The Handbook of Environmental Chemistry 54
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Aleksandar Joksimović · Mirko Djurović
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The Boka Kotorska Bay Environment

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The Handbook of Environmental Chemistry

Founded by Otto Hutzinger

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The Boka seems like a pile of big pearls that cannot be stolen as they are so large that they cannot be hidden

George Gordon Byron, English poet (1788–1824)

Our dear Boka, bride of the Adriatic, covered by the silk blue heaven, Prettier than the sea nymph of yours and brighter than her necklace.

Aleksa Šantić, Serb poet (1868–1924)

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Aims and Scope

Since 1980, *The Handbook of Environmental Chemistry* has provided sound and solid knowledge about environmental topics from a chemical perspective. Presenting a wide spectrum of viewpoints and approaches, the series now covers topics such as local and global changes of natural environment and climate; anthropogenic impact on the environment; water, air and soil pollution; remediation and waste characterization; environmental contaminants; biogeochemistry; geo-ecology; chemical reactions and processes; chemical and biological transformations as well as physical transport of chemicals in the environment; or environmental modeling. A particular focus of the series lies on methodological advances in environmental analytical chemistry.

Series Preface

With remarkable vision, Prof. Otto Hutzinger initiated *The Handbook of Environmental Chemistry* in 1980 and became the founding Editor-in-Chief. At that time, environmental chemistry was an emerging field, aiming at a complete description of the Earth's environment, encompassing the physical, chemical, biological, and geological transformations of chemical substances occurring on a local as well as a global scale. Environmental chemistry was intended to provide an account of the impact of man's activities on the natural environment by describing observed changes.

While a considerable amount of knowledge has been accumulated over the last three decades, as reflected in the more than 70 volumes of *The Handbook of Environmental Chemistry,* there are still many scientific and policy challenges ahead due to the complexity and interdisciplinary nature of the field. The series will therefore continue to provide compilations of current knowledge. Contributions are written by leading experts with practical experience in their fields. *The Handbook of Environmental Chemistry* grows with the increases in our scientific understanding, and provides a valuable source not only for scientists but also for environmental managers and decision-makers. Today, the series covers a broad range of environmental topics from a chemical perspective, including methodological advances in environmental analytical chemistry.

In recent years, there has been a growing tendency to include subject matter of societal relevance in the broad view of environmental chemistry. Topics include life cycle analysis, environmental management, sustainable development, and socio-economic, legal and even political problems, among others. While these topics are of great importance for the development and acceptance of *The Handbook of Environmental Chemistry,* the publisher and Editors-in-Chief have decided to keep the handbook essentially a source of information on "hard sciences" with a particular emphasis on chemistry, but also covering biology, geology, hydrology and engineering as applied to environmental sciences.

The volumes of the series are written at an advanced level, addressing the needs of both researchers and graduate students, as well as of people outside the field of "pure" chemistry, including those in industry, business, government, research establishments, and public interest groups. It would be very satisfying to see these volumes used as a basis for graduate courses in environmental chemistry. With its high standards of scientific quality and clarity, *The Handbook of Environmental Chemistry* provides a solid basis from which scientists can share their knowledge on the different aspects of environmental problems, presenting a wide spectrum of viewpoints and approaches.

The Handbook of Environmental Chemistry is available both in print and online via www.springerlink.com/content/110354/. Articles are published online as soon as they have been approved for publication. Authors, Volume Editors and Editors-in-Chief are rewarded by the broad acceptance of *The Handbook of Environmental Chemistry* by the scientific community, from whom suggestions for new topics to the Editors-in-Chief are always very welcome.

Damià Barceló
Andrey G. Kostianoy
Editors-in-Chief

Foreword

The area of scientific thinking mapped in this very useful publication contributes to the development of new directions in the environmental protection of the Boka Kotorska (the Bay of Kotor), one of the rarest natural beauties of both the Mediterranean and the European continent in general.

Besides the fact that it represents an important, even honourable, research occupation at a time of daily concerns over climate change, environmental protection in the process of natural resource management, and, particularly, over the ecology challenges of the rapid development of the state of Montenegro, this publication also testifies to current scientific understanding and dynamic research interest in the multifaceted and specific qualities of the Boka Kotorska.

The Institute for Marine Biology, in cooperation with scientists and researchers from the University of Montenegro, has been professionally and scientifically dedicated to the very heart of the Boka Kotorska for decades. In its noble mission, the Institute has continuously expanded its areas of cooperation and interest and has achieved good results not only within the Montenegrin scientific community but also amongst the leading scientific institutions of the world, and amongst scientists respected in international circles.

The establishment of a systematic, constructive, research-based and innovative approach and, at the same time, the provision of a certain guarantee of the sustainable development of the Boka Kotorska and Montenegro represent the goals towards which the Institute successfully strives, and the achievement of these aims is evident through this publication. This kind of effort is an important achievement for the State University (The University of Montenegro) and an example to the wider Montenegrin academic community.

The cultural value represented by the town of Kotor under the protection of UNESCO, as well as the picturesque mediaeval towns, the rich cultural and historical heritage of the Boka, and the archaeological remains dating back to even the second century AD, and the promotion of these value to tourists represent an additional responsibility and require us both to consider and be concerned about any endangering of that overall cultural value, as well as the sustainable enhancement of the cultural capital of Montenegro.

Facing the numerous and frequent challenges of tourism development brought about by global trends and given the effects of our ravenous consumer society, this book represents strongly recommended reading material for different levels of society. Its scientific and professional aspect is not undermined by the fact that it is a useful guide for raising awareness of eco-tourism, while this book also both inspires and instructs us when thinking about pragmatic approaches to initiating projects, and promoting so-called "green" and "blue" growth, whether in terms of business and various types of cultural production, or at universities and their research centres.

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Contents

Introduction

Aleksandar Joksimović, Mirko Đurović, Alexander V. Semenov, Igor S. Zonn, and Andrey G. Kostianoy

Abstract This book presents a systematisation and description of the knowledge on environment in the Boka Kotorska Bay in Montenegro (South Adriatic Sea). The publication is based on scientific and research data collected in complex research activities conducted in the Boka Kotorska Bay over the past 50 years, scientific papers mainly published in ex-Yugoslav and Montenegrin editions and long-standing experience of authors of the chapters in the scientific research in Montenegro. Particular attention was paid to activities on the coast of the Bay that have an impact on the status of flora and fauna in the Bay as well as on physico-chemical parameters of water, sediments and biota. Over the past decades, population migration issue has been particularly notable as well as development of tourist

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ship (cruise) transport, shipbuilding, development of mariculture, yachting tourism, natural effects from the land and runoff and evident climatic changes. This book is addressed to specialists working in various fields of environmental problems and ecology, water resources and management, land reclamation and agriculture and regional climate change in Montenegro and this part of the Mediterranean. The main task of this book is to provide scientific information on the status of environment in the Boka Kotorska Bay and give recommendations for the preservation of the living resources and healthy environment through sustainable development of this part of Montenegro.

Keywords Adriatic Sea, Boka Kotorska Bay, Environment, Montenegrin coast, Water resources

Content

The idea of this book was born in the framework of collaboration between Montenegrin and Russian scientists. In June 2014, scientists from S.Yu. Witte Moscow University, Engineering Research Production Center for Water Management, Land Reclamation and Ecology 'Soyuzvodproject' and P.P. Shirshov Institute of Oceanology of the Russian Academy of Sciences (Moscow, Russia) visited Montenegro and signed agreements on collaboration with the Montenegrin Academy of Sciences, University of Montenegro (Podgorica), and Institute of Marine Biology (Kotor). In September of the same year, the consortium of these organisations organised the First International Scientific Conference 'Integrated Coastal Zone Management in the Adriatic Sea', which was attended by about 30 scientists from Montenegro, Croatia, Serbia, Italy, Albania and Russia. The conference started with the welcoming speech given by Academician Momir Djurović, President of the Academy of Sciences and Arts of Montenegro. There were also read-out greetings to participants of the conference from Prof. Radmila Vojvodić, Rector of the University of Montenegro, and Academician Vladimir Fortov, President of the Russian Academy of Sciences. On behalf of the Committee on Education of the Russian State Duma, Prof. Viktor Shudegov welcomed the Conference. Participants of the Conference have proposed to prepare and publish two books: *The Adriatic Sea Encyclopedia* and *The Boka Kotorska Bay Environment*. The first one is under preparation; the second one was published by Springer and is presented to the reader.

The Boka Kotorska Bay has a specific position in the Adriatic Sea. This is a single fjord in Adriatic. Its geographical position is determined with the end points: to the north 42°31′00″, to the south 42°23′32″, to the east 18°46′32″ and to the west 18°30′29″. It consists of four interconnected smaller bays (the Herceg Novi and

Fig. 1 Boka Kotorska Bay, a view from Lovcen Mountain (Photo by A. Joksimović)

Tivat bays that form the outer part and the Risan and Kotor bays that form the inner part) and two straits, one of which connects the open sea with the Herceg Novi Bay and the other (Verige) connects the Tivat with the Risan and Kotor bays (Fig. 1) [1].

The aquatorium area is 87.334 km^2 (0.06% of the Adriatic Sea) of which 22.158 km^2 is the area of the Kotor–Risan Bay and 65.176 km^2 of the Herceg Novi–Tivat Bay. The coastline length is 105.7 km, of which 37.6 km belongs to the Kotor–Risan Bay and 68.1 km to the Herceg Novi–Tivat Bay. The mean depth in the Kotor Bay is 27 m (maximum 58 m), in the Risan Bay 25.7 m (maximum 36 m), in Tivat Bay 25.5 m (maximum 47 m) and in Herceg Novi Bay 31 m (maximum 60 m) [1, 2].

Large quantities of precipitation (Crkvice above Risan 5,480 mm per annum) and enormous inflow of terrestrial waters through two rivers – Škurda and Ljuta – as well as a large number of submerged springs (*vrulja*), have a major influence on hydrographic properties of the seawater in the Bay, particularly the Kotor–Risan Bay. Consequently, a significant decrease in temperature and salinity as well as in transparency of seawater takes place in the period of November–April.

The geographical position of the Bay is such that the sea is for the most part calm but its life is extraordinarily diverse and specific as a result of a large number of springs, submerged springs, brooks and rivulets flowing into it. These factors result in an intensive water mass dynamic, but only in the surface layer of up to about 5 m in depth, which is particularly notable in periods of maximum freshwater inflows (winter and spring, heavy rainfall periods). Rainy season begins in November and lasts until the end of April. Southern winds dominate this period, but in the period from January to March, north wind – Bora – blows occasionally. As a result of its enclosedness, and deep indentation into the land, large waves cannot be formed. Temperature, salinity and density of seawater are under significant influence of hydrometeorological parameters that are specific and susceptible to frequent local changes. Taking into account the structure and vertical stretch of the coastal area, it can be said that there is no coastal plain in the entire Kotor Bay (except for a small, narrow strip on its eastern side) and the Risan Bay, as steep rocky slopes descend to the very surface of the sea, and in these parts, the steep continental area spreads to the very bottom of the bays [3].

The specific geographical position and a combination of abiotic and biotic factors of the environment result in ecological conditions of the Boka Kotorska Bay significantly different from those in the open sea, making the Bay a specific biotope [3].

Fishing and activities related to the use of sea organisms in the diet of the local population in the Kotor–Risan Bay are traditional and date back to as early as the twelfth century. Protected and endangered species in the area of the Kotor–Risan Bay (aquatorium) are Magnoliophyta (*Posidonia oceanica*, *Zostera noltii*), Phaeophyta (*Cystoseira spinosa*), Porifera (*Geodia cydonium*) and Mollusca (*Lithophaga lithophaga*, *Luria lurida*, *Pinna nobilis*, *Tonna galea*). Due to the presence of rare and protected species of marine flora and fauna, particularly along the area from Dražin Vrt to Perast and around Perast Islands, this area should be placed under a special biodiversity protection regime. This implies prohibition of any intervention in the coastal zone, strict prohibition on building up beaches and anchoring of vessels at the depth of less than 30 m [4].

Taking into account the dominant influence of the Mediterranean climate in floristic and vegetation terms, the Boka Kotorska Bay is a diverse and specific area, not only in Montenegro, but far beyond in the eastern shore of the Adriatic Sea. The floristic specificities of this area are even more pronounced as a result of high mountains encircling the Boka Kotorska Bay. This causes vertical stratification of flora and vegetation elements from the sea level to the highest tops of the surrounding mountains.

The extraordinary universal value is a sublimate of cultural and natural values that goes beyond the national borders and is equally important for current and future generations of the entire humankind. The area of Kotor is located in impressive natural and cultural surroundings of the Boka Kotorska, which consists of four interconnected bays framed by high mountains and concentrated around the central visual axis that integrates these elements into an extraordinary landscape ensemble. According to the general principles of the Convention on the Protection of the World Heritage, the extraordinary universal value of the cultural and historical area of Kotor is represented by the quality of its architecture, successful blending of towns and settlements with the natural surroundings of the Bay and unique testimony of the role this area had in spreading of the Mediterranean culture on the Balkans. Quality of artisanal skills of the entire geo-cultural zone is also important, as a testimony of the unique expression created by a blend of eastern and western culture. The karst zone, distinct hydrography and extreme climatic changes from Mediterranean to Alpine in a very small area resulting from unique morphological

Fig. 2 Inner part from the Verige Strait: the Kotor–Risan Bay was included in the UNESCO's list of cultural and natural heritage of the humankind (*orange line*) [4, 5]

and morphogenetic characteristics of the area enabled the creation of numerous rare and unique species of flora and marine fauna, thus contributing to the Boka Kotorska Bay's inclusion in the group of the most beautiful bays of the world [4].

Due to all stated above, it is more than justified that the Boka Kotorska Bay (inner part from the Verige Strait: the Kotor–Risan Bay) was included in the UNESCO's list of cultural and natural heritage of the humankind [5] (Fig. 2) by the World Heritage Committee at the conference held on 22–26 October 1979, in Cairo and Luxor (Egypt), for the purpose of preservation and valuation of authentic geological, geomorphological, biological and cultural heritage.

The main characteristic that gives specific character to the area of Kotor is the vertical landscape profile (Fig. 1). Naturally steep slopes with a specific vertical structure influenced the development of a characteristic 'cross section' composed of the following zones:

- Settlements in the coastal zone grouped in a sequence and developed coast, system of jetties and mole-enclosed berths
- Arable land, terraced gardens in higher elevations
- Older settlements or primeval settlements in the higher zone, most of which have been abandoned
- Terraced gardens in higher elevations
- Slopes with forests or rocky landscape
- All zones connected by a network of old roads/trails

The system of jetties and mole-enclosed berths in Dobrota, Perast, Muo, Prčanj, Stoliv and other towns is characterised by unique coastal development manner, which is an element of particular importance in terms of the cultural landscape and a testimony of the way of living and dwelling culture in the coastal part of the protected area.

The characteristic landscaping form in areas in front of buildings of traditional architecture is arbour (*odrina*) with grapevine or glycine. In a historical environment, these arbours are almost always accompanied by stone-paved gardens, terraces with benches, stone wellheads, multileveled plateaus, trails with pergolas on pillars and other elements from the broad range of cultural heritage in terms of landscaping [4].

Settlements built on the shores of the Boka Kotorska Bay consist of three larger towns (Herceg Novi, Tivat and Kotor) and a number of smaller towns (Njivice, Igalo, Bijela, Kumbor, Zelenika, Meljine, Kamenari, Krašići, Lepetane, Opatovo, Bjelila, Risan, Kostanjica, Morinj, Lipci, Strp, Risan, Perast, Dražin Vrt, Orahovac, Ljuta, Dobrota, Muo, Prčanj, Stoliv) (Figs. 3, 4, 5, and 6). According to results of the census of the population, households and dwellings of 2011, the Boka Kotorska had a population of 67,496. Majority of the population is registered in the Municipality of Herceg Novi, 30,864; followed by the Municipality of Kotor, 22,601; and the Municipality of Tivat, 14,031 [6]. During tourist season, this number multiplies several times.

Tourism and other human activities on the shores of the Bay affect also the quality of the environment, water quality and air quality. Excessive and uncontrolled urbanisation, already recognised as a risk by the UNESCO mission, poses particular risk to the area of Kotor and it could jeopardise its universal value. On the other hand, controlled development results in changes that can develop further the World Heritage Sites [4].

One of the main causes of pollution of the Bay's waters is a still not fully resolved issue of sewage discharge into the sea where, as a result of slow water circulation, bacterial growths occur as well as eutrophication. The continuance or completion of investment works on activation of the Kotor–Tršte sewer system, where all waste water outlets from the Kotor–Risan Bay would be connected to, will eliminate the risk of sea pollution by waste waters (Fig. 7).

The same applies to the Adriatic Sea with an increasing anthropogenic effect originating from the development of tourism, agriculture, industry, sea traffic and port activities (Fig. 8).

The issue of eutrophication and pollution of the Adriatic Sea, particularly in its northern part, began receiving particular attention in the 1960s. As a result of its structure (extreme shallowness) and major influx of nutrients through the Po River, this part of the Adriatic Sea is often exposed to eutrophication. Eutrophication signs are increasingly frequent along the shores of Montenegro's coast, particularly in the Boka Kotorska Bay, and this process of anthropogenic eutrophication (sea enrichment by nutritive salts by human activities on the land) is at present generally one of the most frequent factors of pollution of the coastal sea. Consequences of anthropogenic eutrophication are increase in organic production, changes in composition

Fig. 3 View on Herceg Novi (Photo by A. Joksimović)

Fig. 4 View on Risan (Photo by A. Joksimović)

and relations among species in plankton and benthos, reduced transparency, change in sea colour, decreased oxygen levels in bottom layers along with increase in oxygen levels in depth as well as increasingly frequent phytoplankton blooming. The Boka Kotorska Bay is a very sensitive area from the aspect of anthropogenic eutrophication and its shallowest part – the Kotor Bay – is particularly endangered [7]. This issue needs to be properly addressed, and for those reasons, implementation of the sea monitoring programme began, which is implemented by the Institute of Marine Biology (Kotor, Montenegro) in cooperation with the Centre for

Fig. 5 View on Perast (Photo by A. Joksimović)

Fig. 6 View on Kotor (Photo by A. Joksimović)

Ecotoxicological Research for the Environmental Protection Agency (Podgorica, Montenegro) (Fig. 9). Furthermore, a project of drawing up the list of polluters in the Bay is underway, which would assist in systematic and lasting solution to the issues mentioned above.

The sea is one of the most important resources of the Earth, and it provides basis for the development of economic activities such as bathing and nautical tourism, shipping industry, shipbuilding, fishery and mariculture. Furthermore, it provides opportunities for economic activities that are currently not developed in

Fig. 7 Oil pollution in the Kotor Bay (Photo by A. Joksimović)

Fig. 8 Maritime transport – Kamenari–Lepetane ferry (Photo by A. Joksimovic)

Montenegro – biotechnology, exploitation of living and nonliving components of the marine environment for pharmaceutical purposes and exploitation of minerals, oil and gas, energy and others. Marine ecosystems provide a range of services (production, cultural and others) that are of great importance for economy and human welfare [4]. The total value of benefits from marine ecosystem services in the Mediterranean in 2005 was estimated to more than EUR 26 billion [4, 8].

Fig. 9 Monitoring of the seawater, researchers from the Institute of Marine Biology (Photo by A. Joksimović)

At the beginning of the last century, fishery was one of the important traditional economic branches in the Boka Kotorska Bay, evidence of which are records on small fish processing plants. Today, the Boka Kotorska Bay still disposes of some fish stocks; however, species of lower economic value make most of the catches, such as small pelagic fish (anchovy, pilchard, bogue, mackerel, Atlantic bonito). In addition to these species, fishing of economically profitable species, such as sea bass, dentex, sea bream and common pandora, is less represented (Fig. 10).

More intensive commercial fishing of the said species (trawling) is not done in the Bay as legislation in force prohibits it. However, securing a safe market for more abundant and less expensive fish species would create conditions for revival of the traditional small coastal fishery in the Bay. This would bring multiple benefits to various development fields in the Boka Kotorska Bay. It would enable employment of a larger number of people, develop further the tourist offer with traditional fish dishes and contribute to promotion of this region [4, 8].

Placing the posts on the shore of the Boka Kotorska Bay where seine nets are taken out – so-called fishermen's posts – under protection would, in addition to preservation of this unique fishing method along with the traditional manner of fish preservation by salting, contribute to promotion and valorisation of centuries-old cultural and gastronomic values of the Boka Kotorska and its distinct style of living on the shores of the Bay [4, 8].

Mariculture, as a part of aquaculture, means artificial targeted farming of marine organisms under partly or completely controlled conditions (Fig. 11). In that context, farming of fish species and other marine organisms interesting for the market is a strategic issue for all states that aspire to protect their natural resources. Although farming of edible bivalve molluscs, particularly mussels and oysters, is

Fig. 10 Traditional fishery in Boka Kotorska Bay (Photo by A. Joksimović)

one of the oldest, well-mastered and safest maricultural activity, Montenegrin coast has so far been least used for that purpose in the entire Mediterranean Basin. There are several reasons for such a situation, but even without analysing them, it should be underlined that these do not include unfavourable environment for the development of this or other maricultural activities. The results of years-long experimental, scientific and technical researches conducted by the Institute of Marine Biology show that almost the entire coast of Montenegro is favourable for production of healthy food from the sea and that it satisfies all the preconditions necessary for market production (Fig. 11) [4, 8–12].

The Special Purpose Spatial Plan for the Coastal Zone and the Law on Marine Fishery and Mariculture of Montenegro [9, 10] identify areas favourable for mariculture within the Boka Kotorska Bay. Most of these are in sites where fresh waters flow into the Bay, either through rivers or submerged springs.

The site Orahovac, where river Ljuta flows into the Kotor Bay, is particularly important. Currently, in the Kotor–Risan Bay, there are around 15 farming sites for mussels *Mytilus galloprovincialis*, one and the first farming site for oysters *Ostrea edulis* as well as two fish farming sites for sea bream *Sparus aurata* and sea bass *Dicentrarchus labrax*. Since the capacity of the Boka Kotorska Bay enables production of around 600 t of bivalves, it is necessary to undertake systemic measures for its further development as soon as possible [13].

Mariculture, as a development resource, has undisputable advantages such as preservation of biological diversity and generation of positive economic effects through production of quality food in the sea.

Fig. 11 Fish and mussel farm in the Kotor Bay (Photo by A. Joksimović)

In the whole of Montenegro, the population, property and all resources are continuously exposed to effects of low- and medium-magnitude earthquakes and occasionally to catastrophic earthquakes of large magnitude. A seismically very active area of Montenegro is the Montenegrin coast which includes the seismogenic zone of the Boka Kotorska which is characterised by maximum earthquake intensity of IX degrees by (EMS981).

Following the disastrous earthquake in 1979, based on examination and analysis of all the damaged structures, the concept of integrated review and control of seismic risks was developed. However, in the absence of appropriate institutional system as well as noncompliance with the secondary spatial and urban plans adopted and seismic protection measures prescribed, the seismic risk level has increased compared to the early post-quake period. Illegal construction, illegal and inexpert conservation and restoration works on cultural heritage as well as uncontrolled and excessive urbanisation increase the risk of damages. In such circumstances it is questionable how safe the area of the Boka Kotorska Bay is, in seismic terms, with the exception of the old construction entity of Kotor. The area is exposed also to the risk of other accidents, such as fires, floods and accidents at sea. In Montenegrin coastal area, including the protected area, fires break out usually in summer period, not only as a result of heat or recklessness but also as a result of degraded or faulty electrical wiring, which is particularly dangerous for museums, archives or other facilities where movable cultural properties are kept. The area of Kotor or some of its parts or individual pieces of cultural property are exposed to risk of floods due to heavy rains or sea level rise. Since the entire aquatorium of the Kotor–Risan Bay falls under the protected area, the floristic–

faunistic values are exposed to the risk of various shipping accidents and ecological accidents [4].

With a view to providing a comprehensive and integrated protection of the area of the Boka Kotorska Bay, the Government of Montenegro – the Ministry of Sustainable Development and Tourism – adopted the Integrated Coastal Area Management Programme (CAMP) of Montenegro. The legal basis for implementation of the CAMP in the region of the Mediterranean was formalised with adoption of the Law on Ratification of the Protocol on Integrated Coastal Zone Management in the Mediterranean (ICZM Protocol) as the Seventh Protocol to the Barcelona Convention.

The Montenegrin National Strategy of Integrated Coastal Area Management (NS ICAM) will develop further the system of spatial development and encourage further strengthening of coordination mechanisms, development of result-oriented management practices and introduction of a systematic monitoring of coastal processes. The system thus strengthened will contribute to preservation of integrity of ecologically valuable habitats and ecosystem of the coastal area, landscape and cultural property, protection of the narrow coastal zone from linear urbanisation (Fig. 12) and development of rural areas, thus actually fulfilling the priority objectives of the ICZM Protocol. Additional value of the NS ICAM will also be strengthening the foundations for implementation of the sea use planning [9].

In order to preserve the development potential, it is necessary to establish an efficient integrated management system. It is a long, dynamic, multidisciplinary and iterative process of coastal resources management, aimed at achieving the sustainable development of the coastal area. It concerns the entire process of data collecting, planning, organisation, implementation and monitoring of implementation of the measures and activities planned.

Fig. 12 New urban tourism complex in the Herceg Novi Bay – Kumbor (Photo by A. Joksimović)

Evaluation of the situation in the coastal area under this document includes natural and cultural heritage, coastal resources, natural hazards, economy, social development and management. The evaluation of the situation points also to characteristics, positive trends and advantages of the coastal area as well as to vulnerability of specific environmental and spatial elements, occurrence of excessive pollution and unsustainable use of resources, economic inefficiency and weaknesses in the management system [9].

Marine resources are exposed to various pressures and pollution from untreated municipal waste waters, solid waste and shipbuilding/ship overhaul, from ports and marinas (which, as a rule, do not have adequate reception facilities for ship-generated waste and for minimising the environmental impact) and from vessels and industry. Vulnerability analysis (based on data from the Monitoring Programme of the Ecosystem Status of the Coastal Sea of Montenegro implemented in the period of 2008–2011, Environmental Protection Agency) revealed high vulnerability of the sea in the Boka Kotorska Bay and in certain locations along the Adriatic coast: in Budva, Petrovac, Sutomore, Bar and Ulcinj as well as in the open sea. The narrow part of the Boka Kotorska Bay; the part between the Shipyard Bijela and the Porto Montenegro (Fig. 13), Igalo Bay; and the narrow shallow strip from Valdanos to the mouth of Bojana are identified as extremely vulnerable. The narrow coastal strip of the open sea and the Boka Kotorska Bay is also quite vulnerable to pollution from possible ship accidents at sea.

A demonstration of limitations and possibilities for implementing an ecosystem approach in the context of the future planning of Montenegro's marine area was conducted in the Boka Kotorska Bay under the CAMP activities. Analyses show that the Boka Kotorska Bay is one of the most vulnerable parts of the marine area, under strong effect of anthropogenic factors caused by high population density in

Fig. 13 Shipyard Bijela in Tivat Bay (Photo by A. Joksimović)

the narrow coastal strip, development of tourism and accompanying urbanisation, limited effect of industry (shipbuilding), maritime activities and as of recently quite notable nautical tourism and inbound cruise arrivals. Extraordinary diversity of flora and fauna of the Boka Kotorska Bay is jeopardised by human activities located on the land as well as in the sea. Concentration of sites with high pollution level in a relatively small area shows that internal waters of the Bay are endangered most [8].

In this context, ecosystem approach in development of the plan for the use of marine area of the Boka Kotorska Bay is justified in order to enable the protection of particularly vulnerable marine areas and rational use of its economic resources. Although the optimal scope of the sea use plan is the entire marine area of Montenegro, complementary to the establishing of an integrated sea use planning system, it is pragmatic to begin working on a draft plan for the 'pilot' area. In that way, the data needed and their availability, obstacles in terms of introduction of the spatial plan for the sea and existing capacity for development of spatial plans of the sea can be reviewed in more detail. A demonstration example can significantly strengthen the planners' knowledge on the principles, methods and other technical knowledge for maritime spatial planning. Taking into account the relative availability of the data in the Boka Kotorska Bay, the first demonstration plan could be developed for the area of this Bay and the contiguous open sea [8].

This book will, for the first time, compile all the know-how built-in scientific research on ecosystem of the Boka Kotorska Bay conducted over several decades, for the most part implemented by the Institute of Marine Biology (Kotor, Montenegro) with its associates. In all the aspects of biodiversity of flora and fauna, sea and air pollution, chemistry, hydrography, oceanography, agriculture, tourism development, maritime industry, fishery and mariculture, we will try to summarise the knowledge on ecological status of the Boka Kotorska Bay. Along with all integrated management strategies needed for such a vulnerable area, we believe that the data and know-how presented in this book are invaluable for the future better behaviour towards the Boka Kotorska Bay, the pearl of the Adriatic and the Mediterranean.

A total of 70 scientists from 29 research institutes and faculties from Montenegro, Serbia, Croatia, Italy, Germany and Russia contributed to this book. The book is organised as follows. The first set of chapters is devoted to general physico-geographical characteristics of the Adriatic Sea and Boka Kotorska Bay. The next set of chapters deals with marine chemistry, general pollution and pollution from shipping activities in the Bay. Then we describe the bacterial, phytoplankton, phytobenthos, zooplankton, zoobenthos and ichthyoplankton diversity in the Bay. Going along the food chain, we continue with chapters on marine invertebrates, (Crustacea, Decapoda), aquaculture, fishery and its history and marine mammals in the Bay. On the land we describe a diversity of vascular flora and agriculture. Tourism and integrated coastal zone management have our special attention. Several chapters are focused on satellite monitoring of the Bay and general characteristics of the ongoing regional climate change. And we finish the book with conclusions.

We would like to thank the editors at Springer-Verlag for their timely interest in the Boka Kotorska Bay and the Adriatic Sea and their support of the present publication, because this is the first book on the Boka Kotorska Bay, and only two books on the Adriatic Sea were published in Springer:

- Gambolati G. (Ed.) (1998) CENAS: Coastline Evolution of the Upper Adriatic Sea due to Sea Level Rise and Natural and Anthropogenic Land Subsidence
- Cushman-Roisin B., Gacic M., Poulain P.-M., Artegiani A. (Eds.) (2001) Physical Oceanography of the Adriatic Sea

The editors of the book continue to work on the next planned publication, *The Adriatic Sea Encyclopedia*, which is based on the Russian version of the Encyclopedia published in 2014 [14]. We hope that this updated English version will be published in Springer in 2017.

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References

1. Stjepčević, J. i V. Žunjić (1964) Bokokotorski zaliv - fiziogeografske osobine. Godišnjak geografskog društva SR Crne Gore, pp 75–79
2. Del Bianco F, Gasperini L, Giglio F, Bortoluzzi G, Kljajic Z, Ravaioli M (2014) Seafloor morphology of the Montenegro/N. Albania Continental Margin (Adriatic Sea—Central Mediterranean). Geomorphology 226:202–216
3. Lepetić V (1965) Sastav i sezonska dinamika ihtiobentosa i jestivih avertebrata u Bokokotorskom zalivu i mogućnosti njihove eksploatacije. Studia Marina 1:164
4. Vlada Crne Gore, Ministarstvo kulture (2011) Menadžment plan prirodnog i kulturno-istorijskog područja Kotora. Cetinje, p 198
5. World Heritage in Yugoslavia, UNESCO, Natural and Cultural Treasures (1990) Kotor 88-101. Založba Mladinska knjiga, Ljubljana, p 175
6. Statistical Office in Montenegro (2011) Statistical yearbook of Montenegro
7. Drakulović D (2012) Značaj fitoplanktona kao indikatora eutrofikacije u akvatorijumu Bokokotorskog zaliva. Doktorska disertacija. Univerzitet u Beogradu, Biološki fakultet. Beograd, pp 1–224
8. Vlada Crne Gore, Ministarstvo održivog razvoja i turizma, Nacionalna strategija integralnog upravljanja obalnim područjem Crne Gore, NS IUOP, Podgorica, 2015, p 186
9. Prostorni plan područja posebne namjene za morsko dobro, Ministarstvo zaekonomski razvoj Crne Gore, Javno preduzeće za upravljanje morskim dobrom, Podgorica, Kotor, 2007
10. Vlada Crne Gore, Ministarstvo poljoprivrede i ruralnog razvoja, Zakon o morskom ribarstvu i marikulturi, Sl.list CG 56/09, 47/15
11. Mandić M, Drakulović D, Petović S, Huter A, Mandić S (2014) Development perspectives of fish farming in Montenegro. Agric For 60(2):233–243

12. Bugrov L, Antsulevich A, Joksimović A, Keondjian V, Mandić M (2015) Prospect of marine aquaculture in Adriatic Sea-comparison of sheltered and open sea areas within Montenegro coastal zone. Studia Marina 28(1):39–50
13. Goverment of Montenegro, Ministry of Agriculture, Forestry and Water Management (2006) Montenegro's Fisheries Development Strategy and capacity building for implementation of EU Common Fisheries Policy, Podgorica, p 79
14. Zonn IS, Kostianoy AG, Semenov AV, Yoksimovich A, Kumantsov MI (2014) The Adriatic Sea encyclopedia. Ratehnik, Moscow, p 354 (in Russian)

The Adriatic Sea

Igor S. Zonn and Andrey G. Kostianoy

Abstract This chapter studies the basic physiographical and oceanographical peculiarities of the Adriatic Sea. It describes in brief the islands, coasts, relief, and bottom sediments. It provides the general hydrometeorological characteristics (wind, waves, and precipitations). Special attention is focused on the hydrological regime of the sea (water masses, currents, temperature, and salinity). In addition, it dwells on the present-day development of the Adriatic Sea, i.e., tourism, fishery, mariculture, hydrocarbon production, and shipping.

Keywords Adriatic Sea, Bottom topography, Climate, Coast, Currents, Water masses

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Contents

1 Introduction

As this book is devoted to the Boka Kotorska Bay, one of the largest and most interesting features of the Adriatic Sea, the editors agreed that this book should be opened with the chapter on the Adriatic Sea.

There are many publications on the research of the Adriatic Sea that began in the mid-sixteenth century and goes on till now. Taking into consideration that the Adriatic Sea is professionally studied by many institutes and laboratories of the coastal countries we thought it appropriate to give the general description of the Adriatic Sea having included there not only the oceanographic information, but also the historical and economic aspects.

The Adriatic Sea is a semi-closed water body occupying the northern part of the Mediterranean Central Basin. In the antiquity this sea was called *Mare Superum* (Lat.), and later on *Mare (H) Adriaticum*. The etymology of the name "Adriatic Sea" may be traced to the Etruscan settlement of Adria and the ancient port in the mouth of the Po River (from Illirian word "Adur" meaning "water" or "sea"). But the Greeks applied this name, according to Herodotus and Euripid, only to the northern, upper part of the sea and from the fourth century BC this name meant the whole Adriatic Sea in its present borders. One time it was called the Venetian Bay (Map of Cantelli, 1684). In the Greek–Roman period the name *Mare Dalmatianum* was used. In the Middle Ages the southern Slavs – Croatians, Bosnians, Serbs, Montenegrins, and Macedonians called it the Yadran Sea ("blue sea") as they call it now [1].

The Adriatic Sea is the largest arm of the Mediterranean Sea incising deep into its northern coast between two large peninsulas of Southern Europe – Apennine and Balkan (Fig. 1). The Strait of Otranto or the Otranto Gate or Adriatic Gate is located in the place where the distance between the Corfu Island (Greece) near the southwestern coast of the Balkan Peninsula and the Santa Maria di Leuca Cape (Italy) on the Apennine Peninsula is the minimum. This strait 72 km wide and 741 m deep connects the Adriatic Sea with the Ionian Sea. The International Hydrographic Organization defines the southern boundary of the Adriatic Sea as a line running from the Butrinto River's mouth in Albania to the Karagol Cape in

Fig. 1 The Adriatic Sea (http://www.worldatlas.com/aatlas/infopage/adracsea.gif)

Corfu (Greece), through this island to the Kephali Cape and on to the Santa Maria di Leuca Cape.

The Adriatic Sea washes the coasts of six countries: Italy (1,249 km), Slovenia (47 km), Croatia (1,777 km), Bosnia and Herzegovina (23 km), Montenegro (298 km), and Albania (362 km). The western coast belongs to Italy, the eastern is shared by Slovenia, Croatia, Bosnia and Herzegovina, Montenegro, and Albania [1] (Fig. 1).

The Adriatic Sea extends from the southeast to the northwest for nearly 770–776 km; its width varies from 93 to 248 km. Its coastline is 3,707 km long and adding here islands it makes 6,200 km. The area of the sea ranges from 131,500 to 138,600 km^2 accounting for 4.6% of the area of the Mediterranean Sea. The area of the continental shelf (from the shore to a depth of 200 m) is 102,415 km^2 or 73.9% of the sea area [2]. The volume of the sea is around 35,000 km^3.

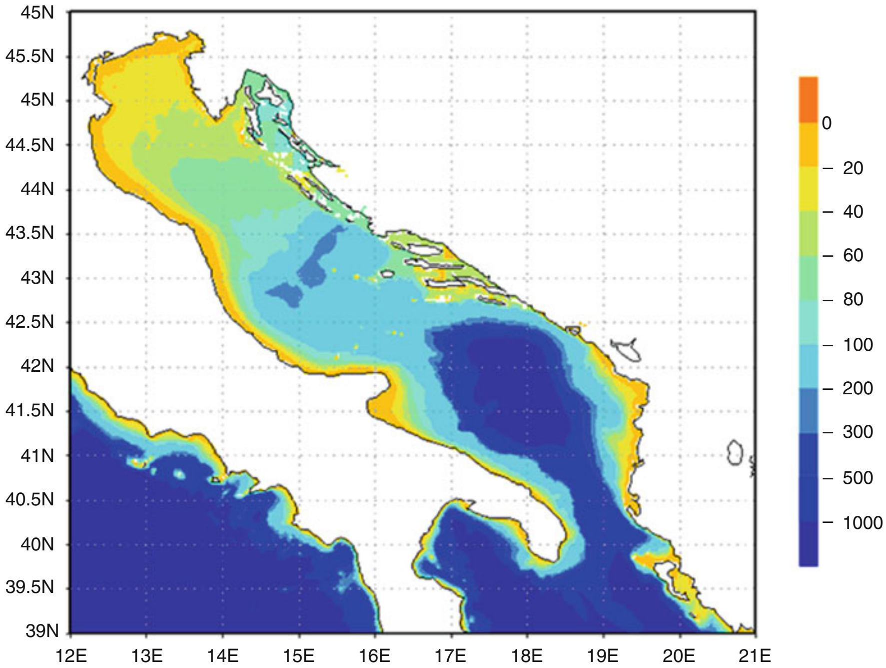

Fig. 2 Bottom topography of the Adriatic Sea (http://oceanlab.cmcc.it/afs/img/AFS/2.png)

The Adriatic Sea is seated in a long depression or synclinal fold (Fig. 2). Its present size and form appeared in the early Quaternary period as a result of transgression. In the late Tertiary period the Earth's crust sagged and the depression was formed that later on was filled with sea water. That time the Otranto Sill was also formed. The analysis of tectonic processes observed on the sea shores led the scientists to a conclusion that for several million years the Apennine Peninsula had been drifting towards the Balkan Peninsula and the Adriatic Sea is slowly, but inevitably shrinks.

