with disease on coral reefs. Science 80(359):460–462
211. Gregory MR (2009) Environmental implications of plastic debris in marine settings – entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philos Trans R Soc B Biol Sci 364:2013–2025. https://doi.org/10.1098/rstb.2008.0265
212. Zettler ER, Mincer TJ, Amaral-Zettler LA (2013) Life in the "plastisphere": microbial communities on plastic marine debris. Environ Sci Technol 47:7137–7146. https://doi.org/10.1021/es401288x
213. Thiel M, Gutow L (2004) Oceanography and marine biology. CRC Press, Boca Raton. https://doi.org/10.1201/9780203507810
214. Suaria G, Aliani S (2014) Floating debris in the Mediterranean Sea. Mar Pollut Bull 86:494–504. https://doi.org/10.1016/j.marpolbul.2014.06.025
215. Deideri J, Deideri M, Beyney MC, Rouger MH (2014) Dix ans de suivi des Fous de Bassan sur la Côte Bleue. Faune-PACA Publ 43:21
216. Stafford R, Jones PJS (2019) Viewpoint – ocean plastic pollution: a convenient but distracting truth? Mar Policy 103:187–191. https://doi.org/10.1016/j.marpol.2019.02.003
217. Wilcox C, van Sebille E, Hardesty BD (2015) Threat of plastic pollution to seabirds is global, pervasive, and increasing. Proc Natl Acad Sci 112:11899–11904. https://doi.org/10.1073/pnas.1502108112
218. Barboza LGA, Dick Vethaak A, Lavorante BRBO, Lundebye A-K, Guilhermino L (2018) Marine microplastic debris: an emerging issue for food security, food safety and human health. Mar Pollut Bull 133:336–348. https://doi.org/10.1016/j.marpolbul.2018.05.047
219. Burton GA (2017) Stressor exposures determine risk: so, why do fellow scientists continue to focus on superficial microplastics risk? Environ Sci Technol 51:13515–13516. https://doi.org/10.1021/acs.est.7b05463
220. Backhaus T, Wagner M (2019) Microplastics in the environment: much ado about nothing? A debate. Global Chall 6:1900022. https://doi.org/10.1002/gch2.201900022
221. Lusher A (2015) Microplastics in the marine environment: distribution, interactions and effects. In: Marine anthropogenic litter. Springer, Cham, pp 245–307. https://doi.org/10.1007/978-3-319-16510-3_10