In the Adriatic Sea the largest are the Gulf of Venice, the Gulf of Trieste, the Gulf of Manfredonia, the Gulf of Quarnero, and Boka Kotorska Bay.

The Adriatic Sea contains from 1,233 to 1,300 islands, mostly, along the eastern shores. The Italians assert that this figure is bigger if add here the islands in the Po River Delta, small islets in the Venetian Lagoon. They include 79 large islands, 525 islets, and 642 outcrops of cliffs.

Out of 1,233 islands of the Adriatic Sea, cliffs, and reefs, 1,185 belong to Croatia. These are the Dalmatian Archipelago located between Dubrovnik and Istria Peninsula at a distance of 120 km from the shore. In some places they extend parallel to the shore (Fig. 3). The biggest coastal islands in Croatia are Cres (406 km^2), Krk (406 km^2), Hvar (299 km^2), Pag (287 km^2), and Korcula (276 km^2), and the Brac Island (396 km^2) whose elevation over the sea level reaches 780 m. By the coastline length the islands may be ranked as follows: Pag – 269.2 km,

Fig. 3 Islands in Croatia (http://www.find-croatia.com/blog/wp-content/uploads/map-croatia-islands.gif)

Hvar – 254.2 km, and Cres – 247.7 km. All big islands are covered with mountains and cliffs which height may be over 400–500 m. They are composed of limestones and karst formations. The most populated islands are Krk and Korcula. The islands along the Italian coast of the Adriatic Sea are mostly small and less numerous compared to the eastern coast.

The watershed area of the Adriatic Sea is 235,000 km^2. About 500 rivers bring their fresh waters into the Adriatic Sea. Among them there are big and many small ones. The main rivers discharging into the Adriatic include the Po, Soča, Isonzo, Krka, Neretva, Drin, Bojana, Vjosë, Seman, Shkumbin, Piave, Brenta, Pescara, and Cetina. Their total average annual flow is 5,700 m^3/s, out of which around 28% or 1,585 m^3/s is contributed by the Italy's biggest Po River running in the northwestern corner of the shallow western part of the sea (Fig. 4) [3]. The second largest source of fresh water is more than 150 small rivers of Albania which total flow makes about 1,300 m^3/s [2].

The coldwater rocky coast of the Adriatic Sea is situated 2 km southward of Vlorë (Albania). There are found 34 karst springs with the total flow of about 900 l/s of very cold water going into the sea [2].

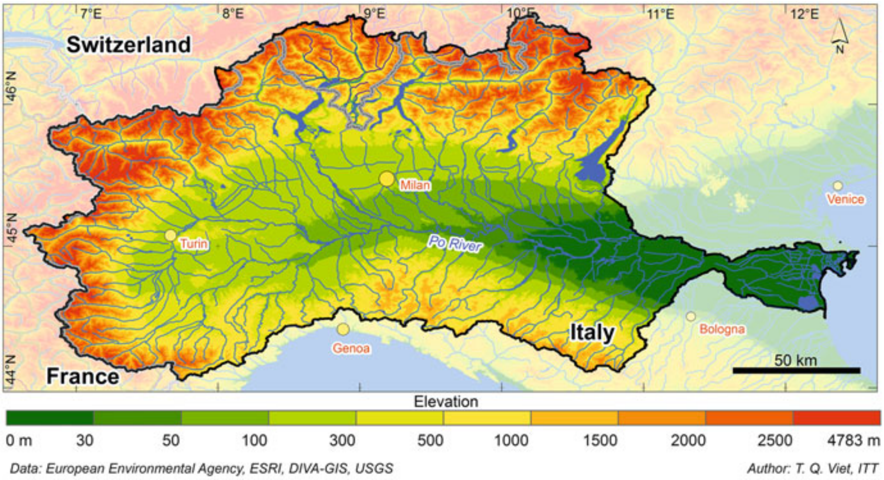

Fig. 4 Po River Basin (http://www.basin-info.net/images/po/pobasin1.jpg)

2 Coasts

The coasts of the Adriatic Sea are asymmetric: its northeastern and southwestern coasts differ greatly in appearance. The southwestern Italian coast in the eastern part of the Apennine Peninsula is represented, largely, by the straight, linear, low-lying, and continuous aggradation shores. Here many long, wide, sandy, and gravel beaches and lagoons can be found which cover about 160,000 ha. It should be noted here that prior to the Roman Times this area was as large as over three million ha. It shrank as a result of drainage works. The southwestern coast of the sea represents the rolling and, in places, terraced plain up to 10–18 km wide composed of the Pleocene and Plestocene marine deposits. The large barrier-and-lagoon complex is formed with wide lagoons and narrow sandy bars covered with dunas which are overgrown with sparse shrub vegetation. Only in some small areas the low-lying scouring benches developed in loose marine and alluvial-marine deposits with narrow beaches are observed. The cliffs in the parent rocks are most typical of the eastern coast of the Gargano Peninsula, the Le-Mourdji Plateau, and further on southwards. Generally, the aggradational coasts prevail to the north of the Gargano Peninsula and the abrasion coasts to the south of it [2].

The Adriatic's northernmost part contacts on the Venetian Lagoon crossed by numerous rivers. The northwestern part of the sea is quickly filled with sediments brought by rivers, mostly Po and Adige, which contribute annually up to 20 million tons of sediments consisting for 7% of clay, 70% of silt, and 23% of sand. This has led to changes in the coastline and active protrusion of the multi-arm delta into the sea (by 40 m per year on the average). As a result, the ancient ports in these deltas with very convenient harbors for ships, such as Acquila and Adria which history could be traced to the Roman Times, are now distanced for over 22 km from the sea.

The marine and alongshore wave currents drifting here catch up some fine sediments of these rivers and move them to the south.

Farther from the coastline the terrain becomes gradually more elevated and acquires the hillocky relief. From time to time in some areas the low mountains composed mostly of dolomite, marble, red and white limestone, and dark sandstone are met. They are usually overgrown with thick shrub vegetation, oak and olive groves. The monotony of this coast is broken only by high and abrupt Gargano Peninsula protruding far into the sea and forming on its southern side the Manfredonia Bay opening widely towards the sea. The northern side of Gargano forms the flat Tremiti Harbor closed by two groups of small islets – Tremiti and Pianosa (Italy).

The northeastern coast of the Adriatic makes up the western part of the Balkan Peninsula. It is mostly upland. By the ratio of tectonic structures it is referred to the well-pronounced longitudinal type. The high Dinarian Upland extends almost along the whole coastline of the sea. Its maritime part (elevations up to 2,500 m) is composed of the Mezosoic limestones and partially flysch. The rocks form large anticlinal folds running parallel to the coastline, while the domes are often broken by denudation processes. As a result of joint action of the Holocene transgression and tectonic subsidence of the coast the sea intruded into the geosynclinal depressions and denudation lowerings in the domes of positive structures and formed numerous long and narrow bays extending along the abrupt coast of the sea. This is considered the world's most incised coast with its great number of harbors, bays, peninsulas and 1,185 islands, and islets, differently shaped rock outcrops forming the most fanciful configurations and having small stony and pebble beaches. It is cut by some gulfs and bays the biggest of which are the Kvarner Gulf and the Gulf of Trieste separated from each other by the elevated Istria Peninsula. Nearby the coast there are numerous large and small islands oriented lengthwise repeating the respective series of positive tectonic folding. The "internal" coast is well protected from the wave effect by the barrier of islands. It was not practically subject to the sea action and kept the vivid traces of its initial dissection (tectonic and denudation) [4].

Moving to the northwest (the Istria Peninsula) and to the southeast (Montenegro coast) the typical features of the Dalmatian type of the coast become less pronounced. The archipelago of elongated islands practically disappears, giving place to the abrasion areas that become dominating in the picture of the mountainous coast.

Along them the benches are usually worked out and the clear-cut terrace step at a depth of 8–10 m may be traced along the whole Adriatic coast marking, perhaps, the ancient sea level.

In the coastal areas where the shore cliffs are composed of the Mezosoic and Tertiary limestones the coastal and underwater karst forms associated with the leaching effect of sea water on limestones are widely developed. In Dalmatia karst formations occur to a depth of some 10–15 m. Multiple protrusions, hollows, funnels, deep troughs, and ridges in limestones in the inshore zone are formed.

Fig. 5 Dalmatian type of the coasts (http://www.butterfield.com/blog/wp-content/uploads/2013/06/croatia-blog-banner.jpg)

Apart from karst processes, the bioerosion also contributes to destruction of the limestone coastal benches which is caused by vital activities of microorganisms and sea urchins eating microflora of animals. The former corrode the rock surface, while the latter scrape off the rock particles in search of feed. The products of limestone destruction accounting for 10–13% dissolve in water and the remaining 70–90% has the texture from silt to fine sand. The distribution of organisms in the coastal belt features certain zonality determined by physical, chemical, and biological factors. This zonality results in different rates of bioerosion in different littoral areas (0.1–1.1 mm/year) and in development of the biogenous erosion niche in the cliff basement at the tide level. Generally, about 11 kg of limestone is annually removed from 1 linear meter of the shore, out of which about 9 kg consists of fine materials making 3–25% of the coastal sediments. Changes in the organism distribution influence significantly the rate of erosion and sediment accumation. Thus, in the 1970s the active propagation of sea urchins was observed in this area as a result the rate of coastal limestone destruction had nearly doubled.

One of the specific geographical features here is the Dalmatian type of the sea coast that has been called so by the name of the southern part of Croatian Adriatic – Dalmacia taking its origin in the Antique Roman Province of Dalmatia. Such type of coasts with initial structural fundamental dissection is characterized by parallel running of coastlines of the greater part of islands to the main direction of the coastal (mainland) relief (Fig. 5). The coast of Albania is quite different. Between the Vlera Gulf and the mouth of the Drin there is the Albanian Lowland 15–18 km wide. Its coastal area abounds in river deltas, lagoons, wetlands, and dunes. Moving farther into the coast the terrain becomes gradually more elevated and hillocky. In the north and south of the Albanian coast the limestone ridges 300–400 m high come close to the shore at some angle creating a series of elevated capes [4].

The low-lying areas and piedmonts of mountains to a level of 200–400 m are overgrown with evergreen shrubs, oaks, and pines. The olive trees, orange and lemon groves, and vineyards prevail above this belt. The islands of the Dalmatian Archipelago are the tops of coastal ridges of the Dinaric Plateau.

The researches have shown that the bottom of the Adriatic Sea in this area is dropping down significantly.

To the northeast of Triest the changes in the coast structure become visible – it becomes irregular, steep, and abrupt. The Istria Peninsula wedges into the sea for 90 km. The Croatian coast and its harbors are more elevated and abrupt than the Istria shores.

The shores of the Adriatic Sea locate in the seismically active zone. The earthquakes with magnitude 6–9 occur near the coasts of Italy, Albania, Montenegro, and Croatia.

3 Bottom Relief and Sediments

The bottom of the Adriatic Sea represents a depression sloping smoothly from the northwest to the southeast (Fig. 2). The seabed relief was formed by tectonic displacements that had occurred several million years ago. In some parts the seabed is leveled out by sediments and the rivers flowing into the sea make the seabed silty.

By the physiographical conditions, bathymetry and bottom relief there are distinguished the Northern, Central, and South Adriatic Basins. The northern basin of the sea is not deep; it is bordered by the Karlobag (Croatia) – Ancona (Italy) line. The depths in the northern basin reach maximum of 70 m. The central basin is confined by the Ploce (Croatia) – Gargano Peninsula (Italy) line. Here the depths reach their maximum of 273 m in the Middle Adriatic Pit (MAP) or else called Jabuka/Pomo Pit. In general, the depths here are to 200 m. The 170 m deep Palagruža Sill is south of the MAP, separating it from the 1,230 m deep ovally shaped South Adriatic Pit or Bari Pit which makes it the deepest part of the Adriatic. Further on to the south, the sea floor rises to 780 m to form the Otranto Sill.

The depths of the Adriatic Sea near coasts are closely connected with the coastline physiography. In places where shores are high and mountains come out here the sea depth nearby such places is great. This is observed near the Istrian and Dalmatian coasts of Slovenia and Croatia. The seabed relief along the Albanian coast is rather flat; the depths are smoothly growing seaward. The isobath of 100 m passes 9–10 km from the coast, while the depths of 800–1,000 m occur 50 km from it. The Croatian coast is rather steep; while moving to the northwest the seabed relief becomes more rugged. The off-sea edges of islands are very steep; in many places the isobath of 100 m passes at 2–4 km from them. Very rugged bottom relief is observed in passages among islands abounding in bars, shoals, and cliffs.

The bottom sediments in the Adriatic Sea are represented by recent sediments of various mineralogical and granulation composition. Silty and sandy deposits cover the greater part of the continental shelf. Such type of deposits prevails in the South and Central Adriatic as well as in the coastal areas in the northeast of the sea, in the Trieste Gulf and a narrow strip along the northeastern coast of Italy. The bottom of the sea is made mostly of silt, fine sand containing many shell residues. Near the abrupt shores the coarser sand appears that overlays the marble basement. Its distribution in the sea is dependent on the sea floor relief and water dynamics. Marine currents determine their longitudinal dispersion. The North and Middle Adriatic accept over 80% of the liquid flow and over 60% of the solid flow. The enrichment with the terrigenous material occurs in the near-mouth areas from where it is spread with currents. The terrigenous material gets into the sea as a result of abrasion and is also brought with the winds [5].

Not long ago the American specialists have found the fault of lithospheric plates about 200 km long under the Adriatic Sea. It takes its origin not far from Dubrovnic. On the basis of the GPS data the scientists concluded that this fault was associated with the formation of the Dinaric Alps – a mountain chain on the Adriatic coast 645 km long and the Dalmatian islands. This fault also influences the position of the Italian "boot" which "heel" moves closer to the Croatian coast by 4.5 mm every year, while the Adriatic floor "slides" under the Balkans. The scientists estimated that approximately in 50–70 million years the Adriatic Sea will disappear from the map of Europe (http://wiki.ru/sites/okeanologiya/id-news-137968.html). It cannot be also excluded that this fault may be connected with the earthquakes that regularly occur in this region. However, so far we have no accurate data in this respect.

4 Climate

The Adriatic Sea extending meridionally between about 40° and 45°45′N belongs to the subtropical climatic zone, while its northernmost part is characterized by moderate climate. The climate here has some Mediterranean features, but, generally, differs significantly from the climate of the Mediterranean Sea. It is determined by the cyclonic and anticyclonic activity over the middle and southern Europe. Cyclones usually travel from west to east over the Adriatic Sea. In summer the spur of the Azores Anticyclone influences greatly the formation of the Adriatic climate. It creates the steadily dry and warm summer with cloudless sky. In winter the cyclonic activity determines the soft, humid, and cloudy winter with accidental sunny periods. Winter normally lasts from December through February. The coldest month is January. The average air temperature in this month is 6–9°C in the northern regions and 10–12°C in the southern regions. Spring is not long (March–April) and its average monthly temperatures are 13–14°C nearly everywhere. In spring the air temperature may rise to 29°C and drop below zero. Summer is the longest season lasting from late April through September. The hottest month is July with the average monthly air temperatures varying from 27°C in the north to 30°C in the south. The maximum air temperature in some coastal areas may be as high as 42°C that was recorded in August. Autumn starts in October when the air temperature drops to 14°C in the north and to 18°C in the south [6].

The cloudiness over the Adriatic coast features the clear-cut annual dynamics: it tends to increase in winter and to decrease in summer. The average monthly cloudiness is 5–6 points. The greatest cloudiness is observed in the northern part of the sea where its average monthly values vary from 6–7 points in winter to 3–5 points in summer. In spring and autumn the cloudiness is not more than 6 points. In the other parts of the sea the average monthly values of cloudiness fluctuate from 4–5 points in winter to 1–3 points in July and August. The average number of cloudless days in a year varies from 120–130 in the south to 100–110 in the north [6].

The average annual precipitations here are around 1,000 mm. The amount of precipitations over the sea decreases from the northwest to the southeast. On the coast the greatest precipitations fall in the northernmost areas (Trieste, Rijeka); their annual amount averages 1,075–1,555 mm. Precipitations are usually represented by rainfalls and rainstorms. The precipitations are distributed within a year very unevenly; the greater part of their annual amount falls in autumn and winter seasons. In these months the average precipitations vary from 60–90 mm on the southwestern coast to 150–200 mm on the northeastern coast. The minimum precipitations are usually recorded in July – not more than 30–45 mm. The precipitations are especially meager in July in the southern part of the sea where their monthly amount makes 13–15 mm. The exception is the northern coast of the sea where the minimum precipitations fall in January–February making 40–60 mm [6].

The average annual number of days with advective sea fogs in many regions of the sea fluctuates from 1 to 10, except the Venetian Plain with its multiple lagoons and the mouth of the Po River which contribute to formation of fogs that are most dense here and may last as long as 30 days. Fogs mostly occur in October through April. In the north of the sea they are observed more frequently that in the middle and southern parts [6].

Such phenomenon as haze is often observed over the Adriatic Sea. It is formed by dust and fine sand brought here with the southern winds blowing from Northern Africa.

Snowfalls are quite rare here and occur only in the northwestern part of the sea. The average annual number of days with snowfalls is 4–6 in the north of the sea and 1–2 in the south of the sea. The snow forms a cover only for a very short time.

Among specific meteorological events observed here there are thunderstorms and snowstorms. Thunderstorms may occur in any season of a year, but they happen here more frequently than anywhere else in Europe. They are most frequent in July, August, and September. In the north they occur to 9 days in a month, on the average, while on the Dalmatian coast only 4 days per month. Thunderstorms are usually accompanied by strong gusts of wind. Here the windforce may be as high as 6–8 points, while during "Garbina" winds – even 11 points. Many thunderstorms observed over the Adriatic cross the sea as thunder squalls from southwest to northwest. Their velocities are about 25–35 km/h. Snowstorms occur very seldom and only in winter in the northern part of the sea [6].

5 Wind and Waves

The wind regime of the Adriatic Sea is determined by the effect of such factors as regional atmospheric activity, coast relief (orography), and local circulation provoked by temperature differences of land and sea. The most typical local winds for the Adriatic are *Sirocco*, *Mistral*, *Bora*, *Gabrina*, and *Tramontane*.

During a year the winds blowing from the north and northeast are prevailing over the Adriatic. Their recurrence in some months is as high as 60%. The exclusion is the southwestern coast where the northwestern winds are dominating.

Sirocco is the warm southern dry tropical wind from the deserts of the Arabian Peninsula and North Africa. It blows from the southwest bringing with it the dreary weather, clouds, and storms. Sometimes, mostly in winter, it can reach the hurricane magnitude. The maximum windforce of Sirocco may reach 7 points; it usually lasts for 2–3 days in succession. In the period from October through May it blows more frequently and with greater force (to 9 points). It may be also followed by a storm with the waves 3–4 m high. The signs of coming Sirocco are rough, surging sea, while in the Central and North Adriatic – tides. After long southern winds the water level in ports may rise.

Mistral is blowing mostly from the northwest in the period from June to mid-September when the low-pressure area gets established over the Balkan Peninsula. It usually starts blowing about 10 h in the morning and reaches its force of 3–5 points by the midday and calms down by the sunset. Mistral is considered to herald good weather – it brings clear blue sky. In the recent years it has been noted that Mistral has occurred more seldom. Nevertheless, it still blows quite frequently, particularly, on the coasts of remote islands.

Bora is typical of the eastern Adriatic coast. This is a cold northeastern wind blowing with sharp and very strong gushes through the passages in the Dinaric Alps on the Adriatic Sea and, at the same time, is one of the causes of extreme and dangerous situations in the coastal area. When strong wind is blowing, especially from the snow-covered mountains, the buildings and ships are quickly coated with an ice crust. This wind may overturn cars and boats. The Bora speed may reach 40 m/s and its may last from several days to several weeks. One more cause of Bora is the sharp differences of temperature and atmospheric pressure between mainland and islands in the Adriatic. The greater is the pressure difference, the stronger are the wind gushes [7].

The strongest Bora gushes are usually recorded in the territory from the Cres Island to the Mljet Island on the western coast of Dalmatia. Bora may also occur at any time of the year, but it still blows most often in winter. On the Velebit Canal, in Split, near the Vrula Bay (north of Makarska) and on the Peleshac Peninsula the Bora gushes even in summertime may reach the force of 8–9 points. In the period from November through April the Velebit Canal becomes one of the most dangerous places in the world.

In summer Bora is usually blowing 2–3 days in succession. Bora of medium intensity may be even positive – it cools the air and makes it clearer. In winter in the North and Central Adriatic Bora may blow for several weeks in succession with only short intervals.

Storms are mostly observed in the areas of Bora action, i.e., on the northeastern and northern coast of the sea. They are most frequent in the period from November through March. The average monthly number of days with storms in this period varies from 2–3 in Dubrovnik to 4–9 in the Port of Trieste. On the southwestern coast of the sea the number of days with storms in this period does not usually exceed one per month and only in the Port of Ankona it is three. In summer the storms are usually not long and occur as individual gusts [7].

The short southwestern storm wind Gabrina usually lasts from 1 to 2 h in summer. It instantly reaches the force of 8–11 points. This wind always brings hurricanes and thunderstorms. It is formed when in the south of the Mediterranean the high pressure area gets established and simultaneously the Adriatic center of low pressure moving eastwards appears in Central Europe or in the north of Italy.

The Adriatic Sea is usually calm because more than 75% of the total number of waves is less than 0.5 m high. Moderate sea prevails most of the year (from 0 to 2 points). Resulting from the prevailing wind belt over the Adriatic the waves in open sea are most frequently rolling from north to south. The waves generated by long *Jugo*, *Jugo-Sirocco* (southeastern) winds are higher than waves from Bora. The greatest waves 10.8 m high were recorded in the north of the Adriatic Sea. Near the Palagruža Island the maximum wave height of 8.4 m during Sirocco and 6.2 m during northeastern Bora was observed. However, it will be improper to think that the waves from the south are more dangerous than from the northeast. Quite the opposite – the period of waves generated by the northeastern winds is twice as shorter than southern winds: 50 m compared to 100 m and more, and their amplitude is very irregular. The waves from summer *Tramontane* (daytime northwestern wind) reach their maximum height of 4 m in the South Adriatic.

6 Hydrology

The hydrological regime (thermohaline properties) of the Adriatic Sea is determined to a great extent by water exchange with the Mediterranean via the Strait of Otranto, river runoff, currents, and climatic conditions. The hydrological regime is also influenced by the sea elongation in the northwestern direction, sharp difference of depths in its northwestern and southeastern parts, and coast irregularity.

The hydrological regime is characterized by high water temperature, high salinity, insignificant water level fluctuations, weak currents, and low recurrence of high waves.

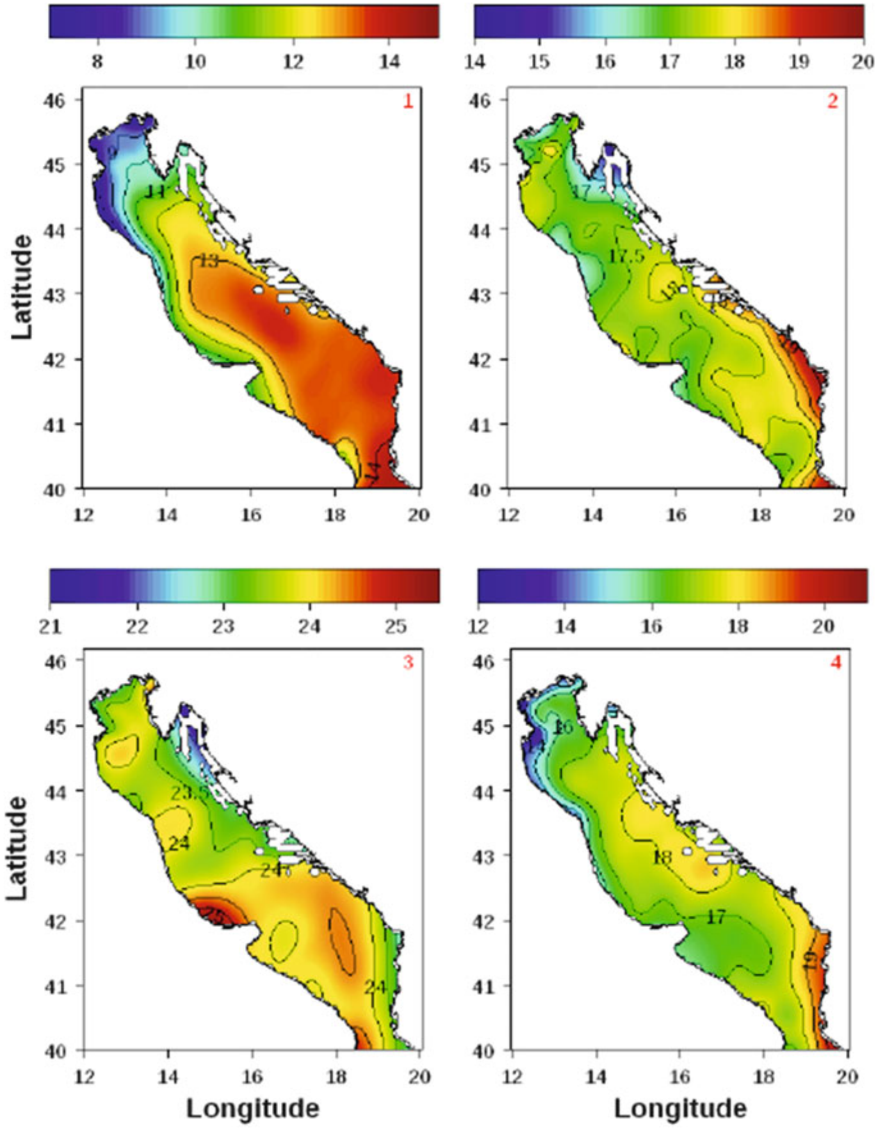

Fig. 6 Climatological maps of SST in the Adriatic Sea in: (1) winter, (2) spring, (3) summer, and (4) autumn (https://www.researchgate.net/figure/266886126_fig5_Figure-5-Climatological-map-of-surface-temperature-C-in-winter)

The Adriatic is a rather warm sea with the clear-cut annual variations of the surface water temperatures (Fig. 6) that tend to increase mostly from north to south and from west to east. The seasonal temperature fluctuations exceed +10°C due to atmospheric heat transfer. The shallower northern part of the sea is filled with the

Adriatic surface water resulted from mixing the waters of the Ionian Sea with the coastal flow. In summer the temperature of this water mass is 22–24°C [6].

In winter when the active cooling and development of convection processes are observed the surface waters mix with the transformed Levantine waters and formed Adriatic bottom water masses getting into the sea. The bottom water fills pits in the Adriatic Sea and is distinguished by uniform features: its temperature ranges from 13.5 to 13.8°C. The lowest temperature is observed from December to February. In this period the average monthly temperature varies from 14 to 7°C nearby the Po River Mouth. Considerable difference of water temperatures is observed between the southwestern and northeastern shores of the sea: near the northeastern shore the water is by 2–3°C warmer, on the average, than near the southwestern shore. In March–April the surface water temperature over the whole sea rises and in May it reaches approximately 17–18°C [5].

In summer when thermocline is at a depth of 30 m in the North Adriatic and 50 m in the Central Adriatic the surface layer is clearly separated from the lower-lying water. The surface water temperature is similar across the whole basin and is equal to 23–24°C in the open sea. In this period the reverse temperature distribution compared to winter is observed. The average monthly water temperature increases westwards from 22°C near the Croatian shoreline to 26°C near the Italian coast. In September the surface water temperature drops and in October–November it makes mostly 16–17°C and only in the southwestern part of the sea it increases to 18°C and in the northwestern part it decreases to 13°C. The average annual water temperature in the sea does not drop below 11°C. The maximum temperatures are recorded in July and August and the minimum in February. The lowest surface water temperature in the sea in winter is around 7°C and quite seldom it may drop still lower. In spring the temperature rises and reaches about 18°C, while in summer it is as high as 22–25°C and in the South Adriatic even 27°C. The lowest sea water temperatures are in river mouths or in bottom freshwater sources.

Salinity of the Adriatic water is rather high, even higher than the world average values – around 38.3–38.9‰, which is less than water salinity (39‰) in the eastern part of the Mediterranean and higher than in its western part (37‰) (Fig. 7). The highest salinity in this area results from the inflow of saline waters from the Levantine Basin through the Strait of Otranto with its peak of 39.1%. In general, the water salinity decreases from south to north and from the open sea towards the shores. The salt balance of surface waters is subject to the river runoff. In the North Adriatic due to river flow the water salinity tends to decrease and varies here from 25–30‰ nearby the Po River Mouth and to 37‰ in the Kvarner Gulf. The fresher coastal waters most noticeable along the western coast are always separated and differ from open sea waters and are marked by the presence of the salinity front [8].

The greatest water density on the sea surface is observed in October through March and varies from 1.026 to 1.030. In the period from April through September it decreases to 1.025 and in the most northwestern part of the sea to 1.022. The waters of the Adriatic Sea are very clear; it is one of the highest in the world; their clarity may reach 56 m.

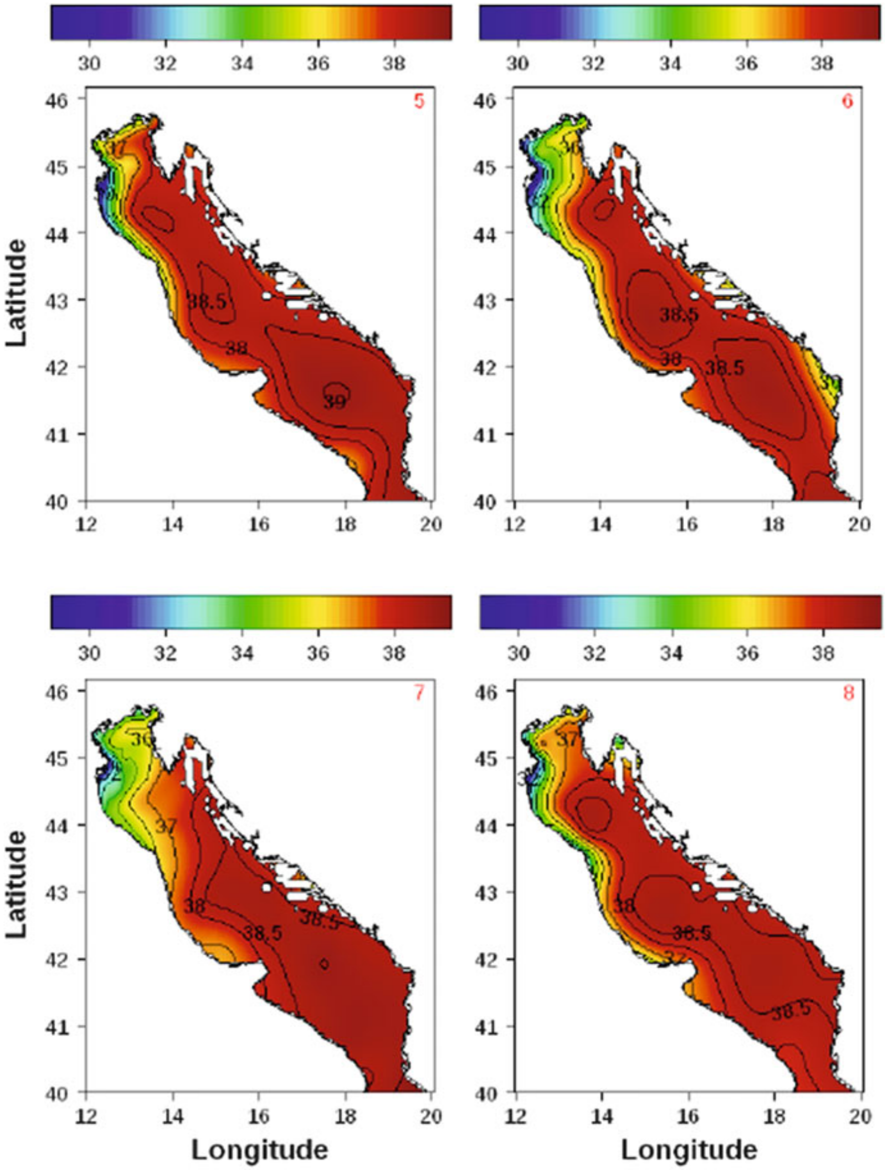

Fig. 7 Climatological maps of sea surface salinity in the Adriatic Sea in: (1) winter, (2) spring, (3) summer, and (4) autumn (https://www.researchgate.net/figure/266886126_fig6_Figure-5-Continued-Climatological-map-of-surface-salinity-in-winter-5-spring-6)

The level fluctuations in the Adriatic Sea are not great and caused mainly by tidal and surge events. Mostly abnormal semi-diurnal tides (up to 1.2 m) prevail here. The abnormal semi-diurnal tides are less distributed and only near the Dugi-Otok

Island the normal diurnal tides are observed. The tides are not high. The average height of the tide varies from 0.2–0.4 m in the south of the sea to 0.7–0.8 m in the north. In the most northwestern part of the sea and near the Gulf of Trieste the tide height may be as large as 1 m [7].

The greater water level fluctuations are caused by winds. When the north-east and south-west winds blow in the harbors in the North Adriatic the water level rises to 0.9 m and in the Port of Venice to 1.8 m. The northern winds may cause such recession of water that the sea floor of lagoons becomes exposed [6].

During Bora the water level drops by 0.4 m on the average. The seasonal variations of the water level in the Adriatic Sea are insignificant. The highest average monthly levels are usually recorded in November and December, while the lowest in January through March.

The seish-like fluctuations of the sea level are also observed; in some places they may be as high as 0.8 m [6].

7 Currents

The permanent tidal and wind currents are observed in the Adriatic Sea. They move at great speeds. Permanent currents represent a whirl directed counterclock-wise being, probably, a continuation of the general water circulation in the Ionian Sea. Waters from the Ionian Sea got into the Adriatic Sea via the eastern part of the Gulf of Otranto and generate the northwestern coastal current (Fig. 8). The backflow is created by cold waters of the North Adriatic (NAdDW) that are formed in winter and move to the south at great depth along the Italian shores. Some of these waters replenish deep waters (MAdDW) near the Pomo Pit in the central part of the Adriatic Sea [5]. The water exchange through the Gulf of Otranto features seasonal differences. In the winter at depths more than 300 m the waters move from the Adriatic Sea; in the horizon 700 m deep the velocities of 20–30 cm/s are recorded. In the summer in the deeper layers of the strait the water current from the Ionian Sea moves to the north with the speed of 5–10 cm/s. However, in the summer the south-directed current may also be observed near seafloor above the sill [9].

The general circulation consists of coastal currents and gyres that vary in space in different seasons. The Eastern Adriatic Current (EAC) goes along the eastern coast of the sea from the south to the north, forming three gyres – South Adriatic Gyre, Middle Adriatic Gyre, and North Adriatic Gyre (Fig. 8) [5]. In the circulation in the North Adriatic dominates the North Adriatic Current (NAdC) that turns waters to the south. In the winter (NAdC) is limited by northernmost part of the basin, while in the spring and summer it extends to the south. The Western Adriatic Current (WAC) goes along the Italian coast from north to south. In the central part of the Adriatic Sea it is known as Western-Middle Adriatic Current (W-MAdC). In autumn NAdC and W-MAdC joint to form the single current that may be traced in the southern part of the Adriatic Basin. Cyclonic Middle Adriatic Gyre (MAdG) is present in the central part of the Adriatic Sea in all seasons, except winter [5]. This

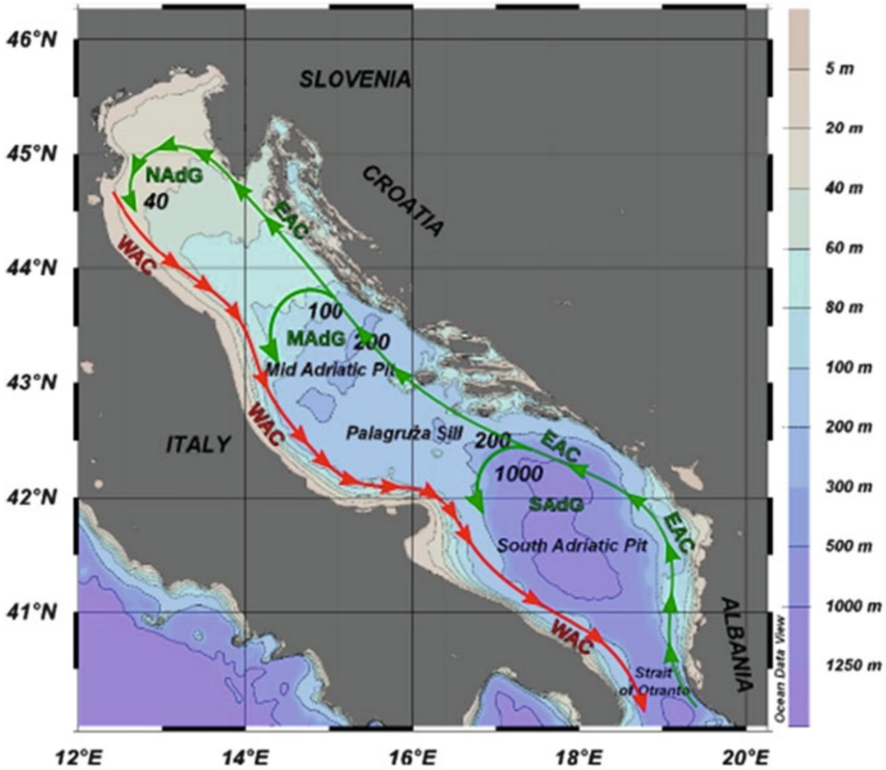

Fig. 8 General currents in the Adriatic Sea. *EAC* Eastern Adriatic Current, *WAC* Western Adriatic Current, *NAdG* North Adriatic Gyre, *MAdG* Middle Adriatic Gyre, *SAdG* South Adriatic Gyre (https://www.researchgate.net/figure/266886126_fig1_Figure-1-Adriatic-Sea-bathymetry-morphology-and-main-surface-circulation-redrawn-with)

current moves along the northeastern coast as far as the Mlet and Lastovo islands which deflect it somewhat to the west and further on it goes more seaward of the islands stretching along the Dalmatian coast and partially among them as far as the Istria Peninsula. From the northwestern coastal current near the Mlet and Lastovo islands the branch of the current deviates to the Palagruža islands and the Testa-del-Gargano Cape. Near the southernmost tip of the Istria Peninsula the current turns to the southwest. Sometimes it is found further to the north near the western shores of the Istria Peninsula [5].

However, in the northernmost part of the Adriatic Sea, to the north of the line Port Ancona – Dugi Otok Island, the system of currents is very complicated and variable. Here numerous gyres associated with the above-mentioned coastal northwestern current, river runoff, configuration of shores, and other factors are observed. It should also be mentioned that the river runoff produces essential influence on currents only after heavy rainfalls and locally. Turning to the southwest near the Istria Peninsula or going round the northernmost part of the sea, the coastal current passes further along the Italian coasts directed generally to the southeast. In the sea top the water gyres are observed rotating in the clockwise direction, thus, near the shore the current may be directed reversely compared to the current in the open sea [5].

At approaches to the Otranto Strait the branch is formed from the southeastern coastal WAC that goes eastwards joining the northwestern coastal current EAC and closing the water cycle in the Adriatic Sea. However, the main part of the southeastern coastal WAC continues its southern movement and gets into the Ionic Sea. The speed of the permanent coastal current is variable and makes, on the average, 0.3–0.5 knots. It depends, to a great extent, on the wind and the season of a year [5].

8 Flora and Fauna

The flora and fauna of the Adriatic Sea is rather diverse – over 7,000 species. More than 750 varieties of algae are growing here that may be divided into three groups: red, brown, and green. Four of the five kinds of algae inhabiting the Mediterranean are met in the North Adriatic along the Slovenian shores and the western coast of the Istria Peninsula in Croatia. *Cymodocea nodosa* and *Zostera noltii* are widespread, but *Zostera marina* and *Posidonia oceanica* are met quite seldom. The coastal area abounds in gastropods and bivalve mollusks having thick and strong shells protecting them reliably from wave impacts as well as *Echinoderm* and *Crustacea*. Currents bring here many soft and transparent jellyfish as well as night-fluorescent hydropolyps. In shallow areas there are many oysters, mussels, sea urchins, starfish, sea cucumbers (*Holothuria*), and small crabs; sea horses inhabit the thick algae growths. At greater depths there are found large *Crustacea* – lobster, large crabs, crawfish, as well as octopus, cuttlefish, starfish; at times eels and morays may appear here. The water mass abounds in plankton and fish fries. Of commercial fish you can find here sardine, scomber, mackerel, bonito, gray mullet, tuna, sea bream, common sea bream, sea bass, flatfish, lancet fish, and swordfish. The fishing of medium-sized shrimps is widespread here. The Adriatic Sea numbers 407 species and subspecies of fish representing 117 families; the *Osteichthyes* group includes 353 species and subspecies and the *Selachii* или *Chondrichthyes* group 54 species, which accounts for 72% of the known species and subspecies of fish in the Mediterranean (about 581 species and subspecies) [10–12]. In the recent decades the new fish species have been described in the Adriatic Sea which increased their number to 453 representing 120 families [13]. These are largely thermocyclic species which is perhaps connected with warming of the Mediterranean waters. Among sharks the pygmy sharks, piked dogfish, blue sharks, and fox sharks are common here, while the giant sharks are met very seldom. Among the mammals the dolphins and monk-seals referred to the threatened species live in the Adriatic Sea.

9 Sea Resource Management

The Adriatic's shores are populated by more than 3.5 million people; the largest cities are Bari, Venice, Trieste, Ravenna, and Rimini (Italy); Split, Rijeka, Zadar, Umag, Poreč, Rovinj, Pula, Opatija, Sibenik, Trogir, Dubrovnik, and Ploče (Croatia); Durres, Vlora, Lege, Fier, and Shkoder (Albania); Koper, Isola, and Piran (Slovenia); Budva, Bar, Herceg-Novi, Kotor, Tivat, and Ulcinj (Montenegro); and Neum (Bosnia and Herzegovina).

The shortest sea and air routes between the Apennine and Balkan peninsulas cross the Adriatic Sea. Railroads and automobile roads running to Central and Eastern Europe originate in northern ports on the Adriatic Sea.

In all times the favorable geographic position and good climate facilitated development of the cargo and passenger national and international shipping. There are nineteen Adriatic Sea ports playing important role in economics of littoral states. Each port handles more than a million tons of cargo per year. The largest cargo ports are Rijeka, Split, Pula, and Dubrovnik (Croatia); Bar, Kotor (Montenegro); Koper (Slovenia); Durres, Vlora (Albania); and Trieste, Venice, Bari, Ancona, and Brindisi (Italy). The greater part of these ports is found on the eastern coast of the sea. The largest cargo seaport in the Adriatic is Trieste, while the largest passenger seaport is Split. There are also numerous small ports being very important for local coastal shipping (Sibenik, Zadar, and others). The Adriatic is the sea for yachtsmen. Traveling on cruise and sport boats, yachting have become very popular here, which required extension of the existing and construction of new marinas as well as private quays and piers. Nautic complexes are widely constructed here. A number of naval bases may be also found on the coast.

Oil and gas are produced in the Adriatic shelf. About 100 platforms locate near the Emilia-Romagna area. Some areas of the Adriatic are used for construction of the liquefided natural gas terminals. The first such terminal was built in 2009 in the North Adriatic near Porto Levante (Rovigo Province, Venice, Italy). The construction of new terminals in the Gulf of Trieste (Alpi Adriatico Terminal) in the Italian territorial waters near Slovenia is planned. Availability of such terminals spurs competition with other marine activities in the Adriatic Sea. Thus, fishery is prohibited around terminals and pipelines connecting terminals with the coast.

ENI (Italy) and INA (Croatia) established a joint venture that started producing gas by platform Annamaria A in 6 wells in the Croatian waters in 2009. In the Italian waters platform Annamaria B started producing in 2010 (Fig. 9) [14].

Commercial and sport fishery and tourism are very important for economic development of the Adriatic Sea. Fishery (sardines, pelamyds) and mariculture are developing in the Adriatic, especially in its northern part, which is the fish-richest region in the Mediterranean. Freshwater river runoff into the shallow shelf of the North Adriatic in addition to the mixed seabed sediments and proximity to shores make this part of the sea highly productive. The Central and South Adriatic are less productive, but their openness to the impacts of the North Adriatic and periodical enhanced influence of the Mediterranean waters also increase productive

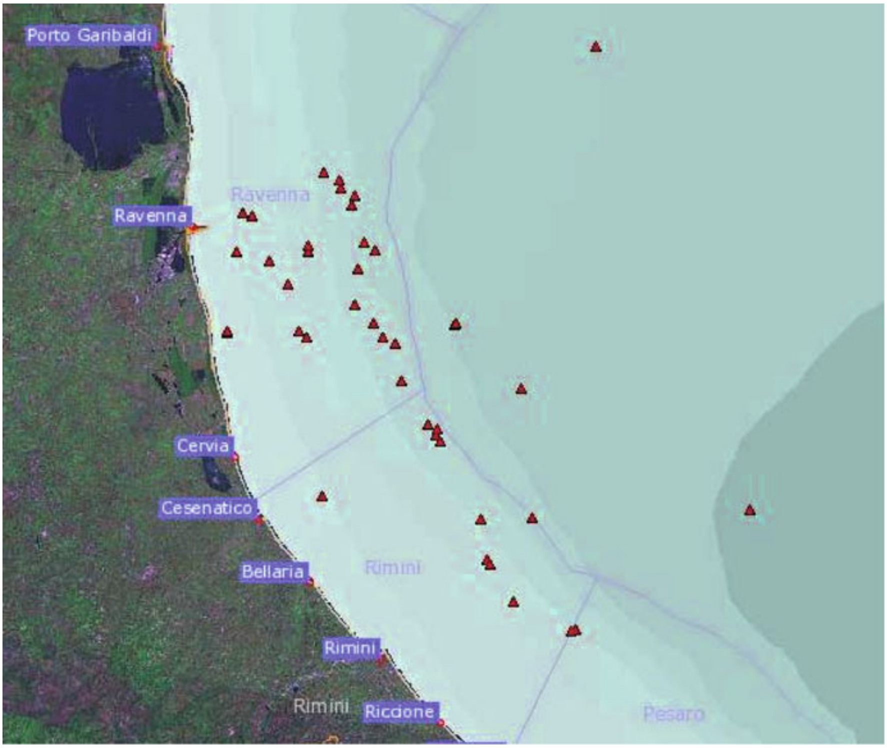

Fig. 9 Platforms along the coast of Emilia-Romagna [12]

capacity of these regions. Open Adriatic waters are considered suitable for pelagic fishing. The areas around Ancona (Italy) and Palagruža Sill are rich in fish, in particular pelagic. The coastal areas of the East Adriatic are traditionally very important fishery regions for professional and sport fishermen who use small fishing tackles.

It is considered that the Adriatic waters possess curative properties. The mixing of marine and mountain air on the coast with Mediterranean vegetation, saturated with the vapors of ethereal oils and phytoncids of the nearby conifer forests, combined with the useful substances contained in the sea proper create the unique conditions for health improvement and prophylaxis of many diseases of the breathing, cardiovascular, and nervous systems.

The Adriatic Sea abounds in seaside resorts and various beaches varying from multi-kilometer sandy, small-pebble, and pebble to rocky and stony. Beginning from the nineteenth century the most popular resorts on the Italian coast are Rimini, Bellaria, Idgea Marina, Cattolica, Pescara, Senigallia, Venetian Riviera (Jesolo Lido and Lingiano), and Palm Riviera (the sea coast from Mare Gabicce to San-Benedetto-del-Tronto). The tourism industry is dynamically developing in Croatia, Montenegro, Slovenia, and most recently in Albania. The Croatian coasts may boast of such seaside resorts as Dubrovnik, Split, Sibenik, Makarska Riviera, Pula as well as resorts on the Dalmatian islands. The main seaside resort in Montenegro is Budvanska Riviera. On not very large coast of Slovenia there are four resort towns – Koper, Isola, Piran, and Portorož. Bosnia and Herzegovina have only one small seaside resort Neum. The resorts in Albania locate around Durres and on the “Coast of Flowers” (from Vlora to Saranda). Active rest may include diving, windsurfing, kitesurfing, paragliding, regatta on yachts or catamarans, various kinds of fishing, underwater hunting, and many others.

To preserve biodiversity in the Adriatic Sea there were established the following marine protected areas (MPA): four in Italy, seven in Croatia, three in Slovenia, and one in Albania. Montenegro and Bosnia-Herzegovina do not have MPAs [12]. The Adriatic Sea is known as the site of major archeological sites and treasures, included in the UNESCO World Heritage List. They are underwater cities – Epidaurum near Cavtat (Croatia), Metamauko the Gulf of Venice, Spina at the mouth of the Po River, Conca near Gabicce, and others.

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References

1. Zonn IS, Kostianoy AG, Semenov AV, Joksimovic A, Kumantsov MI (2014) Adriatic Sea encyclopedia. Ratechnik, Moscow (In Russian)
2. Miho A, Kashta L, Beqiraj S (2013) Between the land and the sea. Ecoguide to discover the transitional waters of Albania. University of Tirana, Tirana
3. Cushman-Roisin B, Gacic M, Poulain P-M, Artegiani A (eds) (2001) Physical oceanography of the Adriatic Sea. Past, present and future. Springer, Dordrecht
4. Kaplin PA, Leontiev OK, Lukjanova SA, Nikiforov LG (1991) The coasts. Mysl, Moscow (In Russian)
5. Cataudella S, Spagnolo M (eds) (2011) The State of Italian marine fisheries and aquaculture. Ministero delle Politiche Agricole, Alimantari e Forestali, Rome
6. Pilot of Mediterranean Sea Part VI. The Adriatic Sea (1960). Department of Chief Hydrographic Service of the USSR Navy
7. Zinchenko AN (2010) Meteoconditions of the Adriatic Sea (In Russian)
8. Artegiani A, Bregant D, Paschini N, Pinardi N, Raicich F, Russo A (1997) The Adriatic Sea general circulation. Air-sea interactions and water mass structure. J Phys Oceanogr 27 (8):1492–1514
9. Zalogin BS, Kosarev AN (1999) The seas. Mysl, Moscow (In Russian)
10. Jardas I (1996) Jadranska ihtiofauna. Školska Knjiga, Zagreb
11. Dulčić J, Soldo A, Jardas J (2003) Adriatic fish biodiversity and review of bibliography related to Croatian small-scale coastal fisheries. Adriatic small-scale fisheries. Report of the AdriaMed Technical Consultation on Adriatic Sea small-scale fisheries. Split, Croatia, 14-–15 October 2003. AdriaMed Technical Documents 15:103–125
12. Joksimović A (2007) Najpoznatije Ribe Crnogorskog Primorja. Crnogorska Akademija Naukai Umjetnosti, Podgorica

13. Dulčić J, Dragićević B (2011) New fishes for the Adriatic and Mediterranean Sea. Institute of Oceanography and Fisheries and DZZP, Split and Zagreb, p 160
14. The Potential of the Maritime Spatial Planning in the Mediterranean Sea. Case Study report: The Adriatic Sea 2001

Physical and Geographical Description of the Boka Kotorska Bay

Sreten Mandić, Ivica Radović, and Dejan Radović

Abstract Compared to other parts of the Adriatic Sea, the Boka Kotorska Bay represents a unique and specific entity with its geographical position and geomorphological, climatological, hydrological and biotic characteristics. The sea deeply penetrates into the continent making it a unique fjord with the Mediterranean climate. The bay coastline length is 105.7 km, and the entire bay can be divided by its geographic–hydrographic properties into three entities: (1) the Kotor–Risan Bay, (2) the Tivat Bay and (3) the Herceg Novi Bay.

In biogeographical terms, the area of the Boka Kotorska Bay belongs to the Mediterranean region of the Adriatic–Ionian subregion of the Adriatic province characterised by sclerophyllous forest vegetation of the *Quercion ilicis* community and its derivatives in the form of shrubby formations of the type maquis, garrigue and rocky vegetation.

In the interior of the bay, in the base of mountains Lovćen, Orjen and Vrmac, there are small picturesque settlements creating an atmosphere of a nostalgia for history with all the magnificent old palaces, churches, cathedrals, towers, fortresses, defensive walls and similar. Almost 70% of all historical and cultural monuments of the whole of Montenegro are situated on the territory of the Municipality of Kotor.

The Boka Kotorska Bay (inner part from the Verige Strait: the Kotor–Risan Bay) was included in the UNESCO's list of cultural and natural heritage of the humankind at the conference held on 22–26 October 1979, in Cairo-Luxor, for the purpose

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of preservation and valuation of authentic geological, geomorphological, biological and cultural heritage.

Keywords Aquatorium (hydrographic and oceanographic characteristics), Boka Kotorska Bay, Geographical features (morphogenesis, geomorphology, hydrology, climatology), Terrestrial ecosystems, vegetation

Contents

1 Introduction

South Adriatic – that the Boka Kotorska Bay is a part of (Fig. 1) – is differentiated from other parts of the Adriatic by the biggest water mass of 26,000 km^3, compared to the total of 32,000 km^3 of the sea in the entire Adriatic, with the deepest part of the sea at 1,330 m, the fastest sea currents (42–88 cm/s, which is up to 6 times the speed of the current in other parts of the Adriatic), the more intensive direct water exchange with the Mediterranean as well as the greatest water transparency, reaching up to 60 m [1–3].

Indeed, all these abiotic parameters provide conditions for diversity in flora and fauna of the South Adriatic, which is incomparably higher than the biological diversity in the northern part. As an illustration of the biodiversity of the South Adriatic, or more specifically – Montenegrin Coast, we can present the fact that out of 435 fish species in the Adriatic, the South Adriatic is inhabited by 402 species, while out of 101 species of Echinodermata of the Adriatic, 57 species are found in the Montenegrin Coast and 42 species are present in the Boka Kotorska Bay [4–6]. The Montenegrin Coast itself covers a narrow strip of land extending from Debeli Brijeg on the north-west to the Bojana River on the south-east, with the total coastline length of 294 km, of which 105.7 km belongs to the Boka Kotorska Bay. To the north and north-east, the Montenegrin Coast is surrounded by steep slopes of the mountains Orjen (1895), Lovćen (1749), Sutorman (1180) and Rumija (1595) that divide it from the hinterland – the karst area and the Zetsko–Skadarska

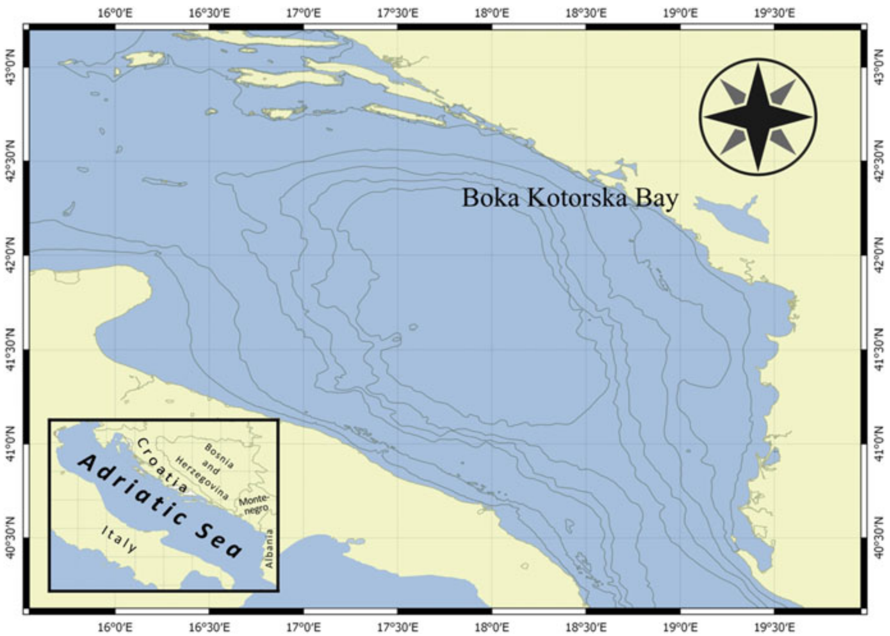

Fig. 1 South Adriatic and position of Boka Kotorska Bay [34]

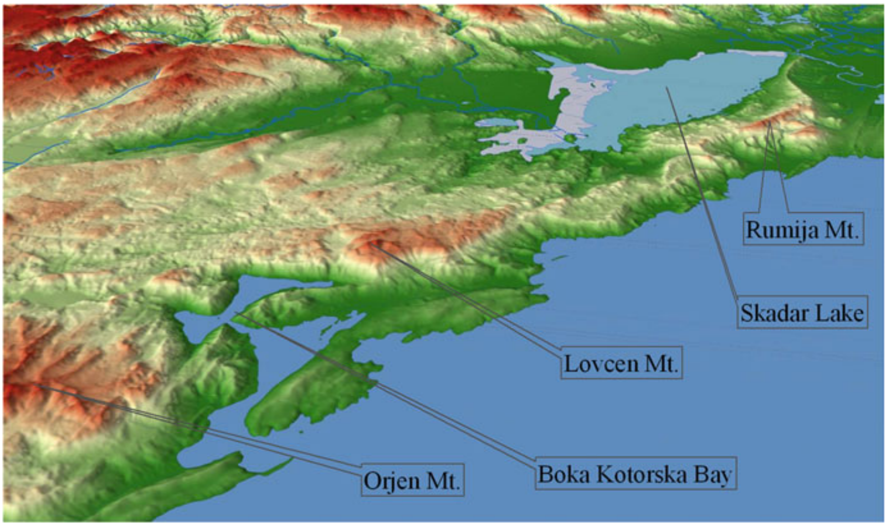

Fig. 2 Montenegrin Coast with the Boka Kotorska Bay [23]

depression (Fig. 2). There are numerous bays, inlets, flysch-like and sandy parts of the coast (beaches) with limestone capes (cliffs), spurs and crests, famous for numerous rock shelters and caves [7, 8].

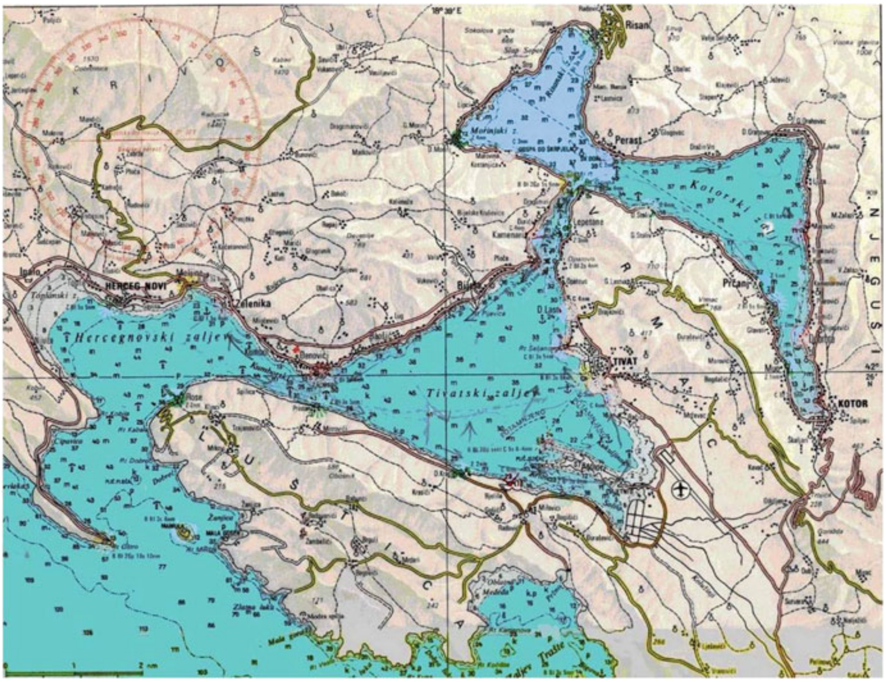

Fig. 3 The Boka Kotorska Bay – topographic map [34]

The Boka Kotorska Bay – one of the most beautiful, not only in the Adriatic, but in the Mediterranean – is clearly distinct in the indented coastline of this part of the Adriatic Sea. Compared to other parts of the Adriatic Sea, the Boka Kotorska Bay represents a unique and specific entity with its geographical position and geomorphological, climatological, hydrological and biotic characteristics. The sea penetrates into the continent deeply (a unique fjord with the Mediterranean climate) through two narrow channels (Kumbor and Verige), after which bays with expansion of around 36 km^2 open up (Fig. 2) [7, 9, 10]. In the interior of the bay, in the base of mountains Lovćen, Orjen and Vrmac, there are small picturesque settlements creating an atmosphere of a nostalgia for history with all the magnificent old palaces, churches, cathedrals, towers, fortresses, defensive walls and similar. Almost 70% of all historical and cultural monuments of the whole of Montenegro are situated on the territory of the Municipality of Kotor. These are surrounded by Mediterranean vegetation of olive, oleander, laurel, pomegranate, evergreen oak and chestnut trees (Fig. 3).

Due to all stated above, it is more than justified that the Boka Kotorska Bay (inner part from the Verige Strait, the Kotor–Risan Bay) was included in the UNESCO's list of cultural and natural heritage of the humankind [11] (Fig. 4), by the World Heritage Committee at the conference held on 22–26 October 1979, in Cairo-Luxor (Egypt), for the purpose of preservation and valuation of authentic geological, geomorphological, biological and cultural heritage.

Fig. 4 UNESCO, World Heritage, Kotor [11]

2 Geographical Features

2.1 Morphogenesis and Geomorphological Characteristics

As already stated, the Boka Kotorska Bay consists of an intersection of intertwined gorges and steep, almost vertical escarpments, surrounding four sub-entities within the bay. The sea penetrates deepest into the continental limestone mass in the base of the Orjen and the Lovćen, thus making the overall geomorphological structure quite diverse and specific.

Complex hydrological and hydrogeographical characteristics of the karst in the Montenegrin Coast resulted in quite pronounced differences in the explanation of morphogenesis and formation of the Boka Kotorska Bay. Thus Savicki, 1912 [from

10], believes that “detailed forms of the Bay were formed by river erosion, but tectonic predisposition must not be forgotten”. An identical view is shared by Milojević [12] who underlines that this area was most probably formed by a combined action of tectonic forces and fluvial erosion.

According to Cvijić [13, 14], the Boka Kotorska Bay was formed by the rising of surrounding mountains during the Pliocene and Pleistocene. Before that, in Cvijić’s opinion, the Grahovska River used to flow there, “karsted parts of which are protected from Grahovo, along Dvrsno and Krivošije to Risan”, followed by the flooding of two parallel valleys – the Hercegnovski–Tivatska and the Morinjsko–Kotorska, considered to be mouths of the former Grahovska River and other smaller watercourses. These two valleys are connected with the erosion rupture Verige, 300 m in width.

However, Radjičić [10, 15, 16] challenges this explanation of the Boka Kotorska Bay formation, stating that today there are no traces of a canyon valley that should have been preserved in the limestone had the “Grahovska River” ever flowed through it. In his view, the Boka Kotorska Bay, just like all the fields in karst, was created in the Pliocene by denudation and fluvial erosion on flysch and intensive corrosion in limestone in zones of contact with flysch.

Steep slopes of the Orjen and Lovćen create the dominant framework of the Boka Kotorska Bay, as well as ridges that connect them. Their parts from Morinj to Kotor, as pronounced karst areas, have very steep cliffs, while in other parts, they lean on younger flysch sediments in the form of overlap faults and overthrust (Figs. 2 and 5). In difference to pronounced karst slopes, flysch slopes are much milder, and in some places, they develop into small basinlike and plain-like parts. The Orjen itself is a quite distinct mountain massif with steep slopes spreading in all directions, except towards the Bijela Gora. It is characterised by quite pronounced forms of karst relief formed by erosion and glaciation. These are primarily depressions and sinkholes, but many other karst relief forms are also present. Glaciation process on the Orjen was intensive, and glaciers had significantly modified the karst relief in their respective directions of movement [17].

The Lovćen and the Orjen rise above the Boka Kotorska Bay almost vertically and then descend more gently towards the hinterland – the plateau of the Katunski Krš, with Njeguško and Cetinjskog Fields, as well as the plateaus Krstac and Ivanova Korita, numerous depressions, hillocks, etc. (Fuštić, Đuretić, 2000) (Fig. 5). Glaciation process on the Lovćen was less intensive than on the Orjen. Nevertheless, glaciation traces can be seen primarily in moraines towards Njeguši, Krstac and Cetinjskog Fields [18].

Eocene flysch parts occur in several places on the territory of the Boka Kotorska Bay. First of all, Sutorinsko–Grbaljska flysch zone can be distinguished, spreading from the Debeli Brijeg through Sutorina and then from Tivat to Jaz. Flysch zones can be seen also around the Morinjski Bay and around Risan, Orahovac and St. Trinity above Kotor [19]. Sutorina is a valley around 7 km in length and 3.5–4 km in width. From the valley, along its right side, the headland and ridge Oštra (361 m) rises, ending with the ridge Kobila and the Prevlaka. Numerous plateaus, floors and slopes spread in various elevations from Sutorina to Morinj.

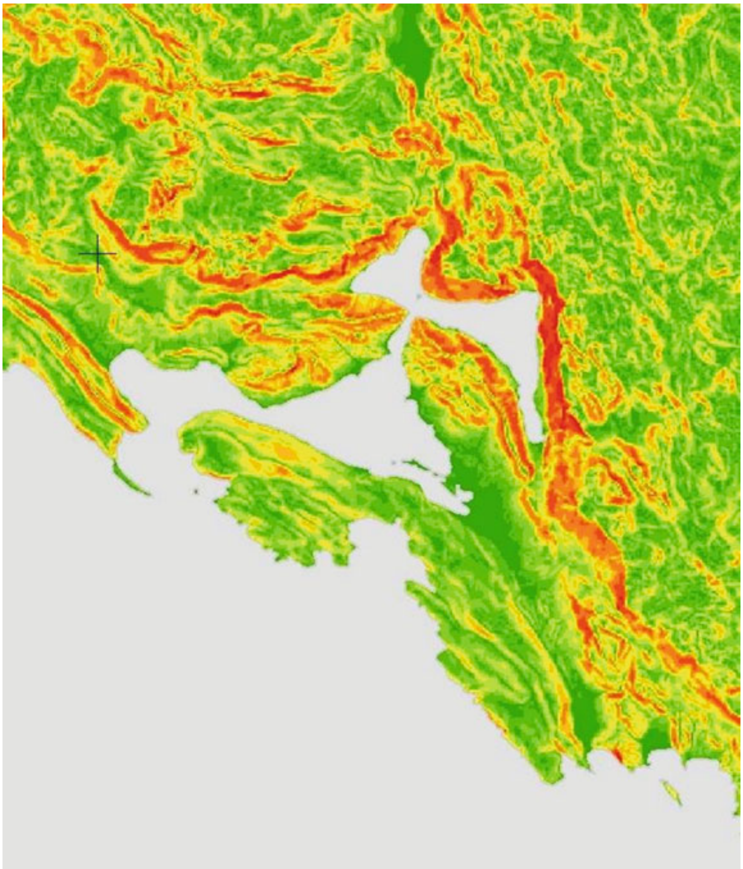

Fig. 5 Boka Kotorska Bay – terrain slope angles [23]

Relief forms are milder from Igalo to Savina, as well as around Zelenika. Steeper terrain can be found on the Devesilj Hill, western slopes of which descend steeply towards Zelenika; south and east slopes descend towards Đenovići, Baošići and Bijela; and on the northern side towards Morinj. The flysch steep terrain spreads further to Vrmac (768 m), northern slopes of which are characterised by a large number of parallel gullies. East of the Tivat Bay towards Jaz, Tivatsko, Grbaljsko and Mrčevo Fields spread out. From these fields, the flysch zone gradually rises towards the Lovćen through mild slopes, terraces and rounded hummocks. The transition from the Tivat Bay and Tivatsko Field into the Luštica Peninsula (around 50 km^2) is also gradual. The Luštica is a flat land with several sinkholes, depressions, passes and ridges. Towards the inner part of the Boka Kotorska Bay, the Luštica Coast is steeper and unindented, while the part towards the open sea has a larger number of capes (8) and coves (9). The Grbaljsko Hill has a similar relief, with a depression stretching over the middle part from the Trašte Bay to the Trsteno

Bay, while the relief towards the open sea is characterised by a large number of capes, coves and steep cliffs.

2.2 Climatological Characteristics

Climatic factors having a major effect on the climate of the entire Montenegrin Coast and hence the Boka Kotorska Bay are latitude and vicinity of the sea and the vegetation cover. Montenegrin coastline belongs to modified Mediterranean or Adriatic climate. The water mass of the Mediterranean and its part of the Adriatic Sea has a more than distinctive effect on the climate of this area. Namely, intense cyclone activity over the Mediterranean in the colder half of the year – and over Africa throughout the year – brings rainfall. On the other hand, during summer period, high-pressure field forms above the Mediterranean Sea, causing calm, warm and sunny weather. Furthermore, it is also necessary to state that the Adriatic Sea belongs to warm seas, so that too is one of the important parameters of climatic characteristics of the Boka Kotorska Bay [20]. The specific and very dynamic relief of the Boka Kotorska Bay also has a significant effect on climatic characteristics. Mean annual temperatures decrease for every 100 m of altitude by 0.6°C, while precipitation rises to an elevation of up to 1,100 m. The climate is also influenced by the direction of relief forms, their concavity, slope angles and exposition. All of this results in higher daily and annual temperature amplitudes in sites and locations farther from the sea.

Mean annual air temperatures of the entire Montenegrin Coast, including the Boka Kotorska Bay, are high, ranging from 14.8°C Tivat, 15.6°C Bar and Ulcinj, 15.7°C Herceg Novi and 15.8°C Budva [7, 21, 22]. Summer periods are long in the entire Montenegrin Coast as the Adriatic Sea, being a warm sea, does not have a major cooling effect on the coast. Mean air temperature in summer in Herceg Novi is 23.2°C, while the extreme maximum air temperature recorded in Herceg Novi is 42°C. Annual mean number of summer days (temperature above 25°C) in the Boka Kotorska Bay is around 110. Frosts occur rarely even in winters, so mean air temperature in winter period in Herceg Novi is 8.8°C, with extreme minimum temperature in Herceg Novi of −7°C (Fig. 6).

Annual rainfall distribution and precipitation are among the most important climatological parameters determining the climate of the Boka Kotorska Bay. Average precipitation on the whole territory of Montenegro is heterogeneous. Average precipitation in the wettest areas of Montenegro is almost 6 times average precipitation in the least rainy areas. It is the south-western part of Montenegro – the area of the Orjen Mt, with the highest annual average precipitation ranging from 3,000 to 5,000 mm. The highest precipitation in the area of the Orjen Mt. is in Crkvice (1,097 m) above the Risan Bay, with annual average precipitation of 4,742 mm, which is the European maximum rainfall. The maximum annual precipitation in Crkvice was recorded in 1,938–8,063 mm [10]. The mean rainfall in Herceg Novi is 1,940 mm (665 mm in winter, 190 mm in summer), while in Tivat it

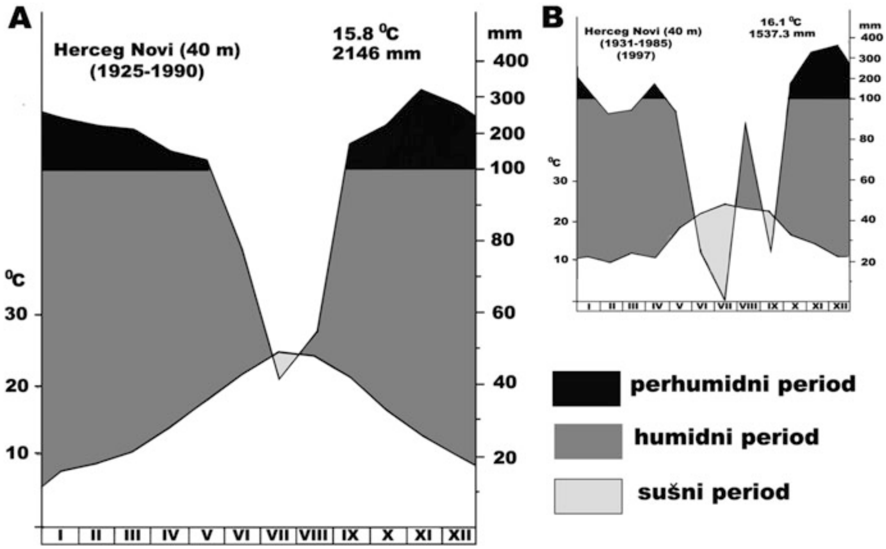

Fig. 6 Climographs of Herceg Novi, (**a**) for period 1925–1990, (**b**) for period 1931–1985 [24]

is 1,674 mm (55 mm in winter, 19 mm in summer). The highest mean monthly precipitation are in November and December in Crkvice – 706 mm. High rainfalls in the Boka Kotorska Bay can sometimes happen in just 1 day. There have been several occasions where rainfall of above 400 mm was recorded in a single day in Crkvice, and on 21 November 1927, the precipitation was 480 mm [10, 23] (Fig. 7).

The above-mentioned annual and maximum monthly precipitation results from air circulation from the south and the Orjen massif spreading perpendicular to the wind direction. In pluviometric regime, the Boka Kotorska Bay is characterised by pronounced aridity in summer periods. This is caused by low precipitation and high temperatures in late spring, summer and early autumn. In some years, dry period can begin in spring and last till late autumn. Such precipitation and rainfall distribution, along with complex geological composition, soil structure and relief not only cause specific and diverse hydrological phenomena and forms in the entire terrestrial part of the Boka Kotorska Bay, it also makes hydrological properties of the seawater of the Boka Kotorska Bay quite specific, almost unique, primarily in terms of high-salinity variation amplitudes (summer–winter period).

Apart from temperatures, it is the winds, their direction, frequency and notably intensity, that form an important climatic element of the Boka Kotorska Bay. It could be generally said for Montenegrin Coast that south-east and east winds prevail. Thus, in Herceg Novi the most frequent wind is east (11.9%), south-east (10.3%) and south (8.6%), while calm periods (no wind), resulting from its sheltered position, account for 40% [24] (Fig. 8). In general, locations in the Boka Kotorska Bay have far more calm periods during the summer period of the year than in winter, opposite to the inland parts of Montenegro where the number of calm periods is higher in winter [7]. Winds characteristic of the Boka Kotorska Bay are

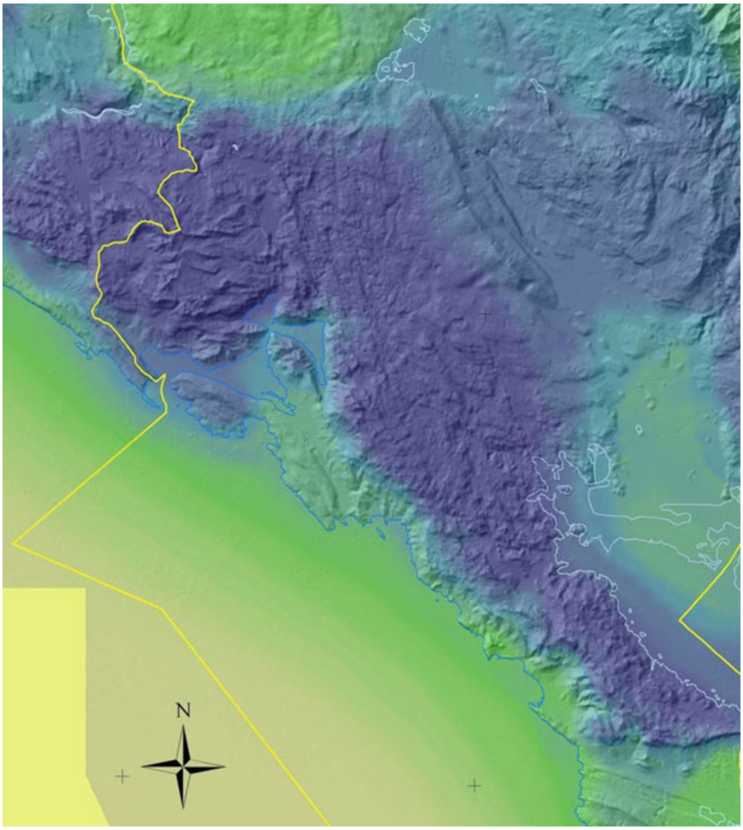

Fig. 7 Winter period precipitation on Montenegrin Coast [23]

Bora, Sirocco and Mistral. Bora blows from the north and north-east. It is mainly katabatic strong anticyclonic, rarely cyclonic wind, plummeting temperatures, reducing cloudiness and air humidity. In the area of the Boka Kotorska Bay, Bora "flows over" the mountain massifs of the Orjen and Lovćen bringing significant temperature drop. It usually blows 3–7 days. In the Boka Kotorska Bay, widely known by intensity are Orahovac Bora and Risan Bora. Bora as a wind has a significant effect on the seawater quality in the bay, since it creates short and strong waves, particularly in winter, which significantly contribute to seawater aeration, that is, increases dissolved oxygen levels.

Sirocco is a warm wind from the southern quadrant, bringing clouds and heavy rainfall. Sometimes it blows for several days at the same speed, as a strong, but rarely stormy wind. When a strong south flow of Africa, bringing volcano dust or volcano ash, penetrates the warm cyclone sector from the Western Mediterranean, it can cause yellow or red rain in the Montenegrin Coast. The air mass it carries, rising up in the coastal mountains Orjen, Lovćen and Rumija in the hinterland, gets the characteristics of the Foehn (south Foehn) and can cause a sudden rise in

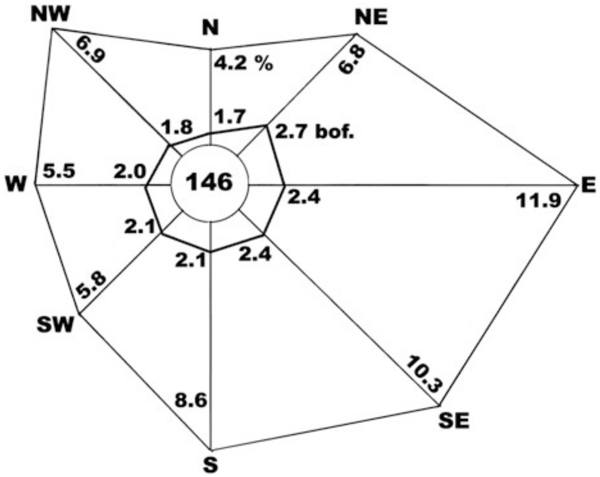

Fig. 8 Wind rose diagram for Herceg Novi [23]

temperatures in winters, followed by snow melting and flooding (typical for the Cetinjskog Field – flood of 1986). Bora and Sirocco blow throughout the year, but they blow more frequently during the winter half of the year [10].

Mistral is a south-west and west wind. It is an even, clear sky wind blowing from the sea towards the land, bringing pleasant refreshment in hot summer days. It is very good for sailing.

Burin, also known as night wind (*noćnik*), blows from the shore towards the sea at nights, particularly after the rain, in mountains close to the sea.

The most frequent wind throughout the year in the Boka Kotorska Bay is south-west (15%), with N, NE and SE equally represented with around 8% each; all other directions are much less frequent. On average, the strongest are N and NE winds with the mean Beaufort force 3.9 and 3.2, respectively [9].

In general, according to the Koppen climate classification, the Boka Kotorska Bay climate belongs to the Mediterranean climate, characterised by hot summers and pronounced summer droughts. Average temperature of the coldest month is above −3°C and below 18°C. Average temperature of the warmest month is above 22°C. This climate type is characteristic for the entire Montenegrin Coast and the area of the Zetsko–Bjelopavlicka Plain [22, 24]. More specifically, the climate of the Boka Kotorska Bay belongs to a perhumid Mediterranean climate type, characterised by high rainfall in winter and spring and even higher in autumn and winter, with a very short dry period in July–August (Fig. 9).

2.3 Hydrographic and Hydrological Characteristics

The entire area of the Boka Kotorska Bay belongs to the Adriatic Sea Basin, and it could be said that it has a poorly developed network of surface watercourses,

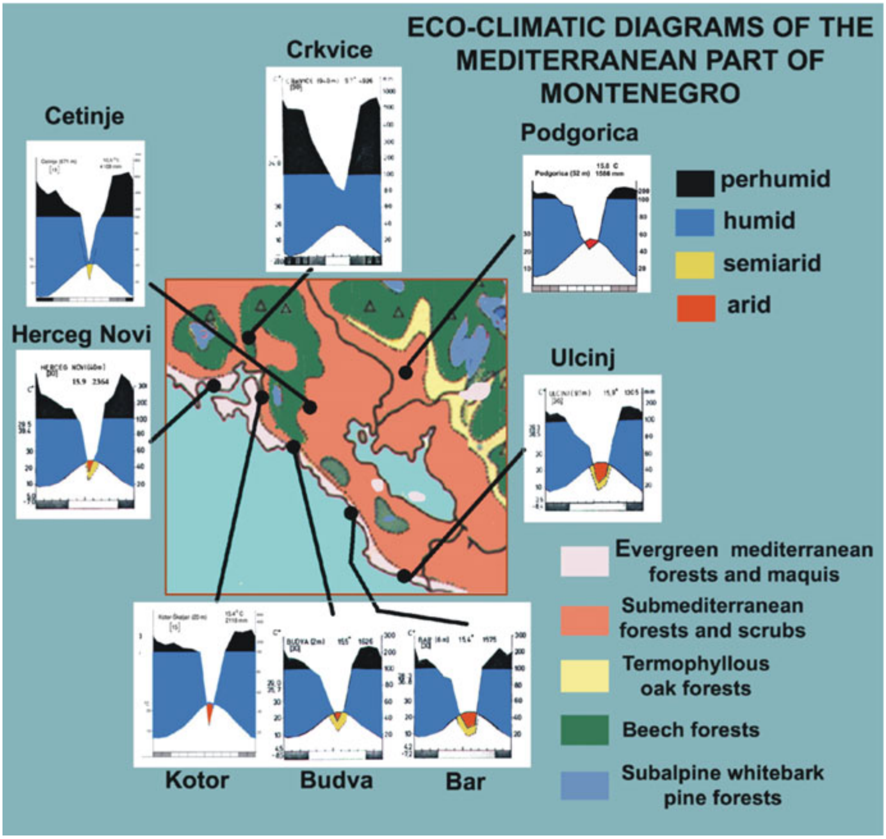

Fig. 9 Ecoclimatic diagrams of the Mediterranean part of Montenegro [24]

resulting primarily from geological structure of the terrain dominated by carbonate rocks, where waters are lost to the highest depths. As regards surface watercourses, in the area of the Bay of Boka Kotorska it consists of a network of short rivulets and brooks, the largest of which is the Sutorina River, in the vicinity of Herceg Novi. On the other hand, groundwaters and ground watercourses in karst are quite specific and complex. Development and circulation of ground holes in limestone take place to their lower limit, often several hundred and even thousand metres below sea level. In the area of the Boka Kotorska Bay, three directions of groundwater movement have been identified. An underground hydrological network was identified between the Grahovska River and Spila well in Risan. Karst valley Trešnjevo drains underground towards the Ljuta well near Orahovac, and underground hydrological connections between the well Ljuta and swallow hole Erakovići in Njeguško Field have been identified. The swallow hole Erakovići supplies the wells Škurda and Gurdić in Kotor with water. Gurdić well receives water by underground conduits from the pit Duboki Do in Njeguško Field, as well as from the swallow hole in Ivanova Korita [10].

Wells and springs are doubtlessly the most interesting forms of all hydrological phenomena in the karst of Montenegro and hence of the Boka Kotorska Bay. Well systems occur in karst, where karst erosion or tectonics created deep gorges where the extensive network of groundwaters is collected. In the area of the Boka Kotorska Bay, there are Morinjska wells, Sopot and Spila near Risan, wells Škurda and Gurdić in Kotor and well Ljuta near Orahovac. In winter part of the year, these wells give approximately 230 m/s of water, on average. In addition to these six wells, the narrow coastal strip between Kotor and Morinj (25 km), 200 m in width, also has a larger number of smaller brackish (briny) wells, so the total number of wells is much higher than anywhere else in the Adriatic–Dinaric Coast [10, 21].

Submerged springs present a specific hydrological phenomenon in karst and they are a special type of springs. These are freshwater springs occurring on the bottom of the sea. They occur when the pressure of freshwater in the underground canal is higher than the pressure of seawater on the canal opening. Well Gurdić in Kotor has characteristics of a submerged spring, and in rainy period of the year, it is rich in freshwater bursts below the sea level. In addition to Gurdić, submerged springs occur in the Boka Kotorska Bay under the steep slopes of the Lovćen between Ljuta and Perast, as well as under the slopes of the Orjen between Risan and Morinj. Submerged spring Risanska, immediately below the Sopot well, is among the most interesting in this area.

In the farthest north-west part of the Boka Kotorska Bay, the major wells can be found in the area of Mokrin, Sutorina and Mojdež. Mokrin wells, extending from the north-west towards south-east, are joining the Morinj wells. The abundance of Mokrin wells is illustrated by the fact that they are included in the water supply system for the population of Herceg Novi. The spring Opačica is situated in the suburban zone of Herceg Novi (Zelenika); it is a spring cave with a complex hydrological network below the sea. Opačica is the only well in the Boka Kotorska Bay whose water does not get salty in summer. In winter, with higher inflow, Morinjska wells supply freshwater, and that is the period when smaller wells (submerged springs), up to 800 m away from the shore, become active. Sopot (by the road Morinj–Risan, 800 m from Risan) is a very specific well. It bursts at the elevation of 40 m from a cave with the entrance of 10 m in width and 4 m in height. Risanska submerged springs are just in front of Sopot and they are hydrologically connected below the sea level. During heavy rainfall, channels of submerged springs cannot absorb all the water, and a part of it bursts via sinkhole channels through the Sopot well, whose water flows into the sea in the form of a waterfall from a height of 40 m. During heavy rainfall, in winter, the abundance of the Sopot can reach 150 m^3/s [10]. Apart from Sopot, Risanska wells include also Spila, north-west from Risan, 300 m from the coastline. The spring orifice is approximately 10 m above the sea level, 8 m in width and 3 m in height. Hydrological explorations identified a connection between the Spila well and the swallow hole in the Grahovsko Field. In rainy period, Spila waters are used to supply Risan with water [10].

The most important well in the area of Orahovac is Ljuta, which is the most abundant brackish well in the Boka Kotorska Bay. The well bursts in the immediate vicinity of Orahovac, on the road to Kotor, between large, steep blocks of rock, above which vertical slopes around 900 m rise. Its abundance is estimated at 300 m^3 /s of water during the periods of heavy rainfall. In rainy period, watercourse Ljuta, around 100 m in length, is formed from the well to the shore.

Kotorska wells – Tabačina, Škurda and Gurdić – are situated immediately by the walls of the Old Town of Kotor. Wells Tabačina and Škurda are captured wells and used to supply the town of Kotor with water (until construction of the regional waterworks supplying water from the Skadar Lake). In times of heavy rainfall, up to 230 l/s of water was pumped. In summer, salinity rose and water could not have been used for drinking. After the catastrophic earthquake struck the Montenegrin Coast in 1979, attempts were made to prevent the influence of the sea and salinisation during summer by injection curtain, but the attempt resulted in a complete failure due to complexity and integrity of the underground hydrological network of Kotor. Hydrological exploration identified an underground connection between the swallow hole Duboki Do in Krstac and these wells. The third of Kotorska wells is Gurdić, located in front of the east gate of the Old Town, and it is a complex well system – brackish well, estavelle and submerged spring. The well orifice is located 12 m below the sea level. It is supplied with freshwater from the Lovćen (Njeguško Field and Ivanova Korita) and its highest abundance is approximately 30 m^3/s. In summer months, when inflow of freshwater is reduced, the estavelle is filled with seawater [10].

In addition to these wells, between Morinj and Kotor, the Plavda well on the road between Lepetane and Tivat should be mentioned; its waters had been used for supplying a part of waters to Tivat. In rainy periods, watercourses Gradiošnica, Vodolježnica and Kol ožun are formed in the Grbaljsko Field, in the base of the Lovćen. A short Jaška River that flows into the sea in the Jaz cove flows through the Mrčevo Field.

As far as river flows in the area of the Boka Kotorska Bay are concerned, the Sutorina is the main river of the region of Herceg Novi. The river source is below Nagumanac (Debeli Brijeg), watersheds towards Konavle and flows into the sea west of Igalo. Throughout its course smaller tributaries flow into it from the left bank, formed from the well and source Mojdež. Mineral water source Slatina is situated in south-western part of the alluvial plain of Igalo and its water is believed to have healing properties. The largest spring is used for the needs of the Institute Dr. Simo Milošević in Igalo, and the second largest is the source next to the Hotel Complex Njivice [10].

3 Terrestrial Ecosystems and Vegetation

In biogeographical terms, the area of the Boka Kotorska Bay belongs to the Mediterranean region of the Adriatic–Ionian subregion of the Adriatic province characterised by sclerophyllous forest vegetation of the *Quercion ilicis* community and its derivatives in the form of shrubby formations of the type maquis, garrigue and rocky vegetation. What makes the Boka Kotorska distinct from the rest of the Mediterranean region of the Montenegrin Coast is the presence of laurel forests (*Laurus nobilis*) on one side and relatively low sub-Mediterranean xerophilic deciduous forest and shrubby vegetation and pseudo-maquis on the other. Effect of winds from the surrounding mountains and high rainfall resulted in widespread Mediterranean phanerophytes resistant to temperature fluctuations, such as a number of sub-Mediterranean deciduous species like *Quercus pubescens*, *Castanea sativa* (in flysch and acid soils), *Ostrya carpinifolia*, *Quercus trojana*, *Carpinus orientalis*, *Punica granatum*, etc., while evergreen elements are relatively rare (*Quercus ilex*, *Arbutus unedo*, *Phillyrea latifolia*, *Spartium junceum*, *Rhamnus alaternus*, *Smilax aspera*, etc.). Present are also *Fraxinus ornus*, *Juniperus oxycedrus*, *Olea oleaster*, *Myrtus communis*, *Pistacia lentiscus*, *Rosa sempervirens*, *Punica granatum*, *Asparagus acutifolius*, *Lavandula officinalis*, *Salvia officinalis* and *Origanum vulgare*. As regards cultured plants, lemons, oranges, tangerines, figs (*Ficus carica*), almond (*Prunus amygdalus*), carob (*Ceratonia siliqua*) service tree (*Sorbus domestica*), pomegranate and olives are grown (countries bordering Mediterranean grow olives most). The Luštica Peninsula is an area with typical Mediterranean perennial vegetation [25].

From the shoreline towards the tops of the Orjen, and partly Lovćen, the following vegetation zones can be observed, in the following order. The lowest zone consists of the Euro-Mediterranean evergreen sclerophyllous forests and maquis formations that are consistent with the Adriatic climate effects and rise up to about 500–600 m. The second zone consists of the sub-Mediterranean thermophyllous oak forests and scrub formations. This zone rises up to beech forests, which make the third zone. Finally, the fourth elevation zone is orobiome which is characterised, mainly in Orjen, by coniferous species *Pinion heldreichii* and *Pinion peucis* (subalpine whitebark pine forests) [24, 26–29].

A larger number of different habitat types can be discerned on the territory of the Boka Kotorska Bay [26] as follows:

- Low tidal highly saline mudflats overgrown by communities from the *Thero-Salicornion* and *Arthrocnemion fruticosi* association. Solila Bay in the Grbaljsko Field, by the Tivat Airport. Formerly used for salt exploitation (saltworks in Tivat).
- Hard-leaved scrub – maquis from the *Quercion ilicis* and *Oleo-Ceratonion cocciferae* and *Oleo-Lentiscetum* association. Maquis is widespread around Igalo, from Zelenika to Morinj, Vrmac, Luštica and Grbalj.
- Community of low shrubs of Euro-Mediterranean and sub-Mediterranean region and thermophilic limestone terrain of the continental part are partly covered by *Chrysopogoni-Satureion*, *Satureion subspicatalae* and *Satureion montanae* associations.
- Mediterranean-sub-Mediterranean herbaceous associations, often mosaically interchanging with rocky grounds: *Vulpio-Lotion* and *Cymbopogono-Brachypodion ramosi*.

- Mediterranean and sub-Mediterranean laurel forests from the *Laurion nobilis* association. Notably present along the line Risan–Morinj–Kostanjica. A protected reserve of laurel (*Laurus nobilis*) and oleander (*Nerium oleander*) community is just above Sopot, towards Risan.
- Mediterranean forests of holm oak forests from *Quercion ilicis* association (community type *Orno-Quercetum ilicis*) as a result of a millennium-long exploitation (from the Roman period for galley building to Venetians for sailing ships) practically do not exist in a preserved form. Today, there are just individual trees or small groups of this oak, primarily on the Luštica. Renewal of these forests could have a major effect on revitalization of original values of coastal areas.
- Natural or artificial Mediterranean forests of Aleppo pine (*Pinus halepensis*) and stone pine (*Pinus pinea*).
- Thermo-mesophilic chestnut forests on acid substrate (seen immediately by the sea –Kostanjica, Stoliv). Within them, laurel and chestnut community is particularly interesting.
- Broadleaved deciduous forests (sub-Mediterranean): beech, sessile oak–hornbeam and sessile oak–Turkey oak and Hungarian–Turkey oak forests (Orjen).
- Sub-Mediterranean xerophilic forests of the Mediterranean hinterland from the *Ostryo-Carpinion adriaticum* association.
- Subalpine forests of Bosnian red cone pine on limestone from *Pinion heldreichii* associations and Macedonian pine forests on silicates from the *Pinion peucis* association (typical of high areas of the Orjen, quite localised on the Lovćen).

4 Hydrographic and Oceanographic Characteristics of the Boka Kotorska Bay Aquatorium

From the geographic and oceanographic viewpoint, the Boka Kotorska Bay is a semi-closed basin with specific hydrographic characteristics. This results in major annual, seasonal, monthly and daily changes of physical oceanographic sea parameters; thus, determining the pattern of certain changes and processes is quite a complex undertaking. Communication of the bay with the open part of the Adriatic takes place through the Cape Oštra–Cape Mirište passage. The bay coastline length is 105.7 km, and the entire bay can be divided by its geographic–hydrographic properties into three entities: (1) the Kotor–Risan Bay, divided from the rest of the bay by the Verige Strait; (2) the Tivat Bay, divided from the rest of the bay by Verige and Kumborski Straits; and (3) the Herceg Novi Bay, divided from the rest of the bay by Kumborski Strait and from the open sea by a junction of Cape Oštra and Cape Mirište [9, 30].

4.1 Bathymetric Characteristics

The main bathymetric characteristic of the entire bay is a relatively great depth in bays and communication straits between certain entities and the entire area with the open sea (Fig. 3, Table 1). The greatest depth of about 60 m at the entry into the bay is gradually decreasing further in, ranging between 40 and 45 m in larger part of the bay. The maximum depth was determined in the Kotor Bay during an exploration of the Boka Kotorska Bay by the Hydrographic Institute of Montenegro's Navy, as a narrow indentation, 64 m in depth, south-east of Perast [31].

The characteristic of all bays is that depths increase towards the central zone and greater depth isobaths are getting closer to the shoreline. Thus, for example, the 20 m isobath follows the configuration of the shoreline at a distance of 200–300 m, except in the eastern part of the Tivat Bay and western part of the Herceg Novi Bay. Such vertical profile of the bay enables a clear stratification of specific oceanographic parameters and creation of a thermocline and pycnocline in specific seasons throughout the year.

Bottom Type According to Lepetić [32], clay is typically found in sea bottom in the Kotor Bay and Risan Bay, while sandy clay is found just in front of the town of Risan. In addition to clay, clayey–loamy sand can be found in the Tivat Bay, while the sea bottom of the Herceg Novi Bay is covered by clay, loamy clay, sand and clayey sand [33]. Central parts of the bay are covered by fine terrigenous mud with detritus elements [30]. Craggy sea bottom with submerged reefs and sinkholes is found in the coastal strip of the inner part of the Boka Kotorska Bay, particularly from Orahovac to Perast and from Risan to Morinj. Submerged reefs can also be found at the entry into the bay and in the Verige Strait. Between the reefs, at the entry into the Boka Kotorska Bay, sandy and muddy elements occur, and in the Verige, the bottom is covered by terrigenous mud [2, 32, 34].

Bay Water Volume The total volume of the Boka Kotorska Bay is approximately 2,412,306,300 m^3, divided into the following entities (Table 2).

Based on annual precipitation, size of the drainage basin area gravitating to the bay as well as freshwater inflow through submerged springs, the average annual inflow is estimated at approximately 15–18 m^3/s, though it varies from 3–4 m^3/s to 180–200 m^3/s. Immediately above the Risan Bay is the area with the highest precipitation in Europe (Crkvice with 4,742 mm annual average for the period

Table 1 Average and maximum depths, by bays [9, 31]

	Average depth (m)	Maximum depth (m)
The Boka Kotorska Bay (as a whole)	27.6	64.0
The Kotor Bay	26.0	64.0
The Risan Bay	25.7	36.0
The Tivat Bay	25.5	46.0
The Herceg Novi Bay	31.0	60.0

Table 2 Volume values of the Boka Kotorska Bay [35]

	%	Volume (m^3)
The Kotor Bay	18.2	439,039,747
The Risan Bay	8.5	205,046,035
The Tivat Bay	36.9	878,079,493
The Herceg Novi Bay	36.4	890,141,025

1961–1990). In fact, such and thus intensive inflow of freshwater is saving the Boka Kotorska Bay from the eutrophication process. Namely, according to the data available, it is estimated that annual inflow of wastewaters into this area is around $5 \times 10\ m^3$, which is around 0.2% of the total water mass of the Boka Kotorska Bay. Such hydro-meteorological situation imposes the need to place diffusers of submarine main drains much farther from the coast, i.e. to conduct all wastewaters from the Boka Kotorska Bay into the open sea [35].

In that regard, any form of new industrial pollution can aggravate the situation further. As already known, the facility for unloading, storage and loading of fuels in Lipci, the Port of Zelenika, overhaul facility in Tivat, shipyard in Bijela (still active), as well as a large number of vessels posed particular risk to the bay water quality in recent history, not only because of continuous pollution of the pelagic and benthic zones but also because of the risk of serious accidents that could have an irreversible effect [25]. Continuous and uncontrolled discharge of wastewaters from households, tourist facilities and urban settlements is particularly intensive in the summer period, when the hydrodynamics of the water exchange in the Boka Kotorska Bay is reduced to the minimum. The quality of the water intended for recreation and mariculture thus significantly deteriorates.

4.2 Physical Characteristics

The values of the basic physical characteristics of seawater surface throughout the year, temperature, salinity and transparency, are given for the Kotor–Risan Bay (Table 3) [1, 36].

4.2.1 Sea Temperature

As regards temperature, the Adriatic Sea as a whole, including the Boka Kotorska Bay, belongs to the group of moderately warm seas with temperatures ranging from 12 to 25.2°C [3, 36, 37]. Since the Boka Kotorska Bay is a quite closed and shallow basin, with an inflow of a large quantity of freshwaters, the temperature regime dynamics is very pronounced. A pattern in this area is that mean temperature values increase from the Kotor towards Tivat and Herceg Novi Bays, primarily due to the freshwater inflow [38].

Table 3 Hydrographic data for the Kotor Bay – SURFACE [1, 36]

Month	Temperature (°C)	Salinity (ppt)	Oxygen (mg/l)
X	21.7	34.2	6.39
XI	18.1	27.7	7.97
XII	7.0	9.5	9.88
I	8.3	12.21	8.69
II	9.9	9.8	8.81
III	11.5	9.43	9.31
IV	13.6	12.0	8.81
V	16.4	9.2	9.11
VI	25.4	22.3	8.01
VII	22.7	34.7	8.07
VIII	25.5	35.2	7.67
IX	24.7	32.8	8.11

In the Kotor–Risan Bay, average surface temperatures throughout the year range from 7.00 to 25.5°C, in the Tivat Bay average sea temperatures range from 12.05 to 26.62°C, and in the Herceg Novi Bay from 11.93 to 25.60°C. However, on 30 July 1998, sea surface temperature in the Kotor Bay (Prčanj) reached the whole of 31.4°C, which is the highest temperature measured since the beginning of temperature recording in this area [1, 3, 36]. On the other hand, in winter, due to the high inflow of freshwaters, the lowest surface temperatures occur in the Kotor and Risan Bays, where as a result of smaller depths and higher inflow of freshwater surface layers cool faster than those in the outer parts – Herceg Novi Bay. Some parts of the Kotor Bay (from Orahovac to Perast) as well as of the Risan Bay in winter may be covered also by a thin ice layer at air temperatures below 0°C.

In intermediate layers (between 10 and 30 m), summer temperatures range between 17.8 and 20.8°C. These temperatures are particularly highlighted because they are important for the water quality in the Boka Kotorska Bay. Summer periods are in any way the most loaded season in the year, when apart from sea heating and calm weather without wind (calm), the population number multiplies (due to the increased number of tourists) along with the wastewater quantity that is discharged untreated into the bay, average depth of which is just 27.3 m [1, 36].

4.2.2 Salinity

Salinity values in the Boka Kotorska Bay vary throughout the year, which can be seen in particular when values are analysed by layers. The highest oscillations occur in the shallow waters of Kotor Bay and Risan Bay, cutting deeply into the land, ranging from 9.2 to 35.2 ppt on the surface, naturally depending on the rainfall and inflow of freshwater from the shore and submerged sources. In the Tivat Bay, oscillations are much lower, ranging from 12.68 to 37.39 ppt, with the lowest ones in the Herceg Novi Bay, ranging from 18 to 37.67 ppt [1, 3, 34, 36].

4.2.3 Oxygen Concentration

Oxygen concentration (ml/l) in the sea shows seawater ventilation, but also the oxygen production by the phytoplankton community in the photosynthesis process. Since production cannot take place in the absence of nutritive salts in the sea, the oxygen values indirectly indicate also the presence of nutritive salts in the sea that are, for the most part, brought into the coastal seawater through sewerage deposits from land. Average oxygen quantities in the Kotor–Risan Bay range between 6.39 and 9.88 ml/l. Average oxygen quantities in the Tivat Bay range between 5.33 and 7.14 ml/l and in the Herceg Novi Bay between 5.00 and 7.49 ml/l. The values stated at the Boka Kotorska Bay in entirety indicate, at the same time, good ventilation and high production, compared to the Adriatic as a whole, where these values are usually around 6 ml/l [1, 3, 36].

4.2.4 Oxygen Saturation

Oxygen saturation is quite high in the entire Boka Kotorska Bay, and it is rather balanced, considering high production. Oxygen saturation values at the level of the bay and in entirety range between 95.08 and 162.63% at the sea surface, which is the result of intensive photosynthetic phytoplankton activity, but also the result of meteorological factors – wind and sea currents [1, 3].

4.2.5 Colour

Seawater colour in the Boka Kotorska Bay (according to Forel–Ule scale) ranges from blue (IV) to greenish (V–VI), particularly in the Kotor part, and then, regardless of the season, during heavy rainfall, it can become yellow brown (XIX–XX). In the Tivat part, colour usually ranges from blue green (VII–VIII) to umber green (XIII–XIV) and, in the Herceg Novi part, from dark blue green (III–VI) to umber (XXI) [1, 3].

4.2.6 Transparency

Sea transparency in the Boka Kotorska Bay is typically lowest in the most indented part – the Kotor Bay – and the highest in the Herceg Novi Bay. However, in summer, transparency is often reduced even in the area around Herceg Novi, from the Hotel Plaža to Njivice (first of all, due to significant inflow of sewage waters). In some years, transparency ranges between 3 and 16.15 m and is never above 20 m. Just as transparency, the sea colour depends, among others, from the quantity of dispersed particles in water, in areas with high production and inflow of freshwater, such as the Kotor Bay (particularly its border parts); such transparency distribution is no surprise [1, 2, 34].

4.2.7 Circulation

Water mass circulation in the Boka Kotorska Bay is rather uneven and depends mainly on the tides and free oscillations, so-called seiches [9]. Wind and water pressure as well as fresh and saltwater mixing have the major impact on the direction and intensity of currents in the Boka Kotorska Bay (Fig. 10). Intensive water mass dynamics for the Boka Kotorska Bay aquatorium in entirety is significant, for the most part, in its surface layer. It is most intensive at the times of maximum freshwater inflows (rainfall, drainage from the shore, submerged sources). In this period, intensive circulation is present only in the surface layer, up to 5 m in depth, which is more a result of surface delevelling than of continuous circulation system, so adequate compensation current in deeper layers and hence the continuous exchange of water mass cannot be relied on. Circulation in deeper layers is mainly the result of effect of tidal currents, causing a low net transport of water masses throughout the bay. In the summer seasons, circulation intensity is even lower, and this particularly refers to the peripheral parts of a number of bays (the Port of Kotor, Risan, Krtole and Topla Bays).

On the other hand, winds and their direction and intensity have a significant effect on seawater circulation. Thus, a high percentage of calm (windless) days on

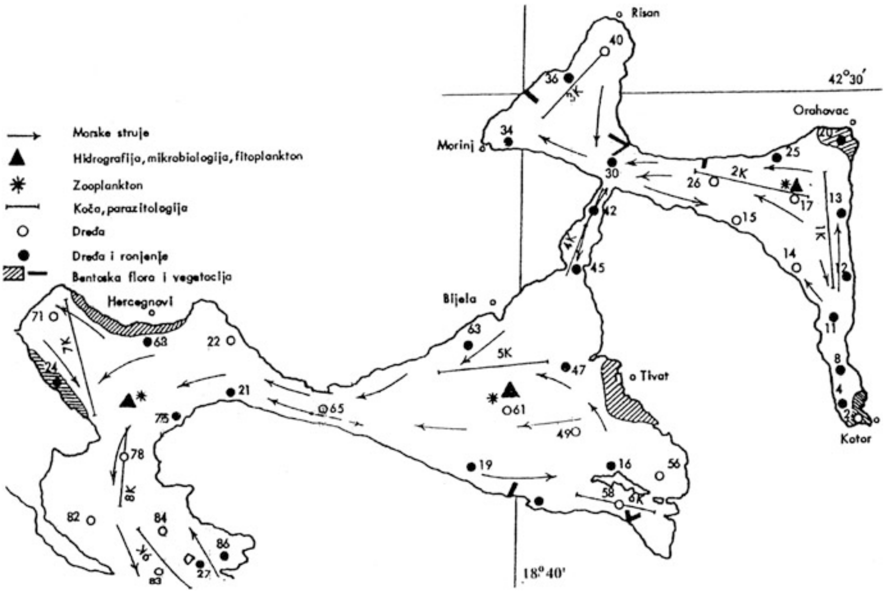

Fig. 10 Seawater circulation in the Boka Kotorska Bay [9]

one side and high frequency of winds blowing towards the shore and the outgoing current significantly reduce the intensity of seawater circulation and purification of the bay. These phenomena actually press the surface layer water towards the shore and thus create unfavourable conditions for wastewater discharge. This is particularly noticeable in summer period in the Tivat Bay, when winds from the west sector, along with calms, account for almost 80%. Similar situation, somewhat more favourable, is typical also for the Herceg Novi Bay, particularly its Topla part. In summer, currents are weak, while in autumn, winter and in spring, they are quite strong. Incoming current, moving in the north-west direction, is stronger in summer. Furthermore, from October to May, vertical water circulation occurs in the Boka Kotorska Bay, quite noticeable in the inner part of the bay. These currents raise deposits of nutritive salts and detritus from the bottom and thus contribute significantly to the increase in quantity of nutrients and productivity in general. In the Kotor and Risan Bays, strong turbulent currents are noticeable, intensity of which grows with the higher inflow of freshwaters, and they are typical also for areas where larger quantities of freshwater flow into – Morinj and Orahovac [39].

In the Kotor–Risan Bay, in months with a relatively low inflow of freshwater on the surface, the circulation flow takes an outward direction, with lowest speeds in peripheral parts of the bay. In the central layer, at the depths of 5 and 10 m, currents maintain the outward direction, but their intensity is much lower. Water circulation speed in the Verige Strait is around 0.66 knots (34 cm/s). In higher inflow of rainfall and spring freshwater, the circulation dynamics becomes more intensive. Dynamics is still the lowest in the peripheral part of the bay, while circular flow currents occur at times, as a result of shore configuration. Speed ranges from 0.1 to 0.5 knots (5 to 26 cm/s). In the Verige Strait, strong outward currents can reach from 0.9 to 1.1 knots (46 to 5 cm/s) [35].

Exploration of diversity of early developmental stages of fish (ichthyoplankton) in the Boka Kotorska Bay confirmed the presence of a large number of eggs and larvae of pelagic fish species, highest percentage of which belong to economically important fish species. It was found that 38 different fish species spawn in the Boka Kotorska Bay (28 genera and 18 families), while diversity analysis shows a high degree of diversity in certain points with pronounced water circulation (Kumborski and Verige Straits) [40].

4.2.8 Tides

As regards analysis of seawater dynamics of tides (high tide–low tide) based on mareograph measuring, it can be said that water level oscillation is slightly more intensive in the area of the Kotor and Risan Bays than in other areas due to the shape of the basin, low-intensity communication with the open seas and higher inflow of rainfall waters. Thus, the value of mean daily amplitude is 25.1 cm and maximum multiannual 125.5 cm, which is approximately 20 cm more than those in the Herceg Novi Bay. In the Herceg Novi Bay, mean daily amplitude is 22 cm, with maximum multiannual amplitude of 106.5 cm [9].

5 Conclusion

Compared to other parts of the Adriatic Sea, the Boka Kotorska Bay represents a unique and specific entity with its geographical position and geomorphological, climatological, hydrological and biotic characteristics. The sea penetrates into the continent deeply (a unique fjord with the Mediterranean climate).

Complex hydrological and hydrogeographical characteristics of karst in the Montenegrin Coast resulted in quite pronounced differences in explanation of morphogenesis and formation of the Boka Kotorska Bay. Thus Savicki, 1912 [from 10], believes that *detailed forms of the Bay were formed by river erosion, but tectonic predisposition must not be forgotten*.

The climate of the Boka Kotorska Bay belongs to a perhumid Mediterranean climate type, characterised by high rainfall in winter and spring and even higher in autumn and winter, with a very short dry period in July–August. Annual rainfall distribution and precipitation are among the most important climatological parameters determining the climate of the Boka Kotorska Bay. The highest precipitation in the area of the Orjen Mt. is in Crkvice (1097 m) above the Risan Bay, with annual average precipitation of 4742 mm, which is the European maximum rainfall.

The entire area of Boka Kotorska Bay belongs to the Adriatic Sea Basin, and it could be said that it has a poorly developed network of surface watercourses, resulting primarily from geological structure of the terrain dominated by carbonate rocks, where waters are lost to the highest depths. Groundwaters and ground watercourses in karst are quite specific and complex. Development and circulation of ground holes in limestone take place to their lower limit, often several hundred and even thousand metres below sea level.

In biogeographical terms, the area of the Boka Kotorska Bay belongs to the Mediterranean region of the Adriatic–Ionian subregion of the Adriatic province characterised by sclerophyllous forest vegetation of the *Quercion ilicis* community and its derivatives in the form of shrubby formations of the type maquis, garrigue and rocky vegetation.

From the geographic and oceanographic viewpoint, the Boka Kotorska Bay is a semi-closed basin with specific hydrographic characteristics. This results in major annual, seasonal, monthly and daily changes of physical oceanographic sea parameters; thus, determining the pattern of certain changes and processes is quite a complex undertaking.

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(1) Grant of project: Research, use and protection of the littoral areas of South Adriatic. Project OSI – 267 (2001) Federal Ministry for Development, Science and Environment. Belgrade.

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(3) Project III 46002 (2011–2016). Ministry of education, science and technology development of the Republic of Serbia.

References

1. Regner D (2001) Biološke karakteristike, zaštita i unapređenje kvaliteta morta, str. 18-41. U: Istraživanje, korišćenje i zaštita litoralnog područja Južnog Jadrana. In: Mandić S (ed) Studija: Projekat OSI-267. Institut za biologiju mora, Kotor
2. Joksimović D (2012) Sadržaj teških metala u ekosistemima Crnogorskog primorja kao posledica zagađenja životne sredine. Doktorska disertacija, Tehnološko-metalurški fakultet, Univerzitet u Beogradu, 174 str. Beograd
3. Joksimović A (2007) Najpoznatije ribe Crnogorskog primorja. Crnogorska akademija nauka i umjetnosti, Posebna izdanja (Monografije i studije). Knjiga 58: 144 str. Podgorica
4. Kljajić Z (2013) Izveštaj: Program monitoringa stanja ekosistema priobalnog mora Crne Gore za 2013. godinu. Institut za biologiju mora Kotor, Univerzitet Crne Gore, Kotor, pp 1–55
5. Kašćelan S, Mandić S, Kljajić Z, Radović I (2006) Synthesis of the Echinoderm fauna of the Boka Kotorska bay. In: Proceedings of the symposium, II international symposium of ecologists of the Republic of Montenegro, ISEM 2, Kotor, pp 37–44
6. Petović S (2011) Contribution to the knowledge of Echinodermata of the Boka Kotorska Bay. Studia Marina 25(1):137–158
7. Fuštić R, Đuretić G (2000) Zemljišta Crne Gore. Biotehnički institut. Univerzitet Crne Gore, 626 str. Podgorica
8. Radović D, Džukić G, Stevanović V, Bulić Z, Bušković V, Lakušić D, Radović I (2006) GIS technologies as a tool for geodiversity and biodiversity conservation of Skadar Lake region. In: Proceedings of the symposium, II international symposium of ecologists of the Republic of Montenegro. ISEM 2. Kotor, pp 391–400
9. Mandić S (2001) Prirodne karakteristike Južnog Jadrana: batimetrijske i hidrodinamičke karakteristike voda Bokokotorskog zaliva, U: Istraživanje, korišćenje i zaštita litoralnog područja Južnog Jadrana. In: Mandić S (ed) Studija: Projekat OSI-267. Institut za biologiju mora, Kotor, pp 1–10
10. Radjičić B (2005) Vode Crne Gore. Filozofski fakultet u Nikšiću, Institut za geografiju, 390 str. Nikšić
11. World Heritage in Yugoslavia, UNESCO, Natural and Cultural Treasures (1990) Kotor 88–101; Založba Mladinska knjiga, Ljubljana, 175 pp
12. Milojević B (1953) Boka Kotorska. Zbornik radova Geografskog instituta SAN, Beograd
13. Cvijić J (1924) Geomorfologija, knj. I, Izdanje državne štamparije, Beograd
14. Cvijić J (1926) Geomorfologija, knj. II, Izdanje državne štamparije, Beograd
15. Radjičić B (1983) Prirodno-geografske karakteristike opštine Nikšić. Urbanistički institut, Zagreb
16. Radjičić B (1996) Geografija Crne Gore – prirodna osnova. Univerzitet Crne Gore, Filozofski fakultet, Nikšić
17. Bešić Z (1969) Geologija Crne Gore, knj. II, Karst, Zavod za geološka istraživanja Crne Gore, Titograd
18. Vasović M (1955) Lovćen i njegova podgorina. NDCG, Cetinje
19. Lješević M (2003) Geografija zemljišta. Univezitet Crne Gore, Filozofski fakultet u Nikšiću, 220 str. Nikšić
20. Mandić S, Mrdak D (2007) Marinska biologija. Kotor, Podgorica, pp 1–124
21. Radulović M (2000) Hidrogeologija karsta Crne Gore. JU Republički zavod za geološka istraživanja, Posebna izdanja GEOLOŠKOG GLASNIKA, Knjiga XVIII: 1–286. Podgorica.
22. Burić M, Micev B, Mitrović L (2012) Atlas klime Crne Gore. Crnogorska akademija nauka i umjetnosti, 131 str. Podgorica
23. Radović D (2008) Primena GIS tehnologija u vrednovanju i zaštiti prirodnih potencijala regiona Skadarskog jezera. Doktorska disertacija. Geografski fakultet, Univerzitet u Beogradu, 361 str. Beograd
24. Radović I, Stevanović V, Regner S, Mandić S, Bulić Z (2005) Adriatic Sea and Coastal Zone of Serbia and Montenegro: characteristic of biodiversity and possibilities for their sustainable

exploitation (Forth plenary: trans regional expertise - Baltic, Mediterranean and Black Sea regions). In: International conference: integrative approaches towards sustainability. Abstracts, p 19, Riga - Jurmala, 11–14 May, Latvia
25. Radović I, Stevanović V, Gržetić I, Tanasković M (2003) Naučno-stručna recenzija/ekspertiza elaborata “Procjena uticaja na životnu sredinu terminala za pretovar cementa u luci Zelenika”, urađen od strane Instituta za razvoj i istraživanje u oblasti zaštite na radu, Zavod za ekologiju Podgorica. Naručilac SO Herceg Novi, 30 str. 3 tab. Herceg Novi
26. Stevanović V (1997) Biogeni potencijali (Biodiverzitet) razvoja Crne Gore 44-74, U: Pravci razvoja Crne Gore ekološke države. Finalni izveštaj. Evropski centar za mir i razvoj, ECPD, Beograd, 362 pp
27. Topisirović Lj (ed) (1997) Studija: Kriterijumi valorizacije aplikativnih potencijala komponenti biodiverziteta Savezne Republike Jugoslavije. Savezno ministarstvo ua razvoj nauku i životnu sredinu, Sektor za životnu sredinu, Beograd, pp 1–187
28. Stevanović V, Radović I, Regner S, Mandić S, Bulić Z, Joksimović A, Radović D (2006) Adriatic Sea and coastal zone of Serbia and Montenegro: characteristic of biodiversity and possibilities for their sustainable exploitation. In: Filho WL, Ubelis A, Berzina D (eds) Sustainable development in the Baltic and beyond. Baltic University programme. Uppsala University, Sweden, University of Latvia, Riga. Peter Lang, Europaisher Verlag der Wissenschaften. GMBH, Frankfurt am Main, Berlin Bern, Bruxelles, New York, Oxford, Wien, pp 239–253. ISSN 1434-3819; ISBN 3-631-55282-3; US-ISBN 0-8204-9915-3
29. Radović I, Stevanović V, Bulić Z, Joksimović A, Radović D, Regner S, Mandić S (2013) Biodiversity and Sustainability of the Mediterranean part of Montenegro. International Science Conference: Reporting for Sustainability. Bečići, Montenegro 7th–10th of May. Conference Proceedings: 83–89 (Invited paper). In: Brčevski I, Laušević R (eds) EMC Environmental Management Center in Serbia, The Regional Environmental Centre for Central and Eastern Europe, Country Office Serbia, Norwegian Embassy in Serbia, Norwegian Ministry of Foreign Affairs, Belgrade, 511 pp, ISBN 978-86-7550-070-4
30. Karaman G, Gamulin-Brida H (1970) Contribution aux recherché des biosensors benthiques du Golfe de Boka Kotorska. Studia Marina 4:3–43
31. DerMap Project Report (2011) Satellite spectral analyses of the Bay of Kotor, Montenegro 2010–2011, 94 p
32. Lepetić V (1965) Sastav i sezonska dinamika ihtiobentosa i jestivih avertebrata u Bokokotorskom zalivu i mogućnosti njihove eksploatacije. Studia Marina 1:3–127
33. Mačić V (2001) Taksonomska, morfološko-anatomska i fiziološka istraživanja morskih trava *Posidonia oceanica* (L.) Del. and *Cymodocea nodosa* (Ucria) Asch. u Bokokotorskom zalivu u cilju zaštite. Magistarski rad Inžinjerstva za životnu sredinu TEMPUS, Univerziteta u Novom Sadu, 97 str. Novi Sad
34. Đurović M (2012) Ekološka istraživanja juvenilnog inćuna *Engraulis encrasicolus* (Linnaeus, 1758) u Kotorskom zalivu. Doktorska disertacija. Biološki fakultet, Univerzitet u Beogradu, 129 str. Beograd
35. Mandić S (2001) Bioekološki potencijali priobalnog mora Crne Gore. U: Istraživanje, korišćenje i zaštita litoralnog područja Južnog Jadrana. In: Mandić S (ed) Studija: Projekat OSI-267. Institut za biologiju mora, Kotor, pp 11–17
36. The influence of anthropogenic factors on wildlife in the coastal zone of the Montenegrin coast. National project (2012–2015). Ministry of Science, Montenegro
37. Pérès JM, Gamulin-Brida H (1973) Biološka oceanografija (Bentonska bionomija Jadranskog mora): Školska knjiga, Zagreb, 493 str
38. Stjepčević J (1967) Makro-Mollusca Bokokotorskog zaliva. Studia Marina 2:3–64
39. Stjepčević J, Parenzan P (1980) Il Golfo delle Bocche di Cattaro - condizioni generali e biocenosi bentoniche con carta ecologica. Studia Marina 9–10:3–149
40. Mandić M (2011) Sezonski aspekti diverziteta ihtioplanktona u Bokokotorskom zalivu. Doktorska disertacija. Biološki fakultet, Univerziteta u Beogradu, Beograd, 169 pp

Morphobathymetry of Boka Kotorska Bay

Giovanni Bortoluzzi, Federico Giglio, Marco Ligi, Fabrizio Del Bianco, Valentina Ferrante, Luca Gasperini, and Mariangela Ravaioli

Abstract Boka Kotorska Bay is an enclosed water body with a narrow and shallow connection to the Adriatic Sea; the shallowest point is only 37.6 m deep at present, limiting exchange of water with the Adriatic. The Bay is one of the most important transitional areas of the Adriatic from both an environmental and a socio-economic viewpoint. High resolution geophysical data collected during several scientific cruises carried out between 2008 and 2013 reveal unknown details of present-day morphology and sedimentary infilling geometry. Multibeam bathymetry combined with seismic reflection images suggests that the observed morphologies are due to the interaction at different timescales of climate, water circulation, sealevel changes, erosion, sedimentation and tectonics constrained by the geological and structural setting of the area. The Bay is composed by three major basins (Herceg Novi, Tivat and Morinj–Risan–Kotor), connected by two narrow straits (Kumbor and Verige) with a maximum depth of 67 m. It shows steep upper slopes and flat sub-basin central sectors lying at depths ranging from 35 to 45 m. Among the several morphological features shaping the seafloor, we note: deeply incised valleys and delta fans related to past sealevel falls; slope failures and mass wasting triggered by strong earthquakes; channels bounding the steep slopes of Kumbor and Verige narrow passages, and sediment wave fields in Verige Strait formed by strong bottom currents; and karst morphologies developing at seafloor with submarine siphons, springs and resurgences (pockmarks) fed by karst hydrology of Boka Kotorska Bay's surroundings.

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Contents

1 Introduction

Littoral morphology results worldwide from the interaction between climate, sealevel changes, erosion, sedimentation and tectonics. Several examples of transitional areas can be found in the eastern border of the Adriatic Sea, characterized by fragmented coastlines, islands and coastal bays. Bays and estuaries interact with the main basin influencing it and being influenced by it in terms of circulation patterns and freshwater supply. One of the most intriguing features along the entire Adriatic coast is the bay of Boka Kotorska, where the sea enters inland for over 20 km. The Bay is located in the southern-eastern Adriatic Sea along the Montenegrinian margin, and is well known since antiquity. The Bay is composed by three main basins, connected by two narrow straits (Kumbor and Verige straits ~350 m wide) with a total shore length of ~106 km, a total surface of ~84 km^2 and a maximum depth of ~60 m (Fig. 1). The Bay is surrounded by high mountains that are part of the Dinaric range; in particular, to the south-east by the limestone massifs of Lovcen mountain (1,749 m) and to the north-west by the slopes of Orjen (1,895 m), Radostak (1,446 m) and Dobrostica (1,570 m) mountains. For this reason the Bay is improperly considered as the southernmost fjord in Europe, although its origin is not related to glacial processes [1, 2]. In fact, Boka Kotorska Bay is part of a ria coastal system, where the valleys were formed mainly during the Messinian Salinity Crisis (~5 Ma), when the Mediterranean Sea was nearly completely dry [3] and sealevel dropped more than 1,000 m, allowing regressive erosion of the landscape. This resulted in a very deeply incised morphology below modern sealevel by a river flowing NE-SW, orthogonal to the orientation of the main tectonic structures, with its tributaries, parallel to them. In the hard limestone formations, narrow and steep valleys were incised while in the soft flysch layers, the river and tributaries formed wide valleys, causing the NW-SE orientation of the

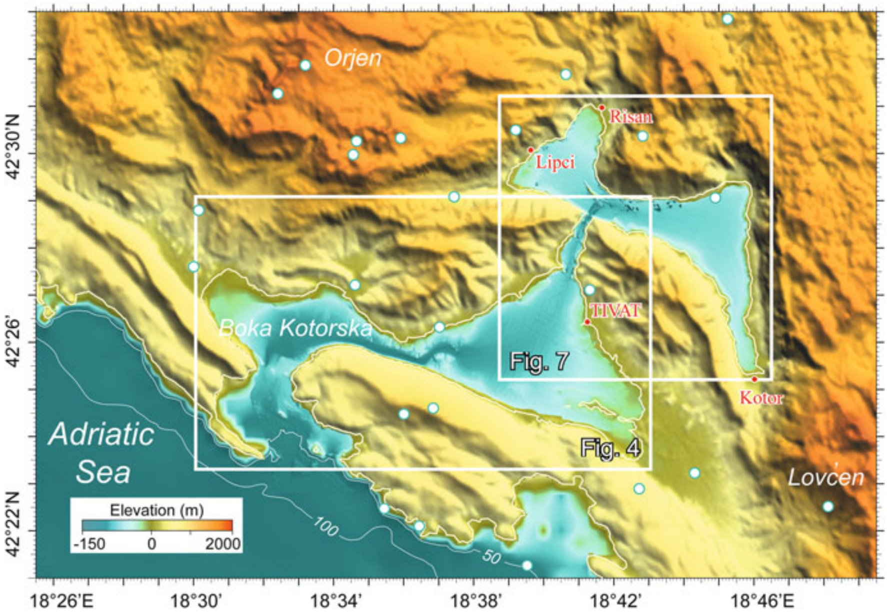

Fig. 1 Topography of the Boka Kotorska Bay. *White dots*, earthquake epicentres with magnitude > 4 since 1976 from International Seismological Data Centre. The numbered *white boxes* refer to the area displayed in Figs. 4 and 7. Isobath contour interval 50 m, *white lines*. Mercator projection at 42°30′N, ellipsoid WGS84

major basins [2, 4]. Today's morphology and coastline were shaped after the last glacial maximum (LGM), when the sealevel rose over 100 m causing more narrowing and widening within the Bay area [4]. The area is the richest region for precipitations in this part of the Mediterranean and represents one of the most highly karstified areas in the world. Starting from the Adriatic Sea, three NW-SE trending geomorphological provinces can be distinguished onshore: 'Coastal Montenegro', 'Budva-Cukali' and 'High Karst' (Fig. 2b). Well-studied surface occurrences of halokarst processes characterize this region, such as karst plains or poljes, temporary rivers, caves, sinkholes, large ponors and concentrated underground flows [2, 4–7].

However, despite the historical and geostrategic role of Boka Kotorska since the pre-roman Illyrian thalassocracy, little is known on the morphology of the submerged portion of the area. Here, we report on the first detailed multibeam morphological and bathymetric mapping of the entire Bay. Data were collected during several geological–geophysical cruises from 2008 to 2013 with the *R/V Dallaporta*, *R/V Urania* and *R/V Maria Grazia* of the Consiglio Nazionale delle Ricerche (CNR), under the framework of ADRICOSM-STAR and MEDPOL projects. Oceanographic cruises ADR08, ADR02_08, MNG01_09, MNG02_09 and MNG03_10 were carried out in 2008, 2009 and 2010, respectively, in order to

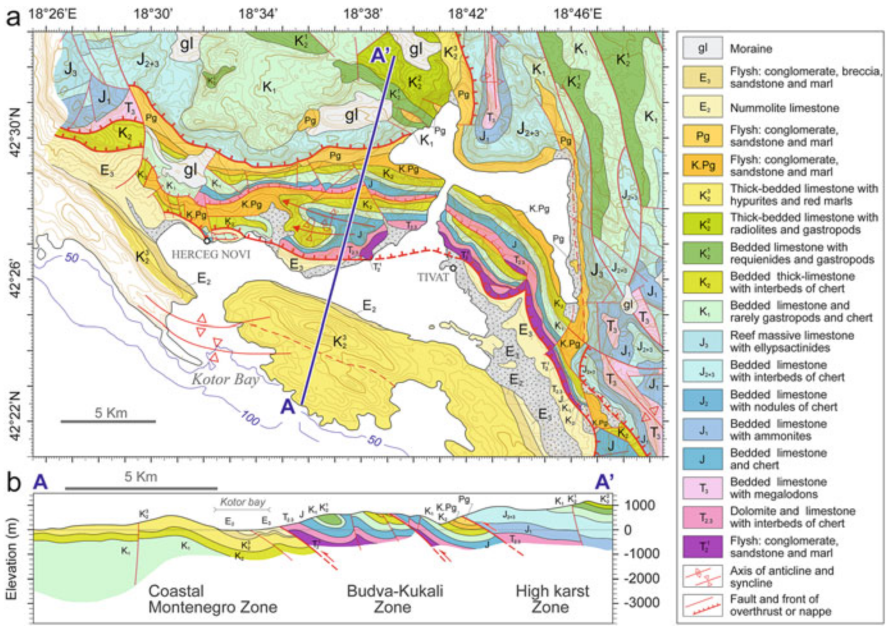

Fig. 2 Geological setting of the study area redrawn from the Kotor Geological Map, Scale 1:100,000 published by Geological Survey of Montenegro. (**a**) Geological map. Dotted grey pattern marks areas of upper Pleistocene alluvial deposits. Mercator projection at 42°30′N, ellipsoid WGS84. (**b**) Geological section across the three main structural and geomorphological domains of the Kotor Bay territory

explore the area with high resolution seismic reflection profiles, magnetics and swath bathymetry data (cruise reports available at http://www.ismar.cnr.it).

2 Geological Setting

Montenegro is part of the complex thrust-and-fold system forming the Dinaric Alps. The Mesozoic and Tertiary evolution of Montenegro and of the adjacent areas has been controlled by the relative movements between the European plate and the Adria microplate. The Mesozoic rifting phase related to extension was followed by continental convergence from the Late Cretaceous/Early Eocene to the Upper Pleistocene, that formed a series of thrust-and-folds belts and associated foreland and back-arc basins [8]. The offshore area of Montenegro forms part of the Apulia foreland which is overthrust by the frontal part of the southern segment of the Adriatic–Ionian (or Dalmatian) Thrust Zone [9]. From Triassic to Cenozoic, the Adriatic area was dominated by carbonate platforms with intervening narrow-deep basins. This area represents the eastern boundary of the Adria microplate, a block of continental lithosphere presently colliding with the Dinarides. The 200-km long plate boundary along Montenegro consists of a WNW trending thrust, cut by N-S and rarely ENE oriented strike-slip faults, which laterally segment the major thrust front [10]. Onshore, Montenegro is dominated by the Dinaric Mountain chain and can be divided into four major NW-SE striking structural units: the Durmitor Zone, the High Karst Zone, the Budva–Cukali Zone and the Coastal Montenegro Zone, which is equivalent to the Dalmatian Thrust Zone north of Montenegro (Fig. 2).

The Coastal Montenegro Zone is the innermost part of the Ionian–Adriatic Thrust Zone, build up by Cretaceous limestones, anhydrites and dolomites, and Eocene–Oligocene flysch deposits. Thrust-folded over this tectonic unit is the Budva–Cukali Zone consisting of Triassic flysch deposits and carbonates, Cretaceous limestones and Paleocene flysch. This structural unit separates the more external Coastal Montenegro Zone carbonate platform from the more internal platform in the High Karst Zone [9]. It is overthrust by the High Karst Zone that has the greater extension in the territory of Montenegro. The terrains of High Karst Zone are made mainly of Mesozoic limestone and dolomites with thickness reaching several kilometres due to reverse faulting and overthrusting that duplicate the carbonate series. Along the northern sector of Kotor Bay from Morinj to Kotor, across Risan and Perast, this unit is in direct contact with the sea (Figs. 2 and 4). The northernmost tectonic unit is the Durmitor Zone consisting of different thrust sheets build up by Late Paleozoic and Lower Triassic sedimentary deposits (clay, marl and sand beds), and Jurassic diabases and cherts rock [5, 11].

An intense seismic activity affects the Bay area, with events ranging in intensity from moderate to strong (Fig. 1). In particular, we note the disastrous earthquake of March 6, 1667 that hit Kotor destroying most of the village edifices and killing more than 200 people, and the M6.9 destructive event of April 15, 1979 in the Bar region [12], whose epicentre was located 10–20 km offshore, along the outermost thrust. The area south of the mouth of Bujana River to W and SW of Cape Rodonit is also seismically active, being interested by a WNE pure-compression thrust and by ENE trending strike-slip faults [13, 14].

3 Data and Methods

3.1 High Resolution Multibeam Bathymetry

Bathymetric data were acquired during the *R/V Urania* cruises using a SEABAT-8160 RESON multibeam system operating at 50 kHz, with 126 beams with a resolution of 0.5° and a 150° aperture, in 2008; and an EM710 Kongsberg-Simrad multibeam system, operating at ~70 kHz with 400 beams, with a resolution of 1° × 2° and a 150° aperture, in 2009. During the R/V Maria Grazia cruise in 2009, the multibeam system was an EM3002D Dual Head (400 m range) by Kongsberg operating at a frequency of 300 kHz, with 508 beams with a resolution of 0.5° and a 170° aperture. A sound velocity probe, located 1 m above the sonar head on the ship's keel, provided continuously surface water acoustic velocity data required for the beam-forming. Conductivity-temperature-depth (CTD) casts using a *SeaBird SBE 911* probe were used to determine sound velocities within the water column. Positioning was provided by a High Precision differential GPS. Multibeam data were processed using Caris Hips & Sips 8.1 software encompassing: (a) tide corrections based on the Split and Durres tidal reference stations; (b) multibeam lines adjustments by patch test on specific targets; (c) statistical and geometrical (angle and distance) filters to remove coherent and incoherent noise in each swath and (d) manual spikes removal due to single fake soundings. Bathymetric data were gridded to produce a high resolution bathymetric map (with cell-size varying from 0.5 to 5 m) extending between 10 and 100 m water depth (Fig. 1). Cartographic data homogenization to WGS84 of digitized maps (with coordinates referring to the Zone-7 of the MGI/Balkans cartographic system) was carried out using DIGMAP and DATUM software [15, 16]. Spatial analysis and mapping were performed using the PLOTMAP [17] and GMT [18] packages. Digital terrain models were produced down to a horizontal resolution of 0.5 m in the northernmost sector of the Bay of Kotor.

3.2 High Resolution Reflection Seismic

The high resolution seismo-stratigraphic study is based on a dense grid of single channel seismic reflection profiles using a Benthos CHIRP-III SBP system (operating with 16 hull-mounted transducers). Maximum sub-bottom penetration is 50–60 m with a vertical resolution of about 0.2–0.5 m. The seismic dataset was processed using SeisPrho software [19], applying time variant gain, automatic gain control and band-pass filters. The marine sub-bottom chirp profiler technique is similar to the land Vibroseis system, differing in that Vibroseis sweeps are much lower in frequency (often less of 100 Hz), while the marine chirp systems are more than several kHz. Chirp technology uses digitally generated frequency modulated acoustic transmissions to produce high resolution images of the sub-bottom layers. The first sweep signal processing step is to correlate the transmitted signal with the received signal [20]. It follows that the long outgoing sweep signal is compressed and the resulting signal is similar to the conventional seismic signal. In particular the Bentos CHIRP III system generates a 0.02-s long signal with frequency linearly varying from 2 to 7 kHz (Fig. 3a). The autocorrelation function of the chirp sweep gives as a result a zero phase Klauder wavelet (Fig. 3b), and represents the compressed source wavelet. The recorded signal may be thought as the result of the convolution between the compressed source signal and the earth reflectivity. The sampling rate of the recorded signal is of 1/32 ms. It follows a Nyquist frequency of 16 kHz, much higher than the maximum frequency generated by the system (7 kHz).

The resolution of a sub-bottom profiler is measured by its ability to separate closely spaced reflectors, that is to detect discrete echoes returning from the

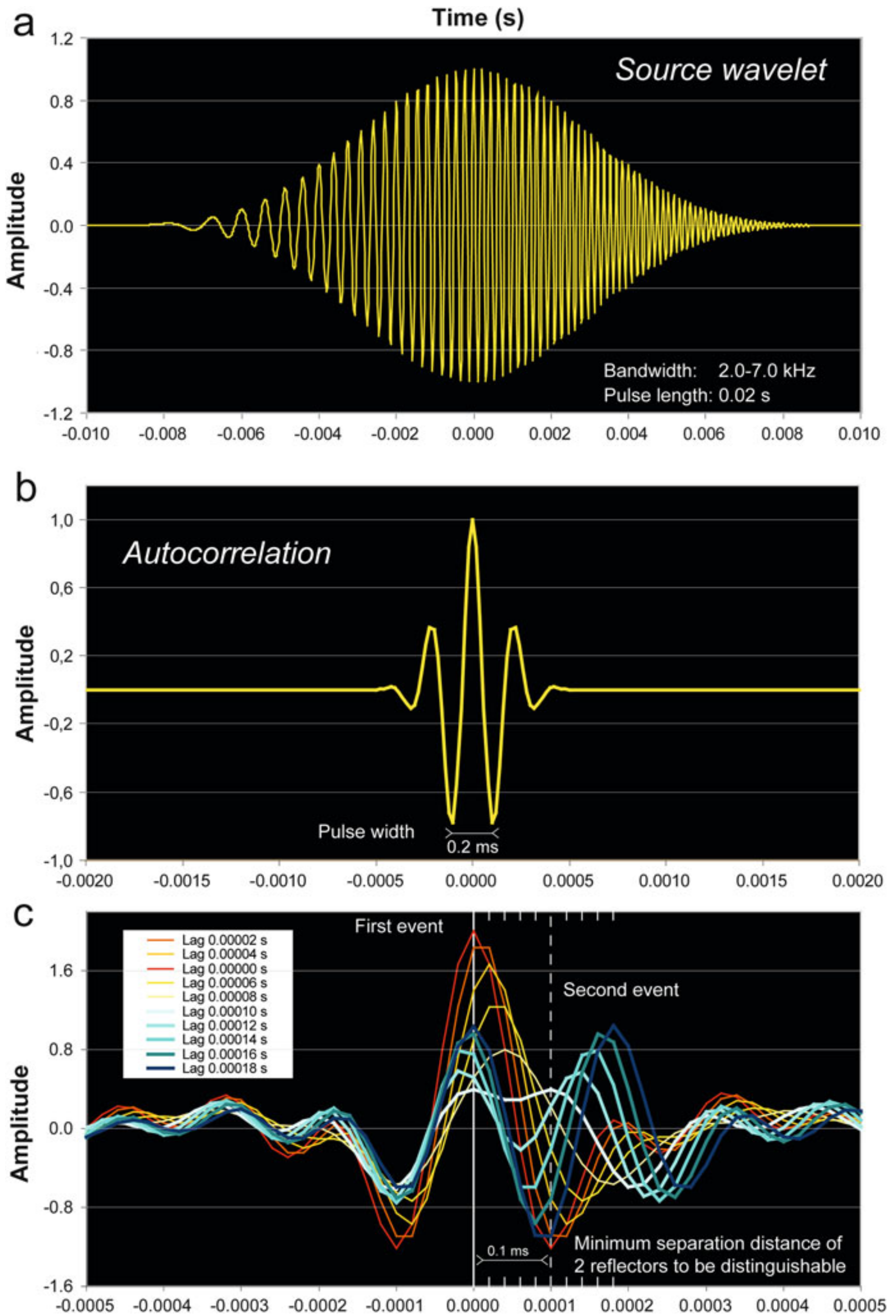

Fig. 3 (**a**) Example of frequency modulated CHIRP III source wavelet (frequency linearly varying from 2 to 7 kHz). Amplitude is scaled with time by a Blackman-Harris envelope function [20]. (**b**) Autocorrelation function of source wavelet. The autocorrelation of a chirp pulse is a zero phase Klauder wavelet. (**c**) Testing resolution. Reflected signals from two interfaces that are placed at increasing distance, with the second interface initially located in the same position of the first interface and then moved down at a rate of 0.00002 s

interfaces between layers. In a conventional single-frequency system, the limit of resolution is determined by the pulse length of the transmitted waveform. In a multi-frequency system, it is the bandwidth of the transmitted pulse that sets the system's theoretical resolution.

The theoretical chirp profiler resolution is calculated by multiplying the width of the central peak of the compressed pulse (Fig. 3b) by the speed of the sound in the medium, and dividing the product by two to account for the ping's round trip travel time [21]. For example, in the CHIRP III system, the pulse width, with a bandwidth of 5 kHz, is 0.0002 s (Fig. 3b, c). The signal travelling at about 1,540 m/s within soft sediments can travel 0.308 m in 0.0002 s. This results in a one-way distance of 0.154 m, thus, the theoretical resolution limit in time for a chirp profiler is half of the pulse width, i.e., 0.0001 s for the system we used (Fig. 3c).

Seismic data interpretation was carried out through the Kingdom Suite software and the seismic dataset was merged together with the high resolution DEM to allow integrated interpretations.

4 Results

4.1 Morphobathymetry and Sedimentary Infilling Geometries

Boka Kotorska is an enclosed water body with a narrow and shallow connection to the Adriatic Sea (Fig. 1); the shallowest point is only 37.6 m deep at present, limiting exchange of water with the Adriatic. Here the 1,450-m wide strait between Cape Kobila and Cape Kabala gives way to the entrance part called Boka Kotorska Door in direct contact with the Adriatic Sea between Cape Oštra (Prevlaka peninsula) and Cape Mirište (Lustica peninsula), a 2.98-km wide gateway with a maximum depth of 58 m (Fig. 4). The continental shelf offshore Boka Kotorska is very narrow and presents four morphological domains: elongated ridges in the inner shelf; large dunes and a major topographic ridge (Kotor Ridge) close to the shelf-break (with an average depth of 120 m); and rough seafloor in the outer shelf [22].

Boka Kotorska is one of the most important transitional areas of the Adriatic from both an environmental and a socio-economic viewpoint. The Bay hosts a large number of species of seabed fauna which has adapted to specific environmental conditions [23]. The seafloor and sub-bottom are mostly covered by well-stratified sedimentary layers of fine mud interbedded to clay loam, clay sand, silt and sand. These unconsolidated sediments, deposited during the last sealevel high stand (Holocene), rest on an erosional surface in direct contact with the Mesozoic-Early Cenozoic basement or above alluvial and/or marine syn- and pre-LGM deposits, and reach their maximum thickness of about 25÷30 m (assuming a P-wave seismic velocity of 1,500 m/s) in the depocenters. Boka Kotorska can be divided into three

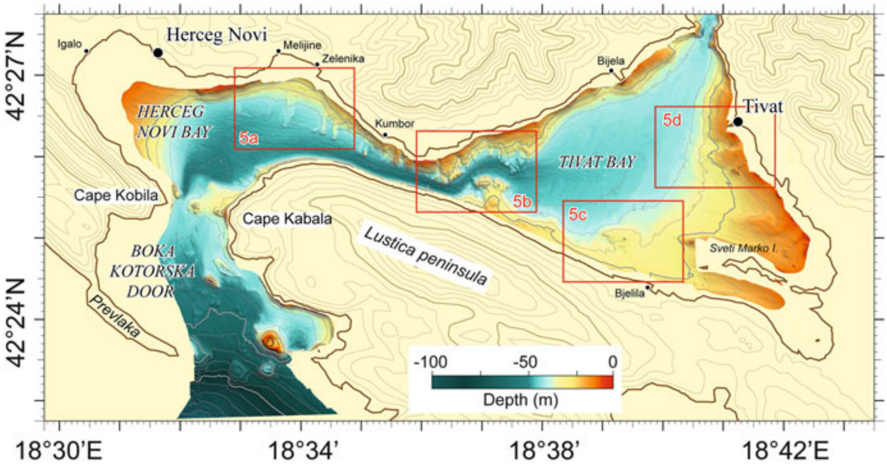

Fig. 4 Multibeam bathymetry of the outermost sector of Boka Kotorska, including Boka Kotorska Door; Herceg Novi and Tivat bays. The numbered *red box* refers to the areas displayed in Fig. 5. Bathymetry contour interval 5 m, *grey lines*. Elevation contour interval 50 m, *brown lines*. Mercator projection at 42°30′N, ellipsoid WGS84

major basins based on morphological and structural differences (Fig. 1): Herceg Novi Bay; Tivat Bay and Morinj–Risan–Kotor Bay.

4.1.1 Herceg Novi Bay

This basin has a sub-triangular shape and lies almost entirely within the 'Coastal Montenegro Zone' with basement mostly represented by Early Cenozoic flysch deposits with conglomerates, sandstones and marls (formation E3, Fig. 2). It shows a flat seafloor with an average depth of ~42 m reaching the maximum depth of ~48 m in the channel entering from the south along the narrow passage to the Boka Kotorska Door (Fig. 4). The steepest flanks are located in the south, toward the Lustica peninsula that is made by Cretaceous and Early Cenozoic limestones and presents slopes ranging from 10° to 20°. The northern flanks show more gentle slopes ranging from <1° to 3°. Despite this, these flanks are affected by several ~5-m high 150-m wide linear ridges running perpendicular to the coast between Melijine to Zelenika in the lower part of the slope (Fig. 4). Figure 5a is a high resolution bathymetric image (grid step 2.5 m) of the northern flank just south the village of Zelenika and shows some of these ridges in great detail. Although their morphologies resemble to debris flows, the seismic profile shown in Fig. 6a suggests that they are relicts of older marine sediments cut by V-shape deeply incised valleys, formed during the LGM and filled by the recent marine deposits.

Toward east, the Herceg Novi Bay is connected to the Tivat Bay through the ~800-m wide ~3.5-km long Strait of Kumbor (Figs. 4 and 5b). The narrow passage shows steep flanks cut by several deeply incised valleys and a central ~100-m wide

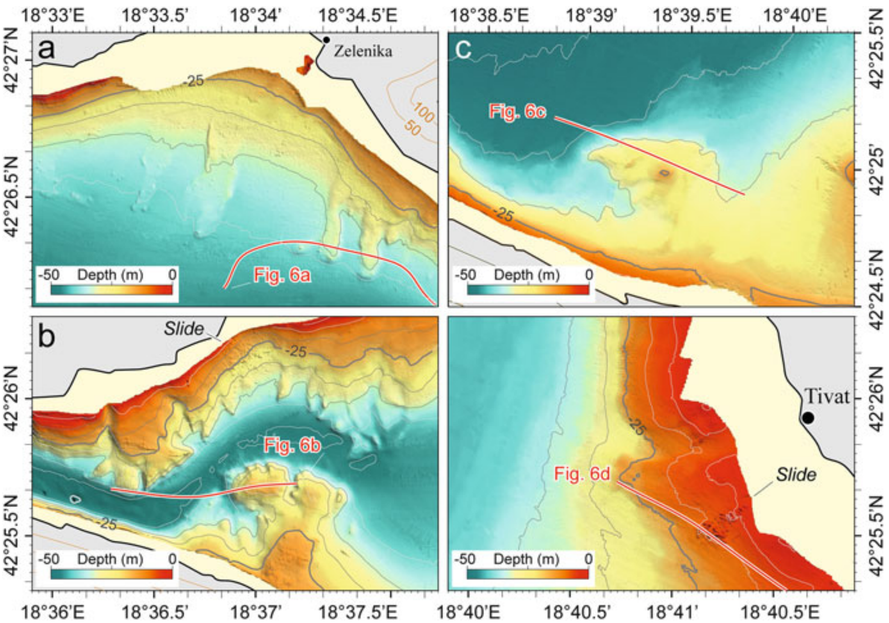

Fig. 5 Multibeam bathymetric details of selected areas. *Red lines* indicate location of Chirp profiles shown in Fig. 6. (**a**) Northern slope of Herceg Novi Bay. (**b**) Eastern sector of Kumbor Strait. (**c**) Southern flank of Tivat Bay, to the west of Sveti Marko and Gospa od Milosrda islets. (**d**) Eastern flank of Tivat Bay

~50-m deep channel that follows three short linear segments running along and perpendicular to the major tectonic lineaments (WNW-ESW, SW-NE and NW-SE, respectively). A seismic profile crossing the SW-NE segment is shown in Fig. 6b. The seismic cross-section shows a ~300-m wide valley with depth ranging from 40 to 45 m, filled by ~20 m of sediments. The valley floor (i.e., the acoustic basement) presents a flat reflector, slightly dipping toward east, offsets by a ~5 m step. The overlying sediments are broken and discontinuous at this step suggesting an active fault at this location.

The sedimentary infill shows different depositional geometries, with layers from the lower part of the sequence lying sub-parallel to the basement, while in the upper part, reflectors dip toward the axis of the valley forming different orders of sedimentary lobes resembling to countorite geometries. An erosional surface marks the top of the sedimentary infilling.

On the eastern side, the seismic profile crosses a lobate structure deeply incised by valleys. Some dipping reflectors are still visible below the erosional surface separating the thin highstand sediments draping the morphological high, suggesting that this structure is probably a relict of older sedimentary deposits. Hummocky terrains in the upper northern slope suggest mass wasting affecting this flank of the Strait (Fig. 5b).

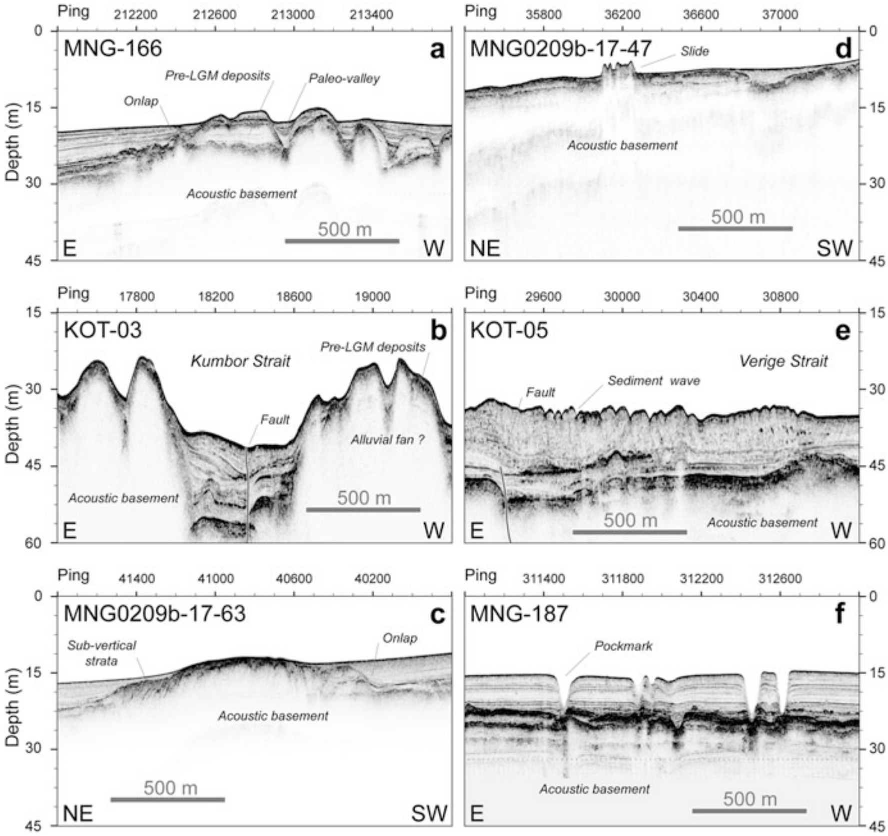

Fig. 6 High resolution seismic profiles (CHIRP III). (**a**) Herceg Novi Bay: profile running parallel to the coastline across the northern slope of the basin. Location in Fig. 5a. (**b**) Cross-section of Kumbor Strait. The SW-NE fault located in the middle of the section is probably an active feature because it cuts the entire sedimentary sequence. (**c**) Tivat Bay, southern slope. The seismic line crosses the structural high in front of Bjelila village. (**d**) Tibat Bay, eastern slope. The profile crosses the small slide located just south of Tivat. (**e**) Verige Strait, along axis profile. (**f**) Morinj–Risan–Kotor Bay: seismic profile running parallel to the northern coast in front of Perast

4.1.2 Tivat Bay

The northernmost area of Tivat Bay, north of the village of Bijela, lies within the Budva–Kukali Zone that overthrusts the Coastal Montenegro Zone, which includes the southern and the central sector of this triangular basin (Fig. 2). A narrow elongated ridge, marked by the alignment of the Ostrvo Cvijeca peninsula and of the Sveti Marko (1.5-km long) and Gospa od Milosrda (200-m long) islands, divides the south-eastern corner area of the Bay in two shallow sub-basins (max depth of 20 m). On the two islands conglomerates, sandstones and marls of the Early Cenozoic flysch unit (E3) outcrop (Fig. 2). The Chirp profile shown in Fig. 6c crosses an elongated structural high parallel to the southern coast and aligned along

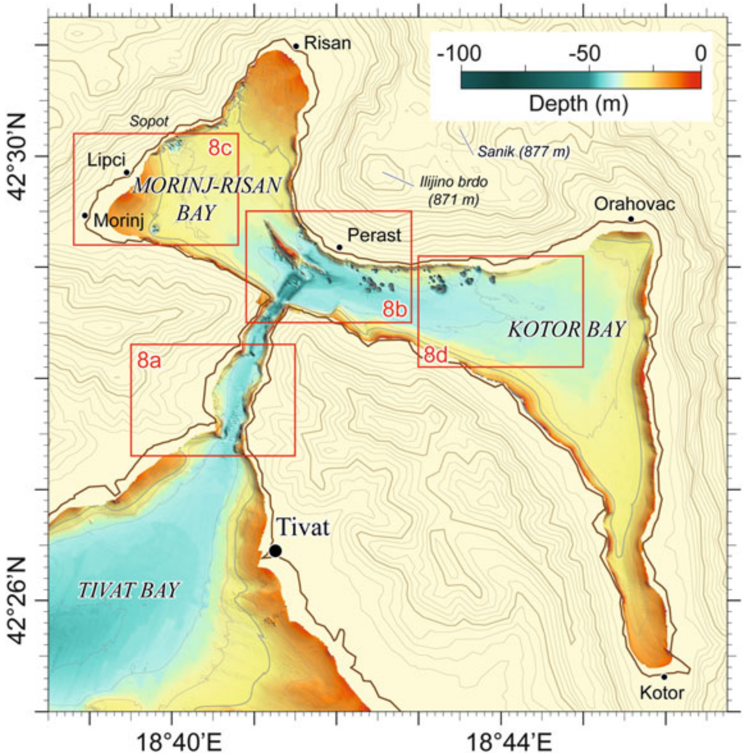

Fig. 7 Multibeam bathymetry of the innermost sector of Boka Kotorska, including Tivat Bay, Verige Strait and Morinj–Risan–Kotor Bay. The numbered *red box* refers to the areas displayed in Fig. 8. Bathymetry contour interval 5 m, *grey lines*. Elevation contour interval 50 m, *brown lines*. Mercator projection at 42°30′N, ellipsoid WGS84

the prosecution of the narrow ridge formed by Sveti Marko and Gospa od Milosrda islets (Fig. 5c). The seismic section reveals a very thin sedimentary sequence (thickness < 10 m) onlapping basement rocks in sub-vertical strata.

The Bay presents a wide-almost flat central area with depths > 35 m, with a maximum depth of 45 m reached close to Kumbor Strait. The northern and the south-western slopes are steeper than the eastern and south-eastern slopes that gently grade toward the deepest central area with gradients < 0.5°. Hummocky terrains with huge (>5 m–high) blocks mark the eastern upper slope of Tivat Bay, just south the town of Tivat. The seismic section crossing this feature shows that blocks are free of sediments, suggesting a very recent mass wasting event.

Tivat Bay is connected to the Morinj–Risan–Kotor Bay by the Verige Strait. The Strait striking SSW-NNE forms a narrow passage (400 m) within the Mesozoic carbonates of the Budva–Kukali Zone and shows very steep flanks. In the central part, the Strait is 600 m wide and becomes narrower toward the southern and the northern end where its width decreases down to ~350 m, and where two deeper channels (max depth of 45 m), bounding a few metre-high central dome, develop.

The southern and northern 200-m wide central domes are characterized by linear sediment wave fields (Figs. 7 and 8a), with waves running almost perpendicular to the axis of the valley. Sediment waves are predominant in the southern sector of the Strait, with a wavelength of 25 m and heights ranging from 1 m up to 3 m. The seismic profile in Fig. 6e shows that the mobilized sediment layer, represented by acoustically transparent material without internal coherent reflections, can reach the thickness of 10 m. This layer overlays a lower sequence with coherent reflectors sub-parallel to the top of the acoustic basement.

4.1.3 Morinj–Risan–Kotor Bay

This Bay represents the innermost basin of Boka Kotorska and straddles the overthrust zone between the High Karst Zone to the north and the Budva–Kukali zone to the south. It displays an hour-glass shape (Fig. 7) and can be divided into two major sub-triangular embayments to the NW and to the SE (Morinj–Risan and Kotor bays, respectively).

The deepest part (~45 m) of the entire basin is found at the mouth of the Verige Strait, where the two channels, that come out from the narrow outlet, impact against a structural high, and join together following a semi-circular path (Fig. 8b). The structural high is formed by a narrow ridge parallel to the northern coastline, with steep flanks and a roughly symmetric cross-section, that rises above sea-surface at Gospa od Skrpjela and Sveti Dordje islets (Figs. 7 and 8b).

The Morinj–Risan Bay is bounded by a high relief (Mt. Orjen massif) and extends from the city of Risan in the northeast, to the city of Morinj, in the southwest. Bathymetric data off the city of Risan, i.e., Risan Bay, show an almost flat basin that reaches the maximum depth of 32 m in the central area. It is bounded by a steep flank to the west and more gentle slopes to the north and to the east. Toward southwest, i.e., in the Morinj Bay, a well-developed fan delta is observed (Fig. 8c). Most of the fan is now >25 m below sealevel, and contains a deeply incised central channel (deeper than adjacent seafloor by up to 10 m). This submerged channel is well-preserved and contiguous with the terrestrial portion of the alluvial fan observed near the village of Lipci [24]. Along the western flank of Morinj–Risan Bay, bathymetry reveals three sectors where a number of circular depressions are present at the base of the slope. The southernmost sector is located off Lipci, where a cluster of sub-circular depressions, with an average radius of 25 m and depth of 6 m, is observed. In some cases, these pits join together to form elliptical depressions with a flat bottom, as observed off the Village of Strp where the bottom depth is ~10 m. Moving northward, isolated circular and funnel-shaped depressions are found, most of which are very small (20–30 m wide) and shallow (2–4 m).

Kotor Bay is an SSE-NNW elongated (about 7 km) embayment that widens from south (about 750 m between the cities of Kotor and Muo) to north (about 4 km). It is bounded by steep flanks and the bottom is quite flat, with depths ranging from about −10 m to a maximum of about −34 m in the northern sector. Mass wasting deposits

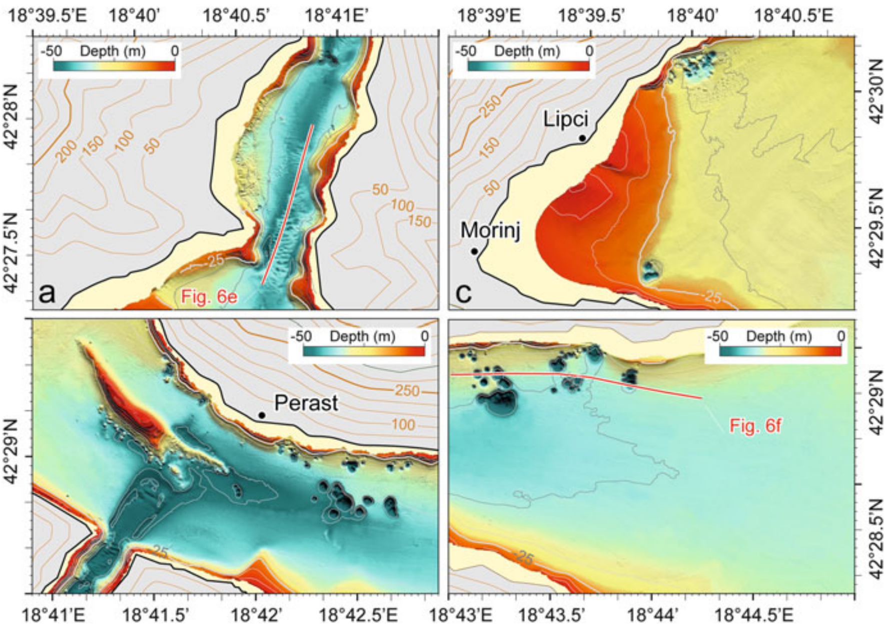

Fig. 8 Multibeam bathymetric details of selected areas. *Red lines* indicate location of Chirp profiles shown in Fig. 6. (**a**) Southern end of Verige Strait. (**b**) Northern end of Verige Strait and central sector of Morinj–Risan–Kotor Bay including Gospa od Skrpjela and Sveti Dordje islets. (**c**) Southwestern flank of Morinj–Risan Bay. (**d**) Northern sector of Kotor Bay

are observed in the northern area on the southern flank of the basin close to Cape Markov [25].

The central area connecting the Risan–Morinj and Kotor bays, in correspondence of the northern foot slope near Perast, displays a large number of circular to elliptical depressions at depths ranging between 27 and 41 m (Fig. 8d). These features are similar to those observed in the western Risan–Morinj Bay, but better defined. They allow us to identify different morphologies: circular, sub-circular and elliptical; isolated and coalescent pits or depressions. Isolated circular depressions are the most representative of the area and occur in a wide range of depths, with diameter ranging from 10 to 100 m. These depressions display a well-developed, funnel-shape vertical section, that can locally cut the entire sedimentary sequence (Fig. 6f). The largest isolated circular depressions are below the 35 m isobaths and often deepen down to 30 m relative to the surrounding flat seafloor. When adjacent pits joint together, they form a sub-circular or elliptical depression with a flat bottom (in most of cases), that can widen up to 200 m and reach the depth of 35 m below the surrounding seafloor. The maximum depth of 67 m is reached in the largest of this depression, just south Perast. These elliptical depressions may originate from the coalescence of aligned adjacent depressions that tend to form larger depressions with the major axis oriented NNW-SSE or N-S, i.e., parallel to the main structural trends.

5 Discussion

Boka Kotorska Bay's physiography, orography, hydrographic characteristics, geological and structural setting, and sealevel changes influence the present-day morphology and sedimentary infilling geometries of the basin. Past sealevel changes together with the geological setting of the area played an important role in shaping the modern Bay. Incised valleys across continental margins represent the response of fluvial systems to changes in their equilibrium dynamics, mainly driven by base level fall forced by glacial-eustatic cycles [26].

During Late Pleistocene glacial maxima (MIS12, MIS10, MIS6 and MIS2), global sealevel fell more than 100 m [27–30], thus the bed of Boka Kotorska (max depth of present day sill toward the open Adriatic Sea is 37.6 m, Fig. 1) would have been exposed. The filled incised valleys on the flanks of Boka Kotorska basins formed probably during the last glacial sealevel lowstand, when most of the southern Adriatic shelf was exposed sub-aerially. The pronounced upstream deepening of the valleys related to river/stream incisions of MIS5e and older highstand deposits forms relict ridges perpendicular to the coastline (Figs. 5a and 6a). Sealevel rise reached Boka Kotorska during the Early Holocene, drowning the Bay and leading to the formation of an embayment confined toward land. At this time, part of the incisions remained under-filled with a marked bathymetric expression; the Bay was then rapidly filled by highstand deposits. Also the two lobate structures on the southern flank of Kumbor Strait and south of Lipci, respectively, interpreted as fan deltas, would have been deposited sub-aerially during sealevel lowstands. Channels cutting the present-day fan surface and extending for several hundred metres down are clearly visible in the bathymetric imagery (Figs. 5b and 8c). This suggests that these channels were incised sub-aerially, and have since been submerged by rising sealevel and subsidence of Boka Kotorska Bay [31]. Recent studies on the Lipci fan (one of alluvial depocentres at Orjen) show clear evidence of post-depositional incision into the MIS12 sediments and strong cementation of the fan. This may have led to preserve the fan sediments from subsequent transgressions, maintaining the channel morphology [30, 32].

High resolution seismic profiles cutting the Late Holocene sedimentary sequence indicate the presence of gas within sediments. It has been postulated that submarine slope failures are spatially linked to the presence of gas hydrates/gas-charged sediments and temporally linked to episodes of climate change [33–35]. Along the steepest upper slope of Boka Kotorska flanks, hummocky terrains (Figs. 5b, d and 8d) suggest mass wasting events probably related to slope failure triggered by the strong earthquakes affecting the region and enhanced by overpressure induced by gas and fluids.

Another important factor that contributes to determine the submerged morphology of Boka Kotorska Bay is the action of water currents. Water circulation in the Bay is mainly driven by meteorological condition and fresh water input, thus it suffers of a strong seasonality. Strong surface currents are due to the action of winds, while bottom currents are controlled by fresh waters input [36]. The freshwater input from the numerous sources in the bays strongly modifies temperature, salinity and current patterns, with formation of density driven flows [36]. Bottom currents are stronger within the narrow passages connecting the several basins forming the Bay. In fact, most of the morphological features observed within the Kumbor and Verige straits can be ascribed to the action of bottom currents, such as incised channels bounding the slopes of the straits (Figs. 5b, 8a and b); contourites forming the lobate sedimentary geometries shown in the cross-section of Kumbor Strait (Fig. 6b) and sediment wave fields at the southern and northern end of the Verige Strait (Figs. 6e, 8a and b).

Small watercourses are present in the Boka Kotorska Bay drainage area, although precipitation in its catchment area is the highest in Europe (>5,000 mm/a) [37] with an enormous mass of freshwater flowing into the basin [38]. Because of karst environment in north-western Montenegro, coastal aquifers may also develop at sea with submarine siphons, springs and resurgences [39]. In the littoral karst of Montenegro, the most important springs are those along the edges of the Boka Kotorska Bay: Gurdic and Skurda Spring near Kotor, Ljuta Spring at Orahovac, Spila Spring at Risan, Morinj Springs and Opacica at Herceg Novi and Plavda at Tivat [40]. All these springs are characterized by high variations in discharge due to intensively karstified rocks in the catchment and an extremely fast propagation of rainfall. Some of those springs even dry out completely during summer (e.g., Sopot), while after intensive rainfall or at the end of winter, some of them can discharge over 100 m^3/s [40].

The deep circular depressions with sharp edges and smooth outer boundaries (Fig. 8) observed at the seafloor in several places across the Bay are interpreted as pockmarks due to groundwater discharge into the basin (i.e., spring outlets). We count over 143 of these features across the entire Bay. Figure 9 is a plot of depth below seafloor versus volume of the circular depressions and shows that there is a depth limit which corresponds to the thickness of the unconsolidated sediments above the basement, i.e., when the basement is reached, an increase of the size of depression does not correspond to a depth increase. Most of these circular depressions are located in Morinj–Risan–Kotor Bay close to the village of Perast. The deepest and largest of these features was investigated during the summer by CTD and sampled by grab, reporting anoxic, seawater conditions on bottom [25]. This suggests no ground water outflow during the dry season. These spring outlets are aligned parallel to the coast, suggesting that they originate at the lateral ramp of the reverse fault between karstified limestone and dolomites of the Sanik mountain and the autochthonous Eocene flysch (Fig. 2). Figure 10 shows a model of groundwater inflow into the basin forming pockmarks at seafloor, a model similar to that proposed for Ombla spring in Croatia [41].

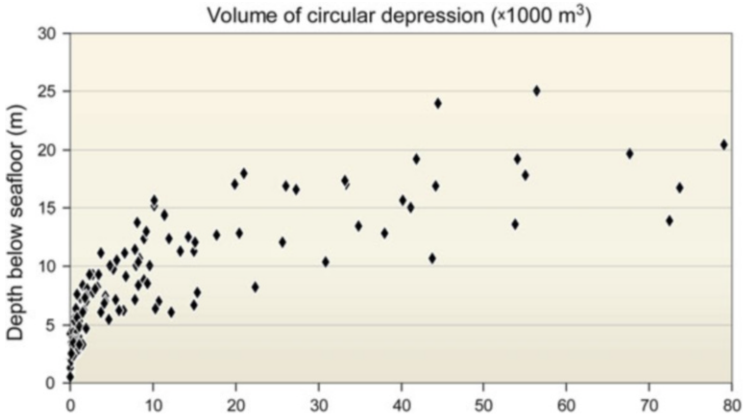

Fig. 9 Depth below seafloor of the bottom of pockmarks in the Morinj–Risan–Kotor Bay versus volume of the depression ($\times 10^3$ m^3). The maximum depth reached by the largest depressions corresponds to the thickness of the unconsolidated sediment

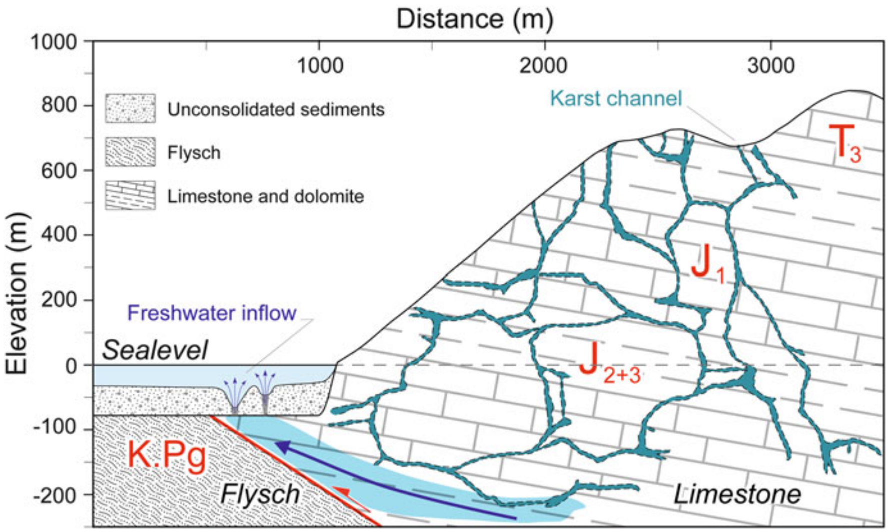

Fig. 10 Idealized hydrological cross-section from Morinj–Risan–Kotor Bay to Sanik mountain across Perast. The model suggests the circular depressions observed in front of Perast as due to freshwater inflow at seafloor

6 Concluding Remarks

New high resolution multibeam and seismic reflection data from Boka Kotorska reveal unknown details of present-day morphologies and sedimentary infilling geometries. Several processes are involved in shaping the bay and its seafloor:

(i) the shape of the sub-basins forming the Bay and the narrow passages between them are related to the geological and structural setting of the area; (ii) slope failures and mass wasting, affecting the eastern slope of the Tivat Bay, the south-eastern flank of the Morinj–Risan–Kotor Bay and the northern flank of the Kumbor Strait, are likely triggered by the strong earthquakes occurring in the area; (iii) deeply incised valleys represent the response of drainage systems to changes in their equilibrium dynamics driven by sealevel falls within glacial-eustatic cycles; (iv) delta fans as relicts of cemented alluvial fans formed during glacial maxima; (v) karst environment and coastal aquifers develop at sea with submarine syphons, springs and resurgences. The deep and steep circular depressions affecting a large part of the seafloor at the base of slopes are the prevalent features related to submarine karst morphology; (vi) the narrow channels at the foot of slopes along the Kobila-Kabala capes, Kumbor and Verige straits are due to bottom currents and (vii) sediment wave fields at the segment ends of the Verige Straits are developed under the action of the strong bottom currents affecting the Strait.

Acknowledgments This work has been carried out in the framework of ADRICOSM-STAR Project with the financial support of the Italian Ministry for the Environment, Land and Sea and the coordination of CMCC. We thank E. Bonatti and M. Cuffaro for their comments that helped to clarify and improve this paper.

We are deeply sorry to report the sudden demise of Giovanni Bortoluzzi, the first author of this paper, on October 5, 2015. Since 1977, he has been working at the Institute of Marine Sciences of the National Research Council of Bologna. He gained a diploma of industrial engineer and never bothered to get a degree, but his scientific contribution, even if interrupted so abruptly, was crucial. The fact of not having degrees or professorships allowed him to cultivate cross and multidisciplinary interests. He contributed in numerous international publications including the very prestigious Nature and Science. He sailed, led or participated to scientific expeditions, not only in the Mediterranean, but also in the Red Sea, the Equatorial and South America, the Pacific and in the peri-Antarctic Oceans. On the one hand, he was unmatched in the management of offshore instrumentation; on the other hand, he was equipped with a great insight to recognize and develop scientific issues of great importance. He had accumulated a wealth of experience that made him a valuable teacher for young scholars, but remained a person of great modesty and humanity.

References

1. Castaing P, Guilcher A (1995) Geomorphology and sedimentology of Rias. In: Perillo GME (ed) Geomorphology and sedimentology of estuaries and developments in sedimentology, vol 53. Elsevier Science, Amsterdam, pp 69–111
2. Frankl A, Lenaerts S, Radusinović S, Spalevic V, Nyssen J (2016) The regional geomorphology of Montenegro mapped using land surface parameters. Zeitschrift für Geomorphologie 60 (1):1–14
3. Hsü KJ, Ryan WBF, Cita MB (1973) Late Miocene desiccation of the Mediterranean. Nature 242:240–244
4. Magas D (2002) Natural-geographic characteristics of the Boka Kotorska area as the basis of development. Geoadria 7(1):51–81

5. Radulović V, Radulović M (1997) Karst of Montenegro. In: Stevanovic Z (ed) 100 years of hydrology in Yugoslavia. University of Belgrade, Belgrade, pp 147–185
6. Lewin J, Woodward J (2009) Karst geomorphology and environmental change. In: Woodward J (ed) The physical geography of the Mediterranean. Oxford University Press, Oxford, pp 287–318
7. Milanović P (2015) Karst of eastern Herzegovina, the Dubrovnik littoral and western Montenegro. Environ Earth Sci 74(1):15–35
8. Cavazza W, Roure F, Ziegler PA (2004) The Mediterranean area and the surrounding regions: active processes, remnants of former Tethyan oceans and related thrust belts. In: Cavazza W, Roure F, Spakman W, Stampfli GM, Ziegler PA (eds) The TRANSMED Atlas. The Mediterranean region from crust to mantle. Springer, Berlin-Heidelberg, pp 1–29
9. Bega Z (2015) Hydrocarbon exploration potential of Montenegro – a brief review. J Petrol Geol 38(3):317–330
10. Del Bianco F, Gasperini L, Angeletti L, Giglio F, Bortoluzzi G, Montagna P, Ravaioli M, Kljajic Z (2015) Stratigraphic architecture of the Montenegro/N. Albania continental margin (Adriatic Sea—Central Mediterranean). Mar Geol 359:61–74
11. Dimitrijević MD (1992) Coloured map of the Geology of Serbia, with overlay and legend. In: Geological Atlas of Serbia, 1:2,000,000. Grafimex, Belgrado
12. Boore DM, Sims JD, Kanamori H, Harding S (1981) The Montenegro, Yugoslavia, earthquake of April 15, 1979: source orientation and strength, 1981. Phys Earth Planet In 27:133–142
13. Aliaj S, Adams J, Halchuk S, Sulstarova E, Peci V, Muco B (2004) Probabilistic seismic hazard maps for Albania. In: 13th World Conference on Earthquake Engineering, Vancouver, BC, Canada, 1–6 August, p 2469
14. Aliaj S (2006) The Albanian Orogen: convergence Zone between Eurasia and the Adria microplate, 2008. In: Pinter N, Gyula G, Stein S, Medak D (eds) The Adria microplate: GPS geodesy, tectonics and hazards. NATO Science Series, IV, Earth and Environmental Sciences 61. Springer, Dordrecht, pp 133–149
15. Bortoluzzi G, Ligi M (1996) DIGMAP: a computer program for accurate acquisition by digitizer of geographical coordinates from conformal projections. Comput Geosci 12:175–197
16. Ligi M, Bortoluzzi G (1989) DATUM: a FORTRAN 77 computer program for datum shift and conversion of geographical coordinates between different cartographic systems. Comput Geosci 15:449–518
17. Ligi M, Bortoluzzi G (1989) PLOTMAP: geophysical and geological applications of good standard quality cartographic software. Comput Geosci 15:519–585
18. Wessel P, Smith WHF, Scharroo R, Luis JF, Wobbe F (2013) Generic mapping tools: improved version released. EOS Trans AGU 94:409–410
19. Gasperini L, Stanghellini G (2009) SeisPrho: an interactive computer program for processing and interpretation of high-resolution seismic reflection profiles. Comput Geosci 35:1497–1504
20. Dal Forno G, Gasperini L (2008) ChirCor: a new tool for generating chirp-sonar seismograms. Comput Geosci 34:103–114
21. Mitchell NC, Ligi M, Rohling EJ (2015) Red Sea isolation history suggested by Plio-Pleistocene seismic reflection sequences. Earth Planet Sci Lett 430:387–397
22. Del Bianco F, Gasperini L, Giglio F, Bortoluzzi G, Kljajic Z, Ravaioli M (2014) Seafloor morphology of the Montenegro/N. Albania continental margin (Adriatic Sea—Central Mediterranean). Geomorphology 226:202–216
23. Slavica P, Olivera M (2016) Characteristics of the zoobenthos in Boka Kotorska Bay. In: Joksimovic A. et al. (eds.), The Boka Kotorska Bay Environment, Hdb Env Chem, Springer, Switzerland. doi:10.1007/698_2016_29
24. Adamson KR, Woodward JC, Hughes PD, Giglio F, Del Bianco F (2016) Middle pleistocene glaciation, alluvial fan development, and sea level change in the Bay of Kotor, Montenegro. In: Hughes PD, Woodward JC (Eds) Quaternary glaciation in the mediterranean mountains. Special Publication of the Geological Society 433 (in press)

25. Bortoluzzi G, Del Bianco F, D'Oriano F, Giglio F, Borgia TTM, Santi D, Bulatović A, Dević, N, Radojević D, Matović M, Sretenović A, Diaconov A, Tola M (2009) Report on the morphobathymetric, oceanographic, geological and geophysical investigations during cruise MNG01-09 (19–27 April 2009, R/V Urania). ISMAR-CNR Interim Technical Cruise Report, Bologna
26. Maselli V, Trincardi F (2013) Man made deltas. Sci Rep 3:1926
27. Rohling EJ, Fenton M, Jorissen FJ, Bertrand P, Ganssen G, Caulet JP (1998) Magnitudes of sea-level lowstands of the past 500,000 years. Nature 394:162–165
28. Rabineau M, Berné S, Olivet J-L, Aslanian D, Guillocheau F, Joseph P (2006) Paleo sea levels reconsidered from direct observation of paleoshoreline position during Glacial Maxima (for the last 500,000 yr). Earth Planet Sci Lett 252:119–137
29. Bintanja R, van de Wal RSW (2008) North American ice-sheet dynamics and the onset of 100,000-year glacial cycles. Nature 454:869–872
30. Rohling EJ, Grant K, Bolshaw M, Roberts AP, Siddall M, Hemleben C, Kucera M (2009) Antarctic temperature and global sea level closely coupled over the past five glacial cycles. Nat Geosci 2:500–504
31. Lambeck K, Purcell A (2005) Sea-level change in the Mediterranean Sea since the LGM: model predictions for tectonically stable areas. Quat Sci Rev 24:1969–1988
32. Adamson KR, Woodward JC, Hughes PD (2014) Glaciers and rivers: Pleistocene uncoupling in a Mediterranean mountain karst. Quat Sci Rev 98:28–43
33. Kayen R, Lee H (1991) Pleistocene slope instability of gas hydrate-laden sediment on the Beaufort sea margin. Mar Geotechnol 10:125–141
34. Hornbach M, Lavier L, Ruppel C (2007) Triggering mechanism and tsunamogenic potential of the Cape Fear Slide complex, U.S. Atlantic coastal margin. Geochem Geophys Geosyst 8: Q12008
35. Lee JY, Santamarina JC, Ruppel C (2010) Volume change associated with formation and dissociation of hydrate in sediment. Geochem Geophys Geosyst 11, Q03007
36. Bellafiore D, Guarnieri A, Grilli F, Penna P, Bortoluzzi G, Giglio F, Pinardi N (2011) Study of the hydrodynamical processes in the Boka Kotorska Bay with a finite element model. Dyn Atmos Oceans 52:298–321
37. Milanović P (2005) Water potential of south-eastern Dinarides. In: Stevanović Z, Milanović P (eds) Water resources and environmental problems in karst. Proceedings of international conference KARST 2005, University of Belgrade, Institute of Hydrogeology, Belgrade, pp 249–257
38. Parenzan P, Stiepcevic J (1980) Golfo delle bocche di Cattaro; Condizioni generali e biocenosi bentoniche con carta ecologica delle sue due baie interne: di Kotor (Cattaro) e di Risan (Risano). Stud Marina 9(10):3–153
39. Fleury P, Plagnes V, Bakalowicz M (2007) Modelling of the functioning of karst aquifers with a reservoir model: application to Fontaine de Vaucluse (South of France). J Hydrol 345 (1–2):38–49
40. Stevanovic Z (2009) Case study: major springs of southeastern Europe and their utilization. In: Kresic N, Stevanovic Z (eds) Groundwater hydrology of springs. Butterworth-Heinemann, Oxford, pp 389–410
41. Milanovic P (2015) Karst of eastern Herzegovina, the Dubrovnik littoral and western Montenegro. Environ Earth Sci 74:15–35

Marine Chemistry of the Boka Kotorska Bay

Danijela Joksimović, Ana Castelli, Milena Mitrić, Rajko Martinović, Ana Perošević, and Slavka Stanković

Abstract Currently, in the country and abroad, numerous investigations focused on analysis of environmental protection and improvement, particularly water as a sensitive and limited resource, are being conducted. One of main environmental tasks is water quality monitoring, i.e. monitoring of the possible presence of harmful substances as well as determining their concentrations in water. Monitoring of marine environment trace metals pollution, which represent a basis for the control of pollution of the marine environment, is usually limited not only by performance and detection limits of the existing analytical techniques, but also by the general lack of interest, since rivers and oceans have for quite some time been used for disposal of various wastes.

In the last decade, human and industrial activities in the coastal areas of the south-eastern Adriatic have been increased, which resulted in different types of contamination, including trace elements. Therefore, investigations of the south-eastern Adriatic marine environment quality have been intensified in the last decade, monitoring seawater, biota and sediment quality related to heavy metals pollution along the Albanian and Montenegrin coastal area, which are naturally connected.

The Boka Kotorska Bay is situated in Montenegro, in the south-eastern part of the Adriatic Sea. This chapter provides an overview of the physical and chemical marine data of seawater, sediment and biota, based on the results of the research

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project studies and published monitoring data conducted in the last decade in the Boka Kotorska Bay.

Keywords Biota, Boka Kotorska Bay, Heavy metals, Nutrients, Seawater, Sediment

Contents

1 Introduction

The Boka Kotorska Bay is a semi-enclosed bay situated in the south-eastern Adriatic Sea (Mediterranean Sea), along the Montenegro coastline (Fig. 1). Due to its natural and cultural values, it is included in the UNESCO's World Heritage List. It is hypothesized that the Boka Kotorska Bay was formed by fluvial erosion. Morphometric characteristics of the Bay are: the entrance of the Bay is 2.95 km; coast line length is 105.7 km long and total surface is 87.3 km^2 and maximum depth is 65 m (http://www.cmcc.it/adricosm-intermediate/Deliverables/ADRICOSM-INTERMEDIATE_D2.1.1.pdf) in the Kotor Bay. The Boka Kotorska Bay has a complex morphological structure, consisting of four embayments naturally divided into smaller bays: the Herceg Novi, the Tivat, the Risan–Morinj and the Kotor Bays [1].

Hydro-geological, hydro-metrological and hydro-graphical characteristics of the Boka Kotorska Bay distinguish it as a unique entity in the southern Adriatic and further in the Mediterranean. Natural resources and the developmental potential of the area, as well as many socio-economic problems in recent decades, have contributed to more intensive pressure regarding pollution and devastation of the marine environment, which is particularly reflected in tourism and urbanization development in this part of the Adriatic coast. On the other hand, the strategy of socio-economic development integrates environmental protection into development plans, which is accepted at the local and the regional levels, has imposed the need to monitor the ecological state of the Bay, not only as a part of research studies and projects, but also through an organized and systematic monitoring in accordance with national and international regulations.

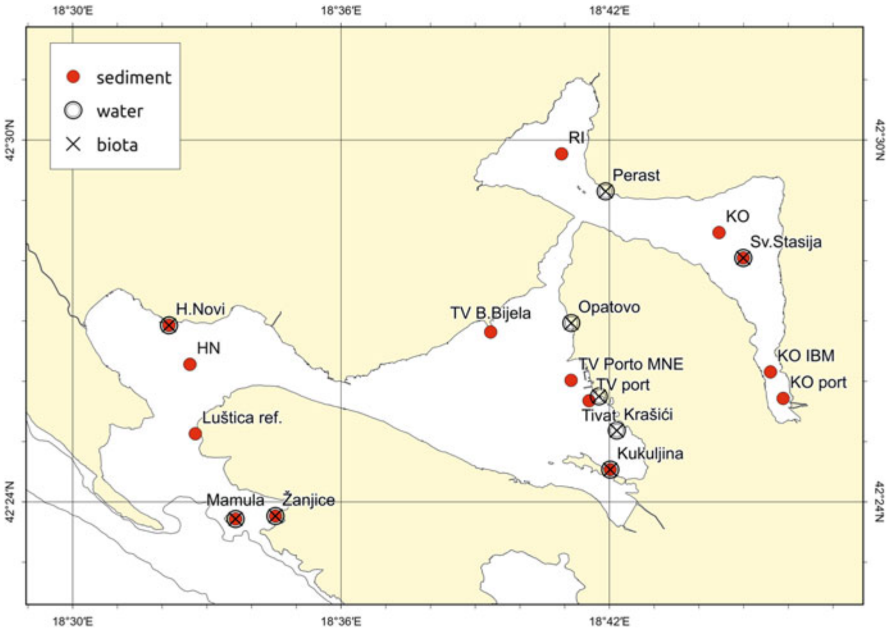

Fig. 1 The Boka Kotorska Bay – map of investigation: *red circles* are sediment stations; *open circles* are water stations and *cross* are biota stations

The studies of the elemental composition in Adriatic sediments date back more than 30 years ago. However, available data and publications refer mostly to selected coastal areas of the eastern and south-eastern Adriatic. The sediment along the Italian coast is more investigated than along the eastern Adriatic coast [2]. On the south-eastern Adriatic coast, the Albanian coastal area has been more intensively investigated in relation to the surface sediment [3–5] and some data have been published regarding the concentrations of the elements in surface sediments in the open Montenegrin coastal area [6–8]. In relation to the Boka Kotor Bay surface sediment, three significant papers were published on monitoring of the quality and chemical composition of the Bay surface sediment [9–11], including major, minor, trace and rare earth elements.

Trace elements are considered serious pollutants of the marine environment because of their toxicity and persistence, poor biodegradability and tendency to concentrate in aquatic organisms [12, 13]. In order to monitor the levels of trace metals in marine waters, particular attention has been paid to the use of marine organisms as bioindicators of trace metal pollution [14–17]. The possibility to use sea grass *Posidonia oceanica* (L.) Delile as a bioindicator of microelement's contamination has been studied in various parts of the world; especially along the Mediterranean coast [8, 13–20].

Posidonia oceanica meadows occur mostly in shallow and sheltered coastal waters anchored in sand or mud bottoms and have a very important role in the ecology of the Mediterranean Sea. This is due to its ability to absorb trace elements directly from the water column and/or from interstitial water in sediments [7, 12] and a high capacity to accumulate trace elements and concentrate pollutants occurring in the environment [18]. The increasing use of sea grasses as indicators of chemical contamination of coastal regions [7, 12, 18, 19] is supported by the fact that many microelements were found in trace amounts in seawater, but often at elevated levels in the sea grass [7, 12].

The metal contamination of the aquatic environment is of a big concern as certain metals have the ability to bioaccumulate and subsequently to have an impact on the exposed organisms within higher levels of the food chain [19, 20]. The concern of the environmental and health effects of the trace metal contamination of the marine environment has been long established primarily for the elements such as Sn, Hg, Cd and Cu and especially in relation to potential contamination of certain seafood [20, 21]. The mussels and other bivalves are the most widely accepted bioindicators of chemical pollution in coastal and estuarine waters and of course, as human foodstuff. This makes the analysis of mussels and other bivalves for the metal contamination an important environmental analytical issue. The mussels have the ability to inadvertently adsorb and bioaccumulate within the soft tissue dissolved metals and chemicals from the water and also to adsorb species from the surface of particulates filtered from the water column. The exposure studies have showed that the total concentration of metals within the tissue and the effect of the size and age of the bivalve are both of the interest for the metal accumulation [21, 22].

On the basis of the reference papers, it can be concluded that there is insufficient data about the Bay seawater and sediment quality. Also, there are no data on elements distribution in the bay sediments by depth, but there have been some investigations with regard to the elemental surface sediment composition and the metal bioaccumulation in *P. oceanica* [7, 23, 24] and in *Mytilus galloprovincialis* in the Boka Kotorska Bay [6, 25]. The aim of this paper is to give a brief overview of the most important data about contaminants in seawater, sediment and biota in the Boka Kotorska Bay, with special focus on heavy metals, in relation to the present investigation.

2 Physicochemical Characteristics of Seawater

Seas and oceans represent the oldest and the largest life area and cover approximately 71% of the Earth. The average depth of the world sea is 3,750 m, while the average land height above the middle sea level is 875 m. Accordingly, overall water volume in seas and oceans is approximately 11 times larger than land volume above the seawater level. Based on overall biomass, sea and ocean life far exceeds living organisms developed on the land. The richness of sea and ocean plants provides the production of enormous amounts of oxygen, exceeding the oxygen production by green plants on the land [26]. Accordingly, seas and oceans are important as oxygen source and organic matter producers [11].

Seawater is an important and inexhaustible source of certain elements and compounds (Mg, Br, NaCl), although the concentration of numerous metals is low and regardless of the enormous supplies, their production from the seawater is uneconomical [27].

According to the chemical content of the seawater, there are certain groups of elements: macroelements, gases and biogenic elements. Biogenic elements are mineral compounds of nitrogen (ammonium ion, nitrates and nitrites), mineral compounds of phosphorus (phosphates) and mineral compounds of silicon (silicates).

The most important components of seawater that influence life forms are salinity, temperature, dissolved gases (mostly oxygen and carbon dioxide), nutrients and pH.

The most important feature of seawater is the presence of high content of salts with average concentrations 35 g per 1,000 g of water in the sea world. Significantly higher deviations of salt concentrations are found in coastal areas and closed bays due to river influence and increased precipitations. During the rainy seasons, salinity of the water surface in the Boka Kotorska Bay decreases to very few grams per 1,000 g of water [28].

Salt concentrations depend on depth; for example, higher values with lesser fluctuations of salinity were recorded in the bottom of open Adriatic Sea, while in the other seas, salinity decreases with higher depth [29]. The average salinity of the Adriatic Sea is 38.3 g/1,000 g, taking into account higher values in southern part and open sea (38.48–38.68 g/1,000 g) [29]. Due to precipitations and freshwater inflow by the rivers, in northern and middle Adriatic, salinity varies periodically more than in southern part. In certain coastal areas or closed bays, salinity is considerably lower. The Boka Kotorska Bay is characterized by submarine fresh water springs (particularly in Kotor, Risan and Tivat bays), as well as numerous springs and streams along the entire sea coast. The capacity of these springs is variable during the year, leading to seasonal variations regarding hydro-graphical features of the bay, particularly temperature and salinity [1, 28]. Many marine organisms are highly affected by changes in salinity. This is the result of the process known as osmosis which is the ability of water to move in and out of living cells, in response to a concentration of a dissolved material, until equilibrium is reached. In general, the dissolved material does not easily cross the cell membrane so the water flows by osmosis to form equilibrium. Marine organisms respond to this as either being osmotic conformers (also called poikilosmotic) or osmotic regulators (or homeosmotic) (www.marinebio.net/marinescience/02ocean/swcomposition.htm).

Life in the sea, apart from nutrients, light and temperature conditions, requires dissolved O_2 and CO_2; CO_2 is present as H_2CO_3. In addition to those, other gases are present in seawater: nitrogen, hydrogen, methane (the Bermuda triangle) or toxic H_2S (the Black Sea). The oxygen in seawater plays an important role in processes of organic matter degradation and energy release, while CO_2 is required for bioproduction of organic matter. Percentage of dissolved oxygen present in seawater is higher than in atmosphere, in absolute amount seawater contains low amount of oxygen [30]. The oxygen content in the sea is decreasing with water temperature and salinity increase. These processes are very important for maintenance of constant pH values in seawater (8.15–8.40). In seawater, buffer action of HCO_3^- and CO_3^{2-} is important. For example, with intensive oxygen processes in the sea with elevated H^+, CO_3^{2-} binds H^+ and transforms into HCO_3^-. Thus, value of seawater alkalinity is maintained. With depth increase, pH value decreases. At locations with lack of oxygen or completely without oxygen, there are low values, pH = 7.5. It is the lowest value recorded in the Boka Kotorska Bay. Reversibility of these processes and maintenance of constant Ph values in seawater are of great importance for organism’s life and their distribution.

Fertilizers, like nitrogen (N), phosphorus (P) and potassium (K), are important for plant growth and are called ‘nutrients’. Phosphates and carbonates are the most important salts in the seawater due to their role in primary production. These salts are present in higher amounts in deeper layers of the seas and oceans. During the vertical movement of deep waters, nutrients are also moved and displaced by the horizontal sea currents in polar sea areas. Accordingly, certain cold coastal sea areas have the highest organic matter production by phytoplankton and sea vegetation. Nitrogen is present as ammonia (NH_3), ammonium ion (NH_4^+), nitrate ion (NO_3^-), nitrite ion (NO_2^-) and phosphorus as phosphate ion (PO_4^{3-}) in the seawater. Considerable nitrate amounts are rinsed from the coast and land, while lower part of phosphates due in seawater from the atmosphere, produced by electrical discharge. The largest amount of phosphates and nitrates in the seawater derives from processes of organic matter degradation. The Adriatic Sea has a lack of phosphates and nitrates. In southern Adriatic phosphates are present in traces 6.6 μg/L, while maximum values in the Boka Kotorska Bay were up to 20 μg/L PO_4. Colder waters of northern seas contain 40–60 μg/L PO_4 [29]. In the Boka Kotorska Bay (Adriatic Sea) the quantity of nitrate is somewhat higher, reaching up to 400 μg/L in the upper layers, nitrite up to 5.6 μg/L while the maximum measured value of silicate ions in the Boka Kotorska Bay (2012) amounted to 945.85 μg/L [31]. Nutrients content, as the most important characteristic of seawater, is higher during the summer period, particularly nitrates and phosphates [32]. This reflects the seawater quality. It is true that different nutrients with inorganic or organic salts are required for sea organism’s growth but too high concentration has a negative effect. Elevated phosphorus and nitrogen concentrations enhance phytoplankton growth and reproduction which leads to ‘algal bloom’ [33] and decrease of light and photosynthesis. There is an increased nutrient input in the seawater in areas with inflow of large amount of waste waters, mouth of the rivers and areas with soil rinsing. These are the main reasons for higher eutrophication level in the Boka Kotorska Bay. Location Crkvice, in the vicinity of the Boka Kotorska Bay, has the highest seasonal precipitation level in Europe (the highest average annual precipitation extreme found in Europe) [34].

Silica and iron are also considered important marine nutrients as their lack can limit the amount of productivity in an area. Silica is needed by diatoms, one of the main phytoplankton organisms that form the base of many marine food chains. Recently, it has been discovered that iron is limiting factor for phytoplankton growth.

Nutrients concentration in the sea can vary according to temperature and climate, or to vertical and horizontal water movement, which can cause periodic variations in bioproduction extant and development of plants and animals in the sea. The same substances and chemical elements are required for organisms in the sea and on the land. Almost all chemical elements are present in the sea environment. Specific elements are present in traces and they are required for development of certain organisms and biological processes. For example, iron is required for photosynthetic pigments production, while copper (as content of blood pigment – hemocyanin) is present in body fluids of many invertebrates.

3 Heavy Metals

Metals are natural constituents of the biosphere. They appear in different concentrations with different chemical characteristics. Majority of them are essential for biological systems. Thus, in absence of a certain metal, organism's growth, reproduction and development are not possible. Except for macroelements (Na, K, Mg and Ca), other metals present in traces are also preferable in certain amounts [19]. Organisms absorb heavy metal ions from the environment, whether they are essential or not, and accumulate them in their tissues. All heavy metal ions are potential toxins if they are present in certain concentration, while nonessential elements (Hg, Pb and Cd) are very toxic, even in low concentrations [19, 20]. Elements required for animal growth: macro elements or macronutrients (N, S, P, Ca, Cl, K, Mg and Na) and microelements or micronutrients (B, Cr, Co, Cu, F, Fe, I, Mn, Mo, Ni, Se, Si, V and Zn) [19, 25]. Curiously, Ba, Cd, Pb and Sr are also included in the list of elements required for life, but in low concentrations [35].

3.1 Heavy Metals in Seawater

Water can accept large amounts of pollutants. Regardless the great self-cleaning capacity, specific pollutants lead to water quality change to a large extent, including majority of heavy metal ions [35]. The waste waters represent the greatest hazard to water quality deterioration by heavy metal ions. Determination of heavy metals content in the seawater is a complex issue. It is due to their appearance in different and complex chemical forms and in very low concentrations, accordingly, it is inevitable to use specific analyses and different measurement methods [36, 37]. Heavy metal dissolution in seawater is influenced by numerous factors such as pH, temperature, salinity and different anions. Any form of heavy metals (dissolved or steady state) is deposited on the sea bottom after long time period.

Anions, such as sulphates, chlorides, fluorides, carbonates, bicarbonates, precipitate soluble metal cations.

Montenegrin coast is exposed to negative anthropogenic pressure by coastal activities. The nature is affected by negative human activities which lead to pollution. Thus, urbanization and industrialization lead to intensive populating of coastal area including the Boka Kotorska Bay, i.e., Montenegrin coast. This brings into question the environment quality and hence of the sea in the Bay.

At the end of twentieth century in the Mediterranean Sea, the concentration of metal ions in the water in the open Mediterranean Sea was within relatively acceptable limits. In the last 20 years, these investigations have become more intensive and more complex. Recent analyses show relatively high values in certain parts of the coast for particular metals, e.g. Cd [38–40]. Values of Pb are higher by 20–40 ng/L approximately in north-western part of the Mediterranean Sea relative to their level in the ocean. Zn concentration was between 150 and 220 ng/L, in the northern part of the Adriatic it was 410 ng/L [38, 39]. In the Adriatic Sea, from southern to northern part, increased concentration of Cd, Pb, Cu and Zn was observed.

Montenegrin coast, particularly the Boka Kotorska Bay, is under high anthropogenic pressure and coastal activities [7, 22]. Coastal waters of the Boka Kotorska Bay (Kotor and Herceg Novi) are the most endangered by the process of anthropogenic eutrophication due to waste, particularly waste waters derived from land activities. Land erosion due to large quantities of atmospheric precipitation in the Boka Kotorska Bay, as well as industrial facilities and hospitals on the sea coast, contributes to negative anthropogenic pressure in this area. The effects of water pollution by heavy metals ions are different and they are primarily manifested by plants, as the most vulnerable organisms in food chain plant–animal–human. Heavy metals are included in food chain by this kind of pollution. According to the first heavy metal studies in the Boka Kotorska Bay, conducted at the end of twentieth century [41, 42], it was concluded that most of analysed water was polluted, i.e. the pollution level exceeded allowable value limits. The values for Cd were (0.1–1.0 μg/L), Hg (0.1–0.7 μg/L) and Cu (2.3–8.4 μg/L). Pb values were up to 10.0 μg/L, Zn up to 16.0 μg/L, As up to 0.9 μg/L and Cr up to 3.0 μg/L. These values indicate that except for arsenic, all of them were above MAC for the seawater [41, 42]. Since the lead and copper concentration in seawater primarily depends on human activities, it is clear that the values were increased due to high anthropogenic impact [39–45]. The concentrations of lead, cobalt, copper, nickel and zinc were under allowable values limit according to OSPAR [46].

World trends lead to increased number of facilities on the sea coast. Construction of ports, moorings, small harbours, inner harbours in natural inlets or other coastal adaptations pose ecological risks. Years of progress and rapid development of the Montenegrin coast, particularly during 2005–2007, resulted in considerable water source pollution.

According to the studies conducted in the period 2005–2007 (seasonal determination – surface/bottom) (Fig. 1), Fe concentration in seawater samples from the Boka Kotorska Bay was higher than MAC value of 0.140 μg/L [38]. In general, Fe content in the bottom is higher than in surface. Certain locations are characterized by higher Fe concentration on the surface as a consequence of geochemical and anthropogenic influence. Usually, Fe is accompanied by Mn/MnO [9]. Accordingly, chemical content of the water column above the sea bottom depends on geochemical content of the bottom, pH and oxygen content of the seawater, i.e. Mn and Fe have higher solubility in low oxygen seawater [47]. Also, they are accompanied by the other metals Co, Ni and Cu. Otherwise, seawater Fe is characterized by increased concentration up to specific depth relative to surface, this was the case with mentioned water samples. Rivers are the primary Fe source in the seawater. Co, Ni and Cu content has similar order of magnitude in autumn and spring samples, from the bottom and surface, and these values were in the following intervals: Co 1.84–10.26 μg/L, Ni 3.4–21.5 μg/L and Cu 1.4–19.7 μg/L. Measured concentrations for Pb, Cd, As and Hg are up to 3 times lower than Mn, Fe, Zn, Co, Ni and Cu, particularly considering spring samples [48–51]: Cd 1.1–11.2 μg/L; As 0.5–2.9 μg/L and Hg 0.3–1.56 μg/L, while Pb was between 0.6 and 27.7 μg/L. Except for the As with values below MAC for seawater (1.8 μg/L), Cd 0.124 μg/L, Hg 0.002 μg/L and Pb were 0.036 μg/L were considerably higher in relation to MAC [38]. For these elements, in autumn 2005, the measured concentrations were higher than in spring samples from 2006, particularly for Cd and Pb. Cd content was between 2 and 10 times higher in autumn samples. Also, higher level of elements was observed in Venice lagoons and on Italian coast, particularly in southern part [52, 53]. As regards Pb content, high value was measured at the site in the Tivat Bay.

Based on the sample analyses, it can be concluded that average content of Fe, Zn, Pb, Cd, As and Hg was higher in autumn samples in comparison with spring samples. In general, concentration of the investigated microelements is higher in surface water samples relative to bottom samples, also in autumn relative to spring samples [48–51], which lead to conclusion that anthropogenic factor is the main reason for seawater pollution. Certainly, such distribution of microelements in seawater surface-bottom and spring-autumn is influenced by tourist season, which entails increased population in the coastal area.

3.2 Heavy Metals in Sediment

Seawater pollution by heavy metals under anthropogenic factor has grown significantly over the last decades. These pollutants have tendency to accumulate in bottom sediments. Consequently, marine ecosystems under the effect of ports and/or other industrialized parts of the coast are facing continuous input of metals and highly contaminated sediments.

Sediments have significant role in defining main chemical, physical or biological characteristics of aquatic environment. Sediments can be the source or deposition place for nutrients, trace metals and organic matter with the influence on numerous chemical reactions. The state of sediment is an archive of marine history and past events and can serve for overall reconstruction of the environmental state [28].

Sediments represent habitat for many aquatic organisms, also it is a deposition place for a large part of chemical substances precipitating and simultaneously dissolved in water column above the sediment according to their equilibrium for specific conditions. In aquatic environment, majority of chemicals and waste substances, introduced by humans, including toxic organic and inorganic pollutants, accumulate in the sediments. Contaminant concentrations in sediments can be several times higher than in the water column above [54, 55].

Part of pollutants and chemicals from the sediment that can enter the water depending on many factors, including their solubility, pH, redox reactions, affinity for sediment and dissolved organic carbon, sediment grain size, mineral composition of sediments (Fe, Mg and Al oxides), etc. Some chemical compounds, i.e., pollutants, are strongly bound to sediments, but these compounds may still be available to the living organisms.

The first investigations regarding heavy metals presence in sediments began in the 1980s. Rivers overloaded by municipal and industrial waste waters via system Skadar Lake – Bojana River yields large amounts of deposit saturated with many pollutants, so all studies were mainly focused on the area around Ada Bojana, as the most vulnerable spot on the Montenegrin coast. More complex investigations of heavy metal concentrations in the Boka Kotorska Bay started at the end of twentieth century. According to the studies, started in 1999, Mn concentration was 389.3–1045.9 mg/kg; Fe 12,447–47,117 mg/kg; Cu 22.6–128.2 mg/kg; Zn 43.4–532.4 mg/kg; Co 0–11.6 mg/kg; Ni 42.1–156.8 mg/kg; Pb 0–68.4 mg/kg; Cd 0–2.7 mg/kg; Hg 0.06–0.25 mg/kg and As 1.7–6.7 mg/kg [56].

Based on these results, it can be concluded that significant amounts of heavy metals are deposited in sediments of the Boka Kotorska Bay. In coastal sediments and central position of the Boka Kotorska Bay, the most present metals are Pb. Cu, Zn, Hg and As, while Cd content was the highest in sediments of Tivat and Risan Bay, Fig. 1 [10, 16, 24]. If we compare the obtained results to MAC values [57], the highest content of the investigated heavy metals is in the coastal and central part of the Kotor Bay, because this area was exposed to the influence of industry and also because of the ports present in the Bay. During the research conducted over the last 10 years, the obtained results indicate significant differences in heavy metal concentrations in sediments in the locations tested [10, 11, 48, 49].

Concentrations of elements were [8, 48, 49]: Mn 155.4–497.1 mg/kg; Fe 1594.2–12,252.7 mg/kg; Cu 4.7–11.8 mg/kg; Zn 5.1–46.2 mg/kg; Co $<$1.0–10.2 mg/kg; Ni 12.7–74.5 mg/kg; Pb 0.1–9.5 mg/kg; Cd $<$0.05–0.8 mg/kg; Hg 0.01–0.09 mg/kg and As $<$1.1–19.6 mg/kg. Concentrations of elements tested were presented in the following order:

$Fe > Mn > Ni > Zn > Cu > Co > As > Pb > Cd > Hg$.

Concentration values of microelements tested in sediment of the Boka Kotorska Bay were higher in relation to specific locations under the influence of open sea [56]. Sediment values of heavy metals tested in the Boka Kotorska Bay and along the entire Montenegrin coast with reference data on the Mediterranean region show that values obtained are approximately within the same interval, and perhaps even lower than in the areas of the Mediterranean and the Adriatic Sea [8, 48–51, 53–56, 58–65].

More complex research of the Boka Kotorska Bay bottom was conducted during six oceanographic surveys in the frame of international project ADRICOSM-STAR between 2007 and 2010 (Fig. 2). Coastal area of northern Albania and Montenegro, with particular focus on Bojana River mouth and the Boka Kotorska Bay, areas were covered by the research. During these studies, in surface sediments samples from 2007 (Bay of Kotor, Tivat and Herceg Novi and a site in front of the bay), it was determined total heavy metal content for sediment fraction <2 mm. Heavy metal concentrations (mg/kg d.w.) were: Pb (18.23–45.30); Cd (0.27–0.73); Zn (61.43–145.94); As (15.85–32.99); Cu (20.46–58.62); Ni (161.93–208.77); Mn (598.68–1052.49); Hg (0.36–1.45) and Cr (141.41–548.30). Maximum Pb, Cd, Zn and Mn concentrations were obtained in sites in the Kotor Bay, while the highest concentration of Cu, Cr and Hg was obtained in sediment in the site in the Tivat Bay. The highest As content was found at sediment position in the bay entrance, while Herceg Novi Bay has the highest content of Ni. The lowest content of Pb, Cd, Zn, Cu, Mn and Hg was measured at the site located at the bay entrance, while sediment in the Kotor Bay had the lowest content of As, Ni and Cr. In sediment from sites in the Kotor and Tivat Bays, the highest percentage of organic matter was found (factor that influences the presence of majority of heavy metals in sediments) [11].

During 2008, content of Cu, Pb, Zn, Ni and Cr in sediments was determined in locations in the Boka Kotorska Bay (Kotor, Tivat and Herceg Novi Bay). In this

Fig. 2 Sampling of sediments

study sediment was sliced in subsamples with frequency of 2 cm and heavy metals analysis was performed for sediment fraction with particle size <63 μm, in order to obtain vertical distribution of the analysed elements for the first 10 cm of sediment surface [66]. Spatial distribution of sediment content in surface layer 0–2 cm indicates that the highest content of Cu, Pb and Ni at the site in the Tivat Bay was 42.8 mg/kg, 41.9 mg/kg and 139.2 mg/kg, respectively. The highest content of Cr (87.0 mg/kg) and Zn (108.0 mg/kg) was measured in sediment of the Kotor Bay. Also, the lowest content of Cu, Pb and Zn was at the site in Herceg Novi Bay 37.1 mg/kg, 29.1 mg/kg and 86 mg/kg and for Ni and Cr at the site in the Risan Bay 120 mg/kg and 71 mg/kg, respectively [67].

For sampled sediments in the Risan and Kotor Bays it can be said that the lowest contents of the elements are shifted towards deeper sediments, while the elements content in the sediments of Tivat and Herceg Novi Bays are the highest in the deeper layers of sediments (segments 6–8 and 8–10 cm) [66].

Along with research in national and international projects in Montenegro, as of 2008, annual surveys of physical and chemical composition of the sediments have been implemented within the national program of monitoring of coastal ecosystem of Montenegro, at the distance of one nautical mile from the coastline. In the framework of the monitoring conducted in 2014 at nine locations in the Boka Kotorska Bay (a map of all sampling) the ecological quality of surface sediments samples (0–2 cm) is evaluated in comparison with the maximum allowable concentrations (MAC) laid down by the rulebook on permitted amounts of hazardous and noxious substances in the soil [57], and with Canadian quality criteria stipulated in the guidelines for sediments quality in order to protect the aquatic world [68]. Canadian standards define three ranges of chemical concentrations in relation to biological effects: under ISQG level, between ISQG and PEL level and above the PEL level, which is indicating rare, occasional and frequent negative biological effects.

Monitoring data showed that the minimum content of all investigated elements Cd, Hg, Cu, Ni, Fe, Mn, Pb, Zn, Cr and As is measured in sediments at the reference site at the Luštica Peninsula which is located far from anthropogenic sources of pollution, and these amounts are: 0.11 mg/kg, 0.05 mg/kg, 12.48 mg/kg, 68.27 mg/kg, 12,200 mg/kg, 341.08 mg/kg, 8.97 mg/kg, 34.52 mg/kg, 44.90 mg/kg and 11.8 mg/kg, respectively. Maximum contents of Cd, Hg, Cu, Ni, Fe, Mn, Pb, Zn, Cr and As are as follows: 12.36 mg/kg (Port of Kotor); 4.40 mg/kg (Porto MNE); 121.51 mg/kg (Shipyard Bijela); 161.68 mg/kg (Herceg Novi); 36,000 mg/kg (Kotor-centre); 1545.12 mg/kg (Kotor-centre); 84.34 mg/kg (Porto MNE), 241.06 mg/kg (Dobrota IBM); 95.80 mg/kg (Herceg Novi) and 39.05 mg/kg (Porto MNE), respectively [69].

In all these locations, the content of Cd in the sediment is below ISQG level, or below the MAC for the land. This means that in terms of content of Cd in sediments in studied locations they are environmentally friendly because they are not dangerous from the standpoint of protection of aquatic biota, i.e. for these, adverse biological effects can rarely be expected. The content of Zn is divided into locations where the content is below the ISQG and locations where the content of these elements is between ISQG and PEL, while its content in relation to the national regulations in all locations in the Bay is below MAC. The content of Hg, Cu, Cr, Pb and Ni is predominantly in the range between ISQG and PEL [57, 68, 69]. These sediments may represent a potential threat to benthic organisms and adverse effects on benthic organisms could be expected occasionally. In accordance with the recommendations of the Canadian sediment quality, we need to conduct further tests in such sites in order to determine whether these elements in sediment pose a significant threat to organisms. In addition, the contents of Ni and Cr (except near Luštica) are in all locations above the MAC prescribed for the land. The share of Pb in most locations is also above the MAC. The share of Cu, As and Hg was higher than MAC only in sediments of the Shipyard Bijela, Porto MNE and the Port of Tivat. The content of As is at all locations between ISQG and PEL level indicating occasional threat to the living world and suggests the need for further research of the influence of As present in the sediment. The content of the elements above the PEL value, which indicates the iterative and significant threat to the living world, was measured for Hg (Porto MNE and the Port of Tivat) and Cu (Shipyard Bijela) [57, 68, 69].

Compared to the same standards, the maximum value of the analysed heavy metals Cd, Hg, Cu, Ni, Pb, Zn, Cr and As in sediment of the Boka Kotorska Bay for the period 1999–2008 is generally between ISQG and PEL values. The highest measured concentrations of Cu and Zn (according to the data from 1999), and Hg and Cr (according to the data from 2007) exceed the PEL value specified for the above-mentioned elements. Thus, the results of the analysis in the long term indicate the necessity of further research and monitoring of sediment quality of the Bay in terms of heavy metal contamination, with special emphasis on determining the nature and extent of the impact on the local biota.

3.3 Heavy Metals in Biota

Living organisms because of its ability to absorb various contaminants from the water are very suitable indicator for the analysis of pollution of the marine environment. The application of living organisms has a number of advantages over standard methods of chemical analysis of trace metals in the samples of seawater and sediments [70]. First of all, the concentration of metals in living organisms is significantly higher than in the seawater, and with the use of living organisms reduces the possibility of contamination of samples in collection and treatment. A particular problem with the classical methods of analysis of samples of seawater and sediment was a lack of correlation between the total concentration of metals in water and sediments and their biological availability. Living organisms, unlike traditional methods, enabling accurate determination of the concentration of biologically available forms of metals in the marine environment. Bioavailability refers to the total concentration of chemical substances in the environment, or the part of it that which marine organisms can absorb. Availability of ions of microelements to the marine organisms depends on their physical–chemical conditions, i.e. most of their biogeochemical cycle, and connects not only the characteristics of chemical compounds, but also the behaviour and physiology of the organism. An important step in this cycle is the accumulation and/or dissolution of trace elements in/from sediments [71].

Certainly, lower organisms are more sensitive to pollutants and can be detected in a very short time interval. These biomarkers provide 'early warning signals' about the possible effects of pollutants on populations or commune. Manifestation of the effects of pollution on the entire population or community requires a longer (latent) period of time [72, 73].

In addition to the above, relationship between the content of metals in the organism and in the surrounding water, the impact of changes in temperature, salinity and other hydrographic factors on the organism should be known. Of course, there is no species that would satisfy all the above requirements. Studies have shown that the mussel *M. galloprovincialis* fits best the requirements listed [74–78].

3.3.1 *Mytilus galloprovincialis*

Metal intake by water organisms (bivalve molluscs) can take place in two ways: through water or through food. In the food that mussels ingest (phytoplankton, bacteria and suspended sediment), metals can be bound to organic or inorganic substances. Mussels, with their well-developed detoxication method, can tolerate far higher heavy metal concentrations than other living organisms [25], by binding them to proteins of small molecular, depositing and neutralizing their toxicity. At the same time, this bivalve mollusc is used as a bioindicator for marine environment pollution by toxic metals [12, 41].

The elemental compositions of mussels *M. galloprovincialis* from the Boka Kotorska Bay were determined by measuring the contents of essential Cl, Si, S, K, P, Ca, Fe, Zn, Mn, Cr, Cu, I, Ni, V and Co, and nonessential As, Sr, Ti, Ce, Ba, Br, Cs, Rb, Pb, Ni, Th, Sb, Sn, Cd, Zr and Hg elements by energy dispersive X-ray fluorescence. Based on the data for thirty analysed elements, in the mussel soft tissue, 98.7% were macroelements (Cl, Si, S, K, P and Ca), while the remaining 1.3% referred to all the remaining elements: 0.76% essential microelements (Fe, Zn, Mn, Cr, Cu, I, Ni, V and Co) and 0.54% nonessential (As, Sr, Ti, Ce, Ba, Br, Cs, Rb, Pb, Ni, Th, Sb, Sn, Cd, Zr and Hg) [25].

The first continuous research on the presence of heavy metals in the tissue of mussels, *M. galloprovincialis*, in the Boka Kotorska Bay began in the fall of 2005 and lasted until autumn 2009. On the basis of these results the concentration of the elements was in the following ranges: Fe: 54.40–751.60 mg/kg, Mn : 1.50–49.60 mg/kg, Zn: 34.40–566.00 mg/kg, Cu: 1.65–15.62 mg/kg, Co: 1.10–14.60 mg/kg, Ni: 1.35–18.90 mg/kg, Cd: 0.90–5.05 mg/kg, Pb: 1.50–17.70 mg/kg, Hg: 0.025–2.65 mg/kg, Cr: 2:00 to 5:50 mg/kg and As: 1.90–17.80 mg/kg [30, 72–74]. As and Cr were detected only in samples in autumn 2005/spring 2007 [7].

In all samples of mussels from the period analysed the highest concentration measured was that of Fe and Zn, while the lowest concentration was measured for Cd and Hg [7]. Concentrations of heavy metals in the body of mussels depend not only on the concentration of heavy metals in the marine environment, but also on the interaction of the organism and environment, and physiology of the organism, so the concentration of other investigated heavy metals (Cu, Co, Ni and Pb) varied from season to season due to the influence of different factors: biological (the speed of filtering of water, growth, biochemical processes, reproductive cycle and metabolism/elimination), environmental factors (physical and chemical properties of seawater) and various anthropogenic influences [7, 20]. If we compare the data obtained in different seasons in 2008 and 2009, we see that the concentrations of heavy metals in the tissue of mussels were generally the highest in winter, then in the autumn, and the lowest in spring samples. Regarding the period of the fall of 2005/2007, the concentrations were also higher in the autumn than in spring samples. Such variation is expected because of the influx of fresh water is the highest in the autumn and winter months, so in that period the solubility of heavy metals is the highest, and in winter the weight of the edible part of mussels is reduced, while the amount of accumulated metals remains the same [20, 73–81].

The highest concentrations of Fe and Zn were measured, for the most part, in samples of the Tivat Bay. Fe is an essential metal, so a high concentration of this microelement was also expected. The concentrations of Zn were often above the maximum allowable concentration (MAC), which is 200 mg/kg [82], in all samples from the autumn of 2007 and winter of 2008, except in one location of the Kotor Bay. As for the rest of the season, higher concentrations were measured in six samples only. Zn is also an essential element, which is not subject to biomagnification and whose concentration generally is regulated by organisms [83]. In comparison with the reference data, this concentration is similar to concentrations found in mussels, *M. galloprovincialis*, from other parts of the Adriatic Sea [52, 65, 84, 85] and the Mediterranean [86–88], and on the shores of the Atlantic Ocean [89–91].

In samples of mussels from the Boka Kotorska Bay, the Mn concentrations were in the range 1.50–49.60 mg/kg, but except for an extreme value found in samples from Žanjica in autumn 2005 (49.60 mg/kg), the range was from 1.50 to 28.70 mg/kg. As regards the reference data, the measured concentrations of Mn in mussels in the Boka Kotorska Bay are similar to the concentrations in the mussels of the Adriatic [52, 65], the Black Sea [92, 93] and the Atlantic Ocean [89–91], and significantly higher than in the Ionian Sea [94], the Sea of Marmara [92, 95, 96] as well as the Spanish Mediterranean coast [88]. Relatively high concentrations of Mn in investigated mussels primarily can be explained by the geochemical composition of the environment of the bay, which is rich in manganese [97].

Mn, Cu and Co are also essential elements and they are crucial for the metabolism of most organisms [98]. As the maximum allowable concentration of copper (MAC) is 10 mg/kg [82], according to the measured values (1.65–15.62 mg/kg), its concentration occasionally exceeded the permissible value at certain locations in Tivat and Herceg Novi Bay. In that regard, deviations from the maximum allowable values are not great and similar concentrations were found in mussels from the Adriatic Sea [65, 85, 99, 100], the conclusion is that mussels in the Boka Kotorska Bay are not contaminated by this metal. Significantly higher concentrations of Cu were found in mussels in the Spanish Mediterranean coast [87, 88] and the Atlantic Ocean [89, 91, 101], as well as in the French Mediterranean coast [87]. Concentrations of Co were significantly higher compared to the reference data of other sites included in the survey [12, 65, 86, 89, 92, 95, 96, 102–104]. Cobalt, among other things, is used in the manufacture of fertilizers. Therefore it can be said that the increased content of Co in the Boka Kotorska Bay is only a consequence of anthropogenic pollution from the land, particularly in the Bay of Tivat, whose hinterland is used as an agricultural area [41]. The nickel concentration was increased in all samples in almost all seasons in relation to the maximum allowable concentration (MAC), which is for Ni 3.40 mg/kg [82]. In comparison with other published data [12, 65, 94–96, 99, 102, 103, 105, 106], Ni content in the mussels is also increased not only as a result of its geological origins in seawater of the Bay [9], but also the human impact should not be disregarded [89, 91, 107].

Compared to the maximum allowable concentrations (MAC), the value of Cd was generally lower than the MAC, which for Cd is 3.7 mg/kg (only two extreme values were found throughout this whole period), while the concentrations of Pb and Hg most were above the allowable (3.2 mg/kg for Pb and 0.23 for Hg) [82]. The concentrations of Pb were particularly increased in the autumn of 2005, 2006, 2007 and 2008 and in the spring of 2006 and 2007, when all the samples (with the exception of two samples of the total) had increased concentration. High concentrations of lead were detected mainly at sites with more frequent maritime and land transport, as well as in locations with ports and harbour for ships. When two extreme values are excluded, measured concentrations of Pb are within the values found in mussels from the Adriatic Sea [65, 99–101], the Sea of Marmara [90, 108], the Mediterranean Sea [88] and the Atlantic Ocean [87, 89, 90]. High levels of mercury can be attributed not only to anthropogenic effects [109], but also to the fact that the Mediterranean Basin is rich in minerals of mercury [110, 111]. The concentration of Cr (autumn 2005/spring 2007) in almost all samples exceeded the maximum permissible concentration (2.5 mg/kg), [82] but when compared with results from the literature, they are within the range or lower than the concentration found in other parts of the Mediterranean, and on the shores of the Atlantic Ocean [65, 89]. The concentration of As was within the permissible values (except for the location Herceg Novi in autumn 2005) [82]. So, after comparing these data with the reference ones, it can be said that the mussels from the Boka Kotorska Bay generally contained higher concentrations of Co, Ni, Pb and Hg [21, 22, 25], as well as relatively higher concentrations of Mn and Zn in the investigated period.

Considering that the mussel *M. galloprovincialis* has been increasingly used as food and that the number of commercial bivalves farms along the coast of the Bay is increasing, the programmes of monitoring and measuring the pollution levels have been designed in order to control the quality of the marine environment without specific emphasis laid on how pollution of the medium could affect the health of organisms and hence human health.

3.3.2 *Posidonia oceanica*

The specificity of the aquatic environment is reflected in the fact that it gives the possibility to organisms to live on the bottom, as well as in the free water. Those organisms that spend their entire life cycle on the bottom of a water basin consists the benthos, and in the seas and oceans we can divide it into phytal (littoral) and aphytal (deep). The boundary between these two systems is presented with the depth to which penetrates the minimum amount of light necessary for life of autotrophic organisms, and it is up to 200 m. Although phytal benthos is only about 8% of the total area of benthos, it is qualitatively and quantitatively considerably richer than aphytal system [112].

In phytal benthos all plant and the vast majority of animal species are present. In sandy and muddy substrates in coastal areas of the sea (40 m deep) presence of underwater meadows ‘sea grass’ is common.

Settlements of sea grass, *P. oceanica* (L.) Delila, make the most typical biocenosis in the Mediterranean Sea (Fig. 3). Underwater meadow of this flowering plant are important not only because of the production of organic matter and oxygen, but because they represent the habitat, food and shelter for many marine organisms. In addition, the meadows of this type have a very important role in retaining the sediment, reducing the movement of water and preventing the erosion of the seabed.

Because of the importance of sea grasses and their sensitivity to changes, these plants are given more attention. Some of them were declared endangered or protected species, for example, according to the Berne Convention of 1998 *P. oceanica* and *Cymodocea nodosa* were declared strictly protected species [113]. Also, in many countries of the Mediterranean Sea national legislation protects various marine flowering plants, including most types of *P. oceanica*, so they were the subject of our investigations [114, 115].

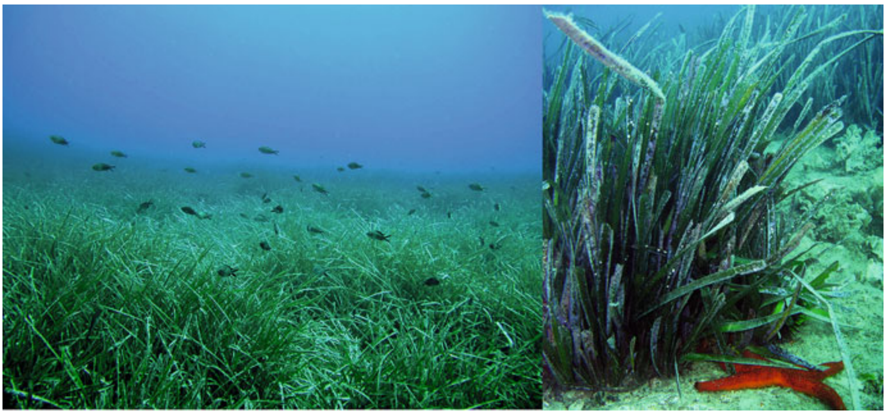

Fig. 3 Underwater meadows of *P. Oceanica*

All meadows of sea grass are found in shallow coastal regions and are therefore greatly exposed to negative human impact [116–119]. With complex systems of physical–chemical and trophic relations and precipitation from the water itself, potential contaminants are distributed from seawater to marine organisms and sediments. Since *P. oceanica* is a quite common sea grass in the waters of the Montenegrin coast, it is important to study its mineral composition, because it often represents the basic food for marine organisms and thus enters the human food chain.

Determination of the concentration of heavy metals in sea grass, *P. oceanica*, along the Boka Kotorska Bay started in 2005. In six locations, which are selected on the basis of increased anthropogenic influence from the mainland, metal concentrations are ranged from: Fe: 334.10–349.8 mg/kg, Mn: 43.40–360.0 mg/kg, Zn: 18.50–370.0 mg/kg, Cu: 1.60–15.60 mg/kg, Co: 2.40–17.60 mg/kg, Ni: 10.60–57.70 mg/kg, Cd: 0.30–9.30 mg/kg, Pb: 2.50–29.0 mg/kg, As: 0.80–13.60 mg/kg, Cr: 0.20–8.70 mg/kg and Hg: 0.025–2.71 mg/kg [73, 115]. All samples of sea grass from this period had the highest concentrations of Fe, Mn, Zn and Ni, and the lowest Hg. However, if we compare the average concentration of individual elements in the studied seasons, it can be seen that the average concentrations of elements in seaweed differ per season. Thus, for example, in 2008 the highest concentrations were measured in the winter, then in spring and in autumn samples, while in 2009 the highest concentrations are measured in the autumn, then in winter and in spring samples [120]. The content of heavy metals in sea grass depends on the amount of tested metals in sediment and in the surrounding water, as well as seasonal conditions. Generally the concentrations of metals in the plants are the higher in the winter, when the period of 'hibernation' of plants begins, while their concentration is the lowest during the period of maximum plant growth [23].

Extreme values of Fe were measured in four samples in the Bay of Tivat. If we exclude these values, the obtained Fe values in sea grass are in compliance with the concentrations found in the reference papers for other parts of the Mediterranean [121, 122], but they are lower than the concentration found in the Bay of Naples, Italy [121]. In comparison with the reference data for the Aegean Sea [122] the results of the Boka Kotorska Bay show higher concentrations of Mn. However, here the main problem is that most of the authors examined the content of Mn in different parts of the plant, which hinders the comparison of results [123–125]. Increased concentrations of Mn in relation to data of Sanz-Lazara et al. [122] primarily could be explained by the geochemical composition of the seabed of the bay, which is rich in Mn [97].

In comparison with the reference data, the concentration of Cu in sea grass of the Boka Kotorska Bay is lower compared to published data from various parts of the Mediterranean [121, 122, 126]. Based on the values published by Nienhuis [127], and which a large number of authors considered natural levels of copper in the seaweed, it can be said that *P. oceanica* from the Boka Kotorska Bay is not polluted by Cu.

When the value of Zn is compared with the reference data, it is clear that the concentrations found in *P. oceanica* from the Boka Kotorska Bay are generally lower than the data published on other parts of the Mediterranean [121, 128]. On the other hand, the concentration of Co was generally higher than in the Mediterranean [24]. As regards the increased content of Co in the mussels, increased concentrations of this element in sea grass are exclusively attributable to anthropogenic pollution from land and from the air, especially since the highest concentrations were found in the Bay of Tivat, where the human impact is the greatest. Ni concentrations are similar to the values published by Catsiki and Panayotidis [126] for the sea grass to the Aegean coast of Greece, and lower in relation to the data released by Sanchiz for sea grass in the Mediterranean coast [128]. Average higher concentrations of Ni obtained in seawater, as well as the mussel, suggest that the concentration of Ni in sea grass is primarily of natural origin, because the geological level of Ni in the south-eastern Adriatic is generally naturally high [9].

Measured concentrations of Cd and Pb were higher than concentrations published by Neinhuis [127] as natural levels of Cd and Pb in sea grass. Cd concentrations were higher in sea grass of the Bay than seen in reference data on sea grass of the Mediterranean [123, 124], and similar values are found along the Spanish Mediterranean coast [128], while the Pb in the samples from the Boka Kotorska Bay was lower than in the reference data [117, 123, 124]. Since Cd and Pb are nonessential metals, measured concentration of these elements is attributed to the anthropogenic pollution [24].

Data on the natural level of mercury in sea grasses do not exist, but the mercury concentrations found in samples grasses of the Boka Kotorska Bay are similar to the results published on areas along the Spanish Mediterranean coast [24]. This suggests that Hg in sea grass is a combination of anthropogenic and natural origin, i.e. that it largely comes from the natural environment because the Mediterranean basin is rich in minerals of mercury [110, 111]. Although for As there is few reference data, in comparison to the research done in some parts of the Mediterranean Sea [123], the measured concentration of As in samples from the Boka Kotorska Bay was lower. The measured concentrations of As are approximately the same in the spring as well as in the autumn samples.

The maximum concentration of Cr is detected in sea grass at the site in the Bay of Tivat (Kukuljina). This was expected considering that the sediment from this location has the highest content of clay and mud, which can contain higher amounts of this element. Adoption of large amounts of Cr in the lower part of the plant is contributed by the bigger surface in relation to the volume of root, which is closely connected to the surface [126]. High levels of Cr in sea grass are result of the significant presence of Cr in the sediment, which is probably of a natural geological origin [9–11]. Cr concentrations were generally higher than in the reference data [12, 129, 130], but are lower than the values found in some parts of the Mediterranean [123].

At this moment the concentration of numerous elements Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Br, Rb, Sr, Zr, Cd, Sn, Sb, I, Cs, Ba, Ce, Hg, Pb and Th, at four locations (Krašići, Kukuljina, Sv. Stasije and Herceg Novi), was analysed in the Boka Kotorska Bay in order to determine the average concentrations of elements, observe their variability, define their natural or anthropogenic origin and to identify possible sources of contamination.

Comparison of the results of current research activities with the results from initial explorations in flowering plants of the Boka Kotorska Bay [24] shows that more recent data show far lower levels of elements analysed in the flowering plants, which can be explained by higher control of seawater quality for entities in the vicinity of the marine environment of the Bay, i.e. by introduction of the rulebook on sustainability of the living environment of the sea for entities on the coast, and in the sea, primarily for industry, tourism, municipal waste and navigation, under which seawater quality is controlled and hence the quantity of heavy metals accessible by the flowering plant.

4 Conclusions

The Boka Kotorska Bay, in terms of nature and socio-developmental conditions, is one of the most interesting bays in the Adriatic. Geographical position, climatic conditions and specific relief of the bay make it unique in terms of hydrodynamics, hydrographic and hydrological characteristics. The tightness of the bay restricts communication with the open part of the Adriatic Sea, and all this affects the monthly, seasonal and perennial variations of hydrographic and oceanographic parameters, thereby making the complex and dynamic ecosystem of the bay. Intensive urbanization, tourism and especially the increasingly present nautical tourism, waste water that flows into the bay are factors of the anthropogenic pressure on the bay.

Reduced speed of water exchange with the open sea affects the smaller capacity of the bay for the reception and degradation of pollutants, which further burdens the bay. This is indicated by the results of testing the quality of the environment of the bay which confirms the load of heavy metals in the water and sediments in the bay, as well as the fact that the value of the tested concentrations of trace elements in sediments of Boka Kotorska Bay is higher than in the individual locations that are under the influence of the open sea. These sediments may represent a potential hazard for organisms exposed to them, and they require additional tests for the final assessment of their ecological status.

Seasonal variability of abiotic environmental factors such as temperature, salinity, pH, inflow of fresh water and nutrients affects the chemistry and circulation of heavy metals in water and sediment, which are reflected in the seasonal changes in the content of these elements in biota (mussel *M. galloprovincialis* and sea grass *P. oceanica* (L.) Delila). The results for the biota clearly indicate the contribution of anthropogenic factors to the composition of contaminants obtained with their analysis. Perennial investigations indicate that the Bay has all the characteristics of eutrophic areas, as a result from the combination of natural and anthropogenic factors in this marine environment.

Also, seawater, sea grass (*P. oceanica*) and mussels (*M. galloprovincialis*) samples were collected from the coastal area of Boka Kotorska Bay, Montenegro, in the period of ten different seasons and analysed in order to determine the seawater quality related to Fe, Zn, Ni, Cd, Co, Cu, As, Pb and Hg. Based on the analysis of biological concentration factor for shellfish and seaweed seasonal pollution of seawater can be monitored and it was also concluded that *P. oceanica* and *M. galloprovincialis* are good indicators of the Bay seawater pollution.

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References

1. Lepetić V (1965) Sastav i sezonska dinamika ihtiobentosa i jestivih avertebrata u Bokokotorskom zalivu i mogućnosti njihove eksploatacije. Stud Mar 1:3–127
2. Obhodas J, Valković V (2010) Contamination of the coastal sea sediments by heavy metals. Appl Radiat Isot 68:807–811
3. Rivaro P, Ianni C, Massolo S et al (2004) Heavy metals in Albanian coastal sediments. Toxicol Environ Chem 86:85–97
4. Çelo V, Babi D, Baraj B et al (1999) An assessment of heavy metal pollution in sediments along the Albanian Coast. Water Air Soil Pollut 111:235–250
5. Rivaro P, Cullaj A, Frache R et al (2011) Heavy metals distribution in suspended particulate matter and sediment collected from Vlora Bay (Albania): a methodological approach for metal pollution evaluation. J Coast Res 58:54–66
6. Joksimović D, Tomić I, Stanković A et al (2011) Trace metal concentrations in Mediterranean blue mussel and surface sediments and evaluation of the mussels' quality and possible risks of high human consumption. Food Chem 127:632–637
7. Joksimović D, Stanković S (2012) Accumulation of trace metals in marine organisms of the southeastern Adriatic coast, Montenegro. J Serb Chem Soc 77:105–117
8. Stanković S, Tanaskovski B, Zlatić B et al (2014) Analysis of trace elements in surface sediments, mussels, seagrass and seawater along the southeastern Adriatic coast – a chemometric approach. Pure Appl Chem 86(7):1111–1127
9. Stankovic S, Kljajic Z, Degetto S (2012) Analysis of macro and micro elements in surface sediments by XRF to evaluate potential contamination of Boka Kotorska bay, Montenegro. MarCoastEcos2012, Tirana, Albania, 25–28 April 2012, pp 123–134. ISBN: 978-9928-137-14-2
10. Tanaskovski B, Petrovic M, Kljajic Z et al (2014) Analysis of major, minor and trace elements in surface sediments by X-ray fluorescence spectrometry for assessment of possible contamination of Boka Kotorska Bay, Montenegro. Maced J Chem Chem Eng 33(1):139–150
11. Tanaskovski B, Jović M, Miličić LJ et al (2016) The geochemistry model of the surface sediment determined by using ED-XRF technique: a case study of the Boka Kotorska bay, Adriatic Sea. Environ Sci Pollut Res. doi:10.1007/s11356-016-6353-6
12. Lafabrie C, Pergent G, Kantin R et al (2007) Trace metals assessment in water, sediment, mussel and seagrass species – validation of the use of Posidonia oceanica as a metal biomonitor. Chemosphere 68:2033–2039
13. Conti EM, Bocca B, Lacobucci M et al (2010) Baseline trace metals in seagrass, algae and mollusks in a southeastern Tyrrhenian ecosystem (Linosa Island, Sicily). Arch Environ Contam Toxicol 58:79–95

14. Richir J, Gobert S, Sartoretto S et al (2010) Posidonia oceanica (L) Delile, a useful tool for the biomonitoring of chemical contamination along the Mediterranean coast: a multiple trace element study. 4th Mediterranean Symposium of Marine Vegetation Audience, centre d'Activités Régionales pour les Aires Spécialment Protégées (CAR/ASP), Tunisie
15. Luy N, Gobert S, Sartoretto S et al (2012) Chemical contamination along the Mediterranean French coast using Posidonia oceanica (L.) Delile above-ground tissues: a multiple trace element study. Ecol Indic 18:269–277
16. Stankovic S, Jovic M, Tanaskovski B et al (2015) Can the origin of some metals in the seagrass Posidonia oceanica be determined by the indexes of metals pollutions? Environ Sci Pollut Res 22(11):8253–8263. doi:10.1007/s11356-014-3953-x
17. Tovar-Sanchéz A, Serón J, Marbà N et al (2010) Long term records of trace metal content of western Mediterranean seagrass (Posidonia oceanica) meadows: natural and anthropogenic contributions. J Geophys Res 115. doi:10.1029/20009JG001076
18. Di Leo A, Annicchiarico C, Cardellicchio N et al (2013) Trace metal distributions in Posidonia oceanica and sediments from Taranto Gulf (Ionian Sea, Southern Italy). Mediterr Mar Sci 14:204–213
19. Stankovic S, Stankovic AR (2013) Bioindicators of toxic metals. In: Lichtfouse E, Schawarzbauer J, Robert D (eds) Environmental chemistry for a sustainable world, vol 2, Green materials for energy, products and depollution. Springer, Berlin, pp 151–231. ISBN 978-94-007-68-36-9
20. Marković J, Joksimović D, Stanković S (2012) Trace element concentrations in wild mussels from the coastal area of the Southeastern Adriatic, Montenegro. Arch Biol Sci Belgrade 64:265–275
21. Stanković S, Jović M, Stanković AR et al (2012) Heavy metals in seafood mussels. Risks for human health. In: Lichtfouse E, Schawarzbauer J, Robert D (eds) Environmental chemistry for a sustainable world, vol 1, Nanotechnology and health risk. Springer, Heidelberg, New York, London, pp 311–375. ISBN 978-94-007-2441-9
22. Stankovic S, Jovic M (2012) Health risks of heavy metals in the Mediterranean mussels as seafood. Environ Chem Lett 10(2):119–130
23. Ali MB, Tripathi RD, Rai UN et al (1999) Physico-chemical characteristics and pollution level of Luke Nainital (U.P., India): role of macrophytes and phytoplankton in biomonitoring and phytoremediation of toxic metal ions. Chemosphere 39:2171–2182
24. Stanković S, Jović M, Petrović M et al (2012) Trace elements concentrations in the seagrass Posidonia oceanica and surface sediments sampled at the southeastern Adriatic coast. Int Conf Mar Coast Ecosm Tirana, Albania, 25–28 April, p 89
25. Tanaskovski B, Jović M, Mandić M et al (2016) Elemental analysis of mussels and possible health risks arising from their consumption as a food: the case of Boka Kotorska Bay, Adriatic Sea. Ecotoxicol Environ Saf 130:65–73. doi:10.1016/j.ecoenv.2016.04.007
26. Clark RB (2001) Marine pollution. Oxford University Press, New York
27. Prospero JM (2002) The chemical and physical properties of marine aerosols: an introduction. In: Gianguzza A, Pelizzetti E, Sammartano S (eds) Chemistry of marine water and sediments. Springer, Heidelberg, pp 36–82
28. Bellafiore D, Guarnieri A, Grilli F, Penna P, Bortoluzzi G, Giglio F, Pinardi N (2011) Study of the hydrodynamical processes in the Boka Kotorska Bay with a finite element model. Dyn Atmos Oceans 52:298–321
29. Buljan M, Zore-Armanda M (1971) Osnovi oceanografije i pomorske meteorologije. Institut za oceanografiju i ribarstvo, Split
30. CCME (1999) Canadian water quality guidelines for the protection of aquatic life CCME water. Quality index 1.0 Technical Report. Canadian Council of Ministers of the Environment
31. Macic V (2015) The influence of anthropogenic factors on wildlife in the coastal zone of the Montenegrin coast. National project (2012–2015). Ministry of Science of Montenegro

32. Joksimović D (2010) Eutrophication in the sea water of the Montenegrian coast at Adriatic Sea in 2005–2007. http://balwois.com/balwois/administration/full_paper/ffp-1446.pdf
33. Raspor B (1985) Anorganska zagađivala u moru. Problematika procjene opasnosti od štetnih tvari u Jadranu. JAZU, pp 27–46
34. Ducic V, Lukovic J, Buric D et al (2012) Precipitation extremes in the wettest Mediterranean region (Krivosije) and associated atmospheric circulation types. Nat Hazards Earth Syst Sci 12:687–697. doi:10.5194/nhess-12-687-2012
35. Ansari TM, Marr L, Tariq N (2004) Heavy metals in marine pollution Perspective-A: mini review. J Appl Sci 4:1–20
36. Sekhar KC, Chary SN, Tirumala KC et al (2003) Determination of trace metals in sea water by ICP-MS after matrix separation. Acta Chim Slov 50:409–418
37. Korkisch J (1978) Analysis of naturally occurring waters for toxic metals using combined ion exchange-solvent extraction procedures. Pure Appl Chem 50:371–374
38. Manfra L, Accornero A (2005) Trace metal concentrations in coastal marine waters of the central Mediterranean. Mar Pollut Bull 50(6):686–697
39. Catsiki VA, Florou B (2006) Study on the behavior of the heavy metals Cu, Cr, Ni, Zn, Fe, Mn and ^{137}Cs in an estuarine ecosystem using Mytilus galloprovincialis as a bioindicator species: the case of Thermaikos gulf, Greece. J Environ Radioact 86:31–44
40. Diamantopoulou E, Dassenalis M, Paraskevopoulou V et al (2008) Heavy metals behaviour and distribution in a shallow Mediterranean lagoon. Fresenius Environ Bull 17:1717–1724
41. Jović M, Stanković AR, Slavković-Beskoski L et al (2011) Mussels as a bio-indicator of the environmental quality of the coastal water of the Boka Kotorska Bay (Montenegro). J Serb Chem Soc 76(6):933–946
42. Joksimović D, Kljajić Z, Filipović S (2001) Some of trace elements in the water of Bokakotorska bay. The 30th annual conference of the Serbian Water Pollution Control Society, Aranđelovac, Serbia, 12–15 June, pp 325–332
43. Ujević I, Kljaković-Gašpić Z, Bogner D (2010) Influence of suspended matter on cadmium accumulation in sediment from Kaštela Bay, Adriatic Sea, Croatia. Acta Adriat 51:79–88
44. Scuollos M (1993) Mediterranean pollution chemical and ecological aspects. In: Briand F (ed) Pollution of Mediterranean Sea, STOA projects, Technical working document for the meeting
45. Scuollos M, Plavšić M, Karavoltsos S et al (2006) Partitioning and distribution of dissolved copper, cadmium and organic matter in Mediterranean marine coastal area: the case of a mucilage event. Estuar Coast Shelf Sci 67:484–490
46. OSPAR (2000) Commission for the protection of the marine environment of the North-East Atlantic-Quality Status Report
47. Worsfold PJ, Achterberg EP, Bowie AR, Sandford R, Cannizzaro V, Gardolinski P (2002) Flow injection techniques for the in situ monitoring of marine processes. In: Gianguzza A, Pelizzetti E, Sammartano S (eds) Chemistry of marine water and sediments. Springer, Heidelberg, pp 385–403
48. Mihajlović R, Joksimović D, Mandić S et al (2002) Macro and micro elements in sea water of Boka. Stud Mar 23(1):41–48
49. Joksimović D, Stanković S (2010) Contents of Lead and Cadmium in sea water and sediments from Bokakotor Bay. The 39th annual conference of the Serbian Water Pollution Control Society, pp 243–249
50. Stanković S, Marković J, Joksimović D (2011) The estimation of sea water quality at the Montenegrin coast for mussels farming. V International conference, Aquaculture and Fishery, pp 248–256
51. Stanković S, Joksimović D (2011) Kvalitet morske vode duž crnogorske obale. The 40th annual conference of the Serbian Water Pollution Control Society, pp 235–240
52. Giusti L, Zhang H (2002) Heavy metals and arsenic in sediments, mussels and marine water from Murano (Venice, Italy). Environ Geochem Health 24(1):47–65

53. Bogner D, Ujević I, Zvonarić T et al (2004) Distribution of selected trace metals in coastal surface sediments from the Middle and South Adriatic sea. Fresenius Environ Bull 13 (11):1281–1287
54. De Forest DK, Brix KV, Adams WJ (2007) Assessment metal bioaccumulation in aquatic environments: the inverse relationship between bioaccumulation factors, trophic transfer factors and exposure concentration. Aquat Toxicol 84:236–246
55. Rivero-Huguet M, Marshal DW (2011) Scaling up a treatment to simultaneously remove persistent organic pollutants and heavy metals from contaminated soils. Chemosphere 83:668–673
56. Mihajlović R, Joksimović D (2002) Heavy metals in sediments from Boka Kotorska Bay. Stud Mar 23(1):49–56
57. Regulations on permitted amounts of hazardous and harmful substances in soil and methods for their testing (Published in "Sl. List RCG", no. 18/97)
58. Joksimović D, Stanković S (2011) Contents of heavy metals in coastal surface sediments from Montenegrin coast. The 40th annual conference of the Serbian Water Pollution Control Society, pp 251–256
59. Balkis N, Çağatay MN (2001) Factors controlling metal distribution in the surface sediment in the Erdek Bay, Sea of Marmara, Turkey. Environ Int 27:1–13
60. Degetto S, Cantaluppi C (2004) Radiochemical methodology for the determination of the mass balance of suspended particulate materials exchanged at the inlets of the Venice Lagoon. J Mar Syst 51:77–94
61. Pekey H, Bakoglu M, Pekey B (2005) Sources of heavy metals in the Western Bay of Izmir surface sediments. Int J Environ Anal Chem 85(14):1025–1036
62. Usero J, Morillo J, Gracia I (2005) Heavy metal concentrations in molluscs from the Atlantic coast of southern Spain. Chemosphere 59:1175–1181
63. Sprovieri M, Sammartino S, Manta DS et al (2006) Heavy metals in top core sediments from the southern Campania shelf (Italy): hints to define large-scale geochemical backgrounds. Chem Ecol 22(1):65–91
64. Yilmaz F (2006) Bioaccumulation of heavy metals in water, sediment, aquatic plants and tissues of Cyprinus carpio from Kizilirmak, Turkey. Fresenius Environ Bull 15:360–369
65. Ščančar J, Zuliani T, Turk T et al (2007) Organotin compounds and selected metals in the marine environment of Northern Adriatic sea. Environ Monit Assess 127:271–282
66. Castelli A, Mitric M, Kljajic Z (2014) Monitoring of the sediment in the Boka Kotorska Bay. Conference proceedings of the 43rd annual conference of the Serbian Water Pollution Control Society "Water 2014", Tara, Serbia, 3–5 June 2014, pp 287–293
67. Joksimovic D (2015) Complex research of the ecosystem of coastal sea of Montenegro. Final study of the KOTOR project. Institute of Marine Biology, University of Montenegro, pp 1–145
68. CCME (2002) Canadian sediment quality guidelines for the protection of aquatic life. Canadian Council of Ministers of the Environment. http://www.ccme.ca/assets/pdf/sedqg_summary_table.pdf. Accessed Apr 2011
69. Ministry of Sustainable Development and Tourism, Environmental Monitoring Programme for 2014, Environmental Protection Agency of Montenegro. Available at: http://www.epa.org.me/images/izvjestaji/Informacija-o-stanju-%C5%BEivotne%20sredine-u-Crnoj-Gori-u-2014.pdf
70. Papatheodorou G, Hotos G, Gerada M et al (2002) Heavy metal concentrations in sediments of Klisova lagoon (Southeast Mesalonghi-Aetolikon lagoon complex), W. Greece. Fresenius Environ Bull 11:951–956
71. Airas S (2003) Trace metal concentrations in the blue mussels Mytilus edulis (L.) in Byfjorden and the coastal areas Bergen. Master thesis in Marine Biology, Institute for fisheries and Marine Biology, University of Bergen
72. Adams SM (2002) Biological indicators of aquatic ecosystem stress. Amer Fish Soc, Bethesda, MD, p 644

73. Smolders R, Bervoets L, Wepener V et al (2003) A conceptual framework for using mussels as biomonitors in whole effluent toxicity. Hum Ecol Risk Assess 9(3):741–760
74. Goldberg ED (1975) The mussel watch, a first step in global marine monitoring. Mar Pollut Bull 6:111
75. Goldberg ED, Bowen VT, Farrington JW et al (1978) The mussel watch. Environ Conserv 5:101–125
76. Goldberg ED, Koide M, Hodge V et al (1983) U.S. Mussel watch: 1977–1978 results of trace metals and radionuclides. Estuar Coast Shelf Sci 16:69–93
77. Phillips DJH, Segar DA (1986) Use of bio-indicators in monitoring conservative contaminants: programme design imperatives. Mar Pollut Bull 17:10–17
78. Widdows J, Donkin P (1992) Mussels and environmental contaminants: bioaccumulation and physiological aspects. In: Gosling E (ed) The mussel Mytilus: ecology, physiology, genetics and culture. Elsevier, pp 383–424
79. Joksimović D, Kljajić Z, Stanković S (2012) Concentrations of heavy metals (Zn, Cu, Pb, Cd and As) in the Mediterranean mussel Mytilus galloprovincialis from the Montenegrin coast of the Southeastern Adriatic Sea. Water Res Manage 2(3):3–9
80. Jović M, Stanković S (2014) Determination of marine pollution by comparative analysis of metal pollution indices. Arch Biol Sci 66(3):1205–1215
81. Jović M, Stanković S (2014) Human exposure to trace metals and possible public health risks via consumption of mussels Mytilus galloprovincialis from the Adriatic coastal area. Food Chem Toxicol 70:241–251
82. Cantilo AY (1997) World mussel watch data. Silver Spring, pp 1–209
83. Heijerick DG, Janssen CR, Karlen C et al (2002) Bioavailability of zinc in runoff water from roofing material. Chemosphere 47:1073–1080
84. Kljaković-Gašpić Z, Odžak N, Ujević I et al (2006) Biomonitoring of mercury in polluted coastal area using transplanted mussels. Sci Total Environ 368:199–209
85. Kljaković-Gašpić Z, Ujević I, Zvonarić T et al (2007) Biomonitoring of trace metals (Cu, Cd, Cr, Hg, Pb, Zn) in Mali Ston Bay (eastern Adriatic) using Mediterranean blue mussel (1998–2005). Acta Adriat 48:73–88
86. Capelli R, Contardi V, Fassone B et al (1978) Heavy metals in mussels (Mytilus galloprovincialis) from the gulf of La Spezia and from the promontory of Portofino, Italy. Mar Chem 6:179–185
87. Deudero S, Box A, March D et al (2007) Temporal trends of metals in benthic invertebrate species from the Balearic Islands, Western Mediterranean. Mar Pollut Bull 54:1545–1558
88. Guerra-García JM, Ruiz-Tabares A, Baeza-Rojano E et al (2010) Trace metals in Caprella (Crustacea: Amphipoda). A new tool for monitoring pollution in coastal areas? Ecol Indic 10:734–743
89. Beiras R, Bellas FN, Lorenzo JI et al (2003) Assessment of coastal marine pollution in Galicia (NW Iberian Peninsula); metal concentrations in seawater, sediments and mussels (Mytilus galloprovincialis) versus embryo-larval bioassays using Paracentrotus lividus and Ciona intestinalis. Mar Environ Res 56:531–553
90. Besada V, Fumega J, Vaamonde A (2002) Temporal trends of Cd, Cu, Hg, Pb and Zn in mussel (Mytilus galloprovincialis) from the Spanish North-Atlantic coast 1991–1999. Sci Total Environ 288:239–253
91. Maanan M (2007) Biomonitoring of heavy metals using Mytilus galloprovincialis in Safi coastal waters, Morocco. Environ Toxicol 22:525–531
92. Topcuoglu S, Kirbaşoglu Ç, Yilmaz YZ (2004) Heavy metal levels in biota and sediments in the Northern Coast of the Marmara Sea. Environ Monit Assess 96:183–189
93. Romeo M, Frasila C, Gnassia-Barelli M et al (2005) Biomonitoring of trace metals in the Black Sea (Romania) using mussels Mytilus galloprovincialis. Water Res 39:596–604
94. Tsangaris C, Cotou E, Papathanassiou E et al (2010) Assessment of contaminant impacts in a semi-enclosed estuary (Amvrakikos Gulf, NW Greece): bioenergetics and biochemical biomarkers in mussels. Environ Monit Assess 161:259–269

95. Ünlü S, Topcuoğlu S, Alpar B et al (2008) Heavy metal pollution in surface sediments and mussel samples in the Gulf of Gemlik. Environ Monit Assess 144:169–178
96. Özden O, Ulusoy S, Erkan N (2010) Study of the behavior of the trace metal and macro minerals in mussels Mytilus galloprovincialis as a bioindicator species: the case of Marmara Sea, Turkey. J Verbr Lebensm 5:407–412
97. Degetto S, Cantaluppi C, Desideri D et al (2006) Proceeding of 7th international conference on the Methods and Applications of Radioanalytical Chemistry – MARC VII, Kailua-Kona, Hawaii, p 83
98. Metian M, Warnau M, Hédouin L et al (2009) Bioaccumulation of essential metals (Co, Mn and Zn) in the king scallop Pecten maximus: seawater, food and sediment exposures. Mar Biol 156:2063–2075
99. Oreščanin V, Lovrenčić I, Mikelić L et al (2006) Biomonitoring of heavy metals and arsenic on the east coast of the Middle Adriatic Sea using Mytilus galloprovincialis. Nucl Instrum Methods Phys Res, Sect B 245:495–500
100. Locatelli C (2007) Heavy metal determinations in algae, mussels and clams. Their possible employment for assessing the sea water quality criteria. J Phys 107:785–788
101. Cravo A, Lopes B, Serafim A et al (2009) A multibiomarker approach in Mytilus galloprovincialis to asses environmental quality. J Environ Monit 11:1673–1686
102. Topcuoglu S (2000) Black Sea ecology, pollution research in Turkey of the marine environment. IAEA Bull 42:12–14
103. Ergul H, Alkan A, Topcuoglu S (2007) Trace metals in mussels and sediment samples from southeastern coast of the Black Sea. Rapp Comm Int Mer Médit 38:254
104. Desideri D, Meli MA, Roselli C (2010) A biomonitoring study. ^{210}Po and heavy metals in marine organisms from the Adriatic Sea (Italy). J Radioanal Nucl Chem 1–10
105. Çevik U, Damla N, Kobya AI et al (2008) Assessment of metal element concentrations in mussel (M. galloprovincialis) in Eastern Black Sea, Turkey. J Hazard Mater 160:396–401
106. Blackmore G, Wang WX (2003) Comparison of metal accumulation in mussels at different local and global scales. Environ Toxicol Chem 22(2):388–395
107. Maanan M (2008) Heavy metal concentrations in marine molluscs from the Moroccan coastal region. Environ Pollut 153:176–183
108. Kljaković-Gašpić Z, Odžak N, Ujević I et al (2006) Biomonitoring of trace metals (Cu, Cd, Cr, Hg, Pb, Zn) in the eastern Adriatic using Mediterranean blue mussel (2001-2005). Fresenius Environ Bull 15:1041–1048
109. Kayhan FE, Gulsoy N, Balkis N et al (2007) Cadmium (Cd) and lead (Pb) levels of Mediterranean mussel (Mytilus galloprovincialis Lamarck, 1819) from Bosphorus, Istanbul, Turkey. Pak J Biol Sci 10:915–919
110. Aston SR, Fowler SW (1985) Mercury in the open Mediterranean: evidence of contamination? Sci Total Environ 43:13–26
111. Bargagli R, Ferrara R, Maserti BA (1988) Assessment of mercury distribution and partitioning in recent sediments of the western Mediterranean basin. Sci Total Environ 72:123–130
112. Dobson M, Frid C (1998) Ecology of aquatic system. Addison Wesley Longman, Essex, p 225
113. Bern Convention Annex I (1998) P. oceanica: extremely protected species of flora
114. EC (2000) Water framework directive 2000/60/EC. Off J Eur Communities L 327:73
115. Fernández-Torquemada Y, Díaz-Valdés M, Colilla F et al (2008) Descriptors from Posidonia oceanica (L.) Delile meadows in coastal waters of Valencia, Spain, in the context of the EU Water Framework Directive. ICES J Mar Sci 65(8):1492–1497
116. Shüürmann G, Market B (1998) Ecotoxicology: ecological fundamentals, chemical exposure and biological effects. Wiley, New York, p 900
117. Kljaković-Gašpić Z, Antolić B, Zvonarić T et al (2004) Distribution of cadmium and lead in Posidonia oceanica (L.) Delile from the Middle Adriatic Sea. Fresenius Environ Bull 13:1210–1215

118. Pergent G, Leoni V, Pasqualini V et al (2005) Descriptors of Posidonia oceanica meadows: use and application. Ecol Indic 5:213–230
119. Lafabrie G, Pergent G, Pergent-Martini C (2009) Utilization of the seagrass Posidonia oceanica to evaluate the spatial dispersion of metal contamination. Sci Total Environ 407:2440–2446
120. Stanković S, Jović M, Mihajlović ML et al (2015) Metal pollution determined by pollution indices for sea grass P. oceanica and surface sediments. Arch Biol Sci 67(1):91–101
121. Warnau M, Ledent G, Temera A et al (1995) Heavy metals in Posidonia oceanica and Paracentrotus lividus from seagrass beds of the north-western Mediterranean. Sci Total Environ 171:95–99
122. Sanz-Lazaro C, Malea P, Apostolaki ET et al (2012) The role of the seagrass Posidonia oceanica in the cycling of trace elements. Biogeosci Discuss 9:2623–2653
123. Gosselin M, Bouquegneau JM, Lefebvre F et al (2006) Trace metal concentrations in Posidonia oceanica of North Corsica (northwestern Mediterranean Sea): use as a biological monitor? BMC Ecol 12:1–19
124. Roméo M, Gnassia-Barelli M, Juhel T et al (1995) Memorization of heavy metals by scales of the seagrass Posidonia oceanica, collected in the NW Mediterranean. Mar Ecol Prog Ser 120:211–218
125. Baroli M, Cristini A, Cossu A et al (2001) Concentrations of trace metals (Cd, Cu, Fe, Pb) in Posidonia oceanica seagrass of Lyscia Bay, Sardinia (Italy). In: Faranda FM, Guglielmo L, Spezie G (eds) Structure and processes in the Mediterranean ecosystem, vol 14. Springer, Heidelberg, pp 95–99
126. Catsiki VA, Panayotidis P (1993) Copper, chromium and nickel in tissues of the Mediterranean seagrasses Posidonia oceanica & Cymodocea nodosa (Potamogetonaceae) from Greek coastal areas. Chemosphere 26:963–978
127. Neinhuis PH (1986) Background levels of heavy metals in nine tropical seagrasses species in Indonesia. Mar Pollut Bull 17:508–511
128. Sanchiz C, Garcia-Carrascosa AM, Pastor A (2000) Heavy metal contents in soft-bottom marine macrophytes and sediments along the Mediterranean coast of Spain. Mar Ecol 21:1–16
129. Campanella L, Conti ME, Cubadda F et al (2001) Trace metals in sea grass, algae and molluscs from an uncontaminated area in the Mediterranean. Environ Pollut 111:117–126
130. Lafabrie C, Pergent-Martini C, Pergent G (2008) Metal contamination of Posidonia oceanica meadows along the Corsican coastline (Mediterranean). Environ Pollut 151(1):262–268

Estimation of Air Pollution from Ships in the Boka Kotorska Bay

Danilo Nikolić, Radmila Gagić, and Špiro Ivošević

Abstract The Boka Kotorska Bay, with the Port of Kotor, has become one of the most attractive cruising destinations at the Adriatic Sea. It shows not only great potential in terms of economy, but also great danger if environmental issues are taken into consideration. Emission from cruise ships represents majority of anthropogenic emissions of pollutants in this area, since there are no merchant ports and industrial plants in the bay.

In this paper exhaust emission from ships in the Boka Kotorska Bay in 2015 was calculated by using emission estimation methodology. Only cruise ships were taken for research since that is the only shipping activity in the bay, besides yachting. Cruise ship's gross tonnage, marine engine types, marine fuel types, navigation modes and retention times of the ship in the Bay were taken into consideration in the study. Total emissions from cruise ships in the Boka Kotorska Bay area in 2015 were estimated as follows: 258.50 t y^{-1} of NOx, 578.80 t y^{-1} of CO, 24,996.74 t y^{-1} of CO_2, 126.87 t y^{-1} of VOC, 9.42 t y^{-1} of PM and 7.84 t y^{-1} of SOx in the case when assumed that cruise ships burn low sulphur fuels and 418.95 t y^{-1} of SOx in the case of high sulphur fuels.

Keywords Air pollution, Boka Kotorska Bay, Cruise ships, Exhaust emission estimation

Contents

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1 Introduction

Over the past few decades, the global maritime community has developed effective regulations for control and reduction of air pollution while it is necessary to underline significance of restriction of air pollution in coastal areas specifically in inland waters and ports. The rapid growth of maritime industry which is characterized by an increase in the number and size of world's ship fleet made serious impacts on the development of port areas and their environment. Thus, air pollution from ships has to be considered with much more attention having in mind long-term consequences to the human health and environment in port cities' areas.

International Maritime Organization (IMO) made efforts to create numerous regulatory systems for control and prevention of pollution as well as guidelines for national authorities in order to improve implementation of adopted regulations. IMO's Marine Environment Protection Committee (MEPC) adopted the International Convention for the Prevention of Pollution from Ships – MARPOL 73/78 [1]. On 27 September 1997, the MARPOL Convention has been amended by the Protocol which includes Annex VI titled 'Regulations for the Prevention of Air Pollution from Ships'. MARPOL Annex VI sets limits on NOx and SOx emissions from ship exhaust. MARPOL Annex VI also regulates shipboard incineration, the emissions of volatile organic compounds from tankers, and prohibits deliberate emissions of ozone depleting substances. This Protocol entered into force on 19 May 2005, and applies to all engines with power above 130 kW. MEPC revised MARPOL Annex VI in 2008 tightening emission limits. This Annex also establishes Emission Control Areas (ECA), as sea areas in which stricter controls were established to minimize airborne emissions (SOx and NOx) from ships as defined by Annex VI (Tables 1 and 2). Existing ECAs include the Baltic Sea, the North Sea, 200 nm of North American coasts including the US, Puerto Rico, the US Virgin Islands and Canada. Ships trading in ECAs have to use on board fuel oil with a sulphur content of no more than 0.10% from 1 January 2015 onwards, while outside the ECAs the current limit for sulphur content of fuel oil is 3.50%. Regarding NOx

Table 1 MARPOL Annex VI NOx emission limits for marine diesel engines [2]

Tier	Ship construction date on or after	Total weighted cycle emission limit (g/kWh) n – engine's rated speed (rpm)		
		$n < 130$	$n = 130–1{,}999$	$n \geq 2{,}000$
I	1.1.2000	17.0	$45\ n^{-0.2}$	9.8
II	1.1.2011	14.4	$44\ n^{-0.23}$	7.7
III	1.1.2016	3.4	$9\ n^{-0.2}$	2.0

Table 2 MARPOL Annex VI marine fuels sulphur gap [2]

Fuel sulphur cap	Area	Date of implementation
Max. 1.0% m/m S in fuel	SECA	1 July 2010
Max. 3.5% m/m S in fuel	Globally	1 January 2012
Max. 0.1% m/m S in fuel	SECA	1 January 2015
Max. 0.5% m/m S in fuel	Globally	1 January 2020

emission limits, the Tier III emission standard applies only to the ships while operating in North American ECA, while outside this area the Tier II standard applies, Table 1 [2].

Furthermore, in July 2011, IMO adopted measures to reduce greenhouse gas emissions from ships. A new Chapter 4 to MARPOL Annex VI entitled "Regulations on energy efficiency for ships" was adopted, which includes a suite of mandatory technical and operational measures, with the aim of improving the energy efficiency of new ships through improved design and propulsion technologies, and for all ships by improving operational measures, which could help to reduce emissions of carbon dioxide (CO_2). These regulations entered into force on 1 January 2013 and apply to all ships over 400 gross tonnage [2].

Cruise ships and cruise ship tourism have experienced massive growth in the last 30 years. Cruise ship tourism is the fastest-growing category in the leisure travel market. Since 1980, this industry has experienced an average annual passenger growth rate of approximately 7.2% per year [3]. In 2015, it is estimated that around 23 million passengers cruised all over the world, which is around 4% increase over 2014 [3]. Globally, this expansion led to around 1,000 new cruise ship ports in the most attractive cruising regions [3]. Some of the most popular tourist destinations are those which, at the same time, are the most sensitive to environmental disturbance. Cruise ships generate hundreds of tons of different kinds of waste, including exhaust emission of pollutants as fossil fuels are burned. This fuel is not only used to actually move the ship along but also to maintain all the electrical systems of this floating city in operation. Cruise ships tend to use lower quality fuel to keep costs down. Cruise ships constitute a small fraction of the global fleet and contribute marginally to these emissions along the shipping lanes. Yet, cruise ships increasingly target ports-of-call in areas where they may represent the highest anthropogenic emission source. In such areas the emissions from a single cruise ship may disproportionately impact air quality compared to urban ports-of-call, where background concentrations of pollutants are high. In the Adriatic Sea region, as one of the most attractive tourism regions, there is a growing activity of all marine tourism dimensions. It all shows not only great potential in terms of economy, but also great danger if we take environmental issues into consideration. Exhaust emission from cruise ships, while manoeuvring and berthed in these ports, represents the highest risk for local air quality and degradation of old buildings made of limestone in majority of these destinations [3].

The Boka Kotorska Bay, with the Port of Kotor, has become one of the most attractive cruising destinations at the Adriatic Sea [3]. Emission from cruise ships represents majority of anthropogenic emissions of pollutants in this area, since there are no merchant ports and industrial plants. This paper gives an estimation of annual airborne emissions from cruise ships while manoeuvring through the Boka Kotorska Bay and at the berth in the Port of Kotor.

2 Cruise Ship Traffic in the Boka Kotorska Bay

The Port of Kotor, at the end of the Boka Kotorska Bay, is a part of the Mediterranean/Adriatic cruise ship destinations. Attractiveness of the Adriatic region is focused on accessibility to the coastal areas and city centres which provide numerous attractions of historical and cultural significance. The Old Town of Kotor is a part of UNESCO cultural heritage which significantly influenced the ranking of the port in the list of most attractive cruise ship destinations.

The Boka Kotorska Bay itself is 28 km long, from the entrance to the Port of Kotor, with a shoreline extending 107.3 km (Fig. 1). The narrowest section of the Bay is only 340 m wide. The Bay is surrounded by two massifs of the Dinaric Alps rising more than 1,800 m.

According to the detailed statistical analysis of the cruising situation in the Mediterranean Region since 2010, Adriatic region is in the second place after the West Mediterranean Region with an impressive number of cruise calls 2,555 in 2015 and 4,493,707 passengers in total for the same year [3]. This means that this region hosted 16.5% of the total passenger movements as well as 19.5% of the total

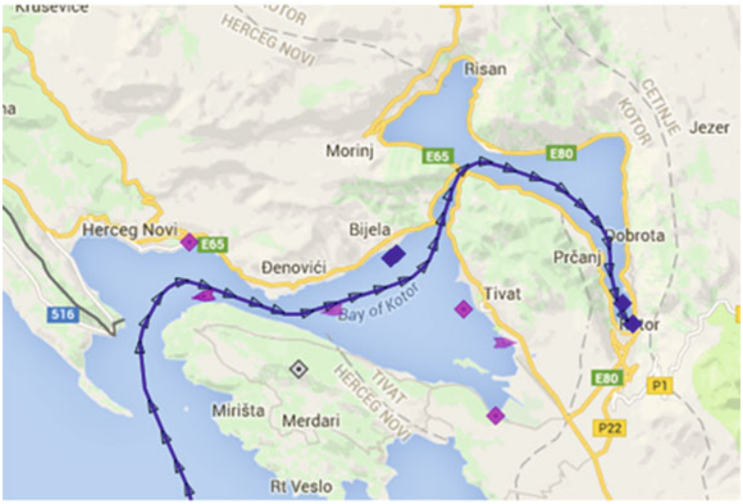

Fig. 1 Map of the Boka Kotorska Bay with the cruise ships navigation route [4]

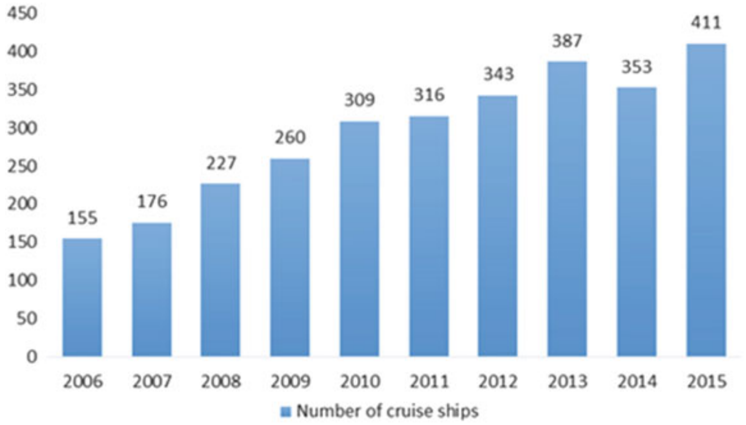

Fig. 2 Statistical indicators of cruise ships visits in the Port of Kotor [5]

cruise calls. However, there is some minor decrease in the total passenger movements compared to 2014, approximately by 1.5%, but there is still a significant increase comparing to 2010 of approximately 9.7% [3].

The Port of Kotor represents one of the 13 cruise ship ports located in the Adriatic region. The most important fact about cruising growth in the Port of Kotor is the identified crucial increase in the number of cruise ships call in 2015 by exactly 16.43% compared to 2014 and by 33.01% compared to 2010, Fig. 2. This resulted in the Port of Kotor becoming the third Adriatic cruise port. Also, Kotor is the third port on the Adriatic Sea by statistical records on the total transit passengers with variation between 2015 and 2014 of 41.96% and between 2015 and 2010 of 202.45%, Fig. 3 [3].

All mentioned above characterize the Port of Kotor as a prospective cruise ship destination, but there are issues which have to be considered. However, there are various negative impacts of the rapid development of cruising on the environment, including exhaust emission of pollutants while manoeuvring and berthed in port area, such as nitrogen oxides (NOx), sulphur dioxide (SO_2) and particulate matter (PM). Despite many activities performed by port authorities aimed at the preservation of environment from cruise ships in the Bay area [3], there are no ongoing research activities dealing with assessment of exhaust emission from cruise ships.

3 Methodology for Quantification of Pollutant Emission

Many authors proposed different methodologies for quantification of exhaust emission from ships [6–14]. Generally, methodologies could be divided into two categories: simplified and detailed. Simplified inventories are relevant for estimations when the specific ship's technical data is not available and then it is proposed

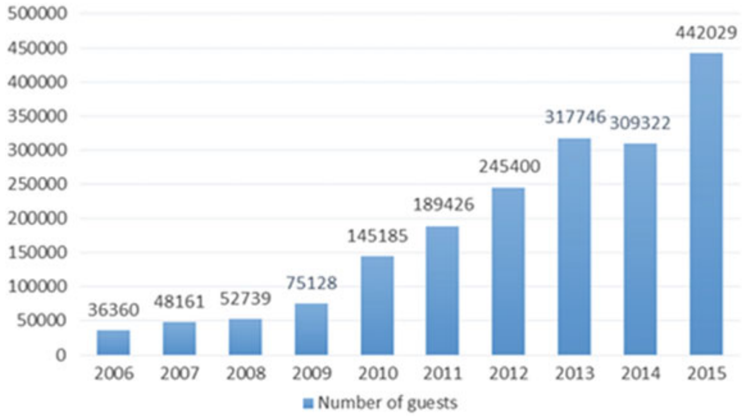

Fig. 3 Statistical indicators of cruise ship guests in the Port of Kotor [5]

to use average emission factors based on the daily fuel oil consumption for specific ship type, fuel oil type and working days [12]. Simplified methodology usually takes into account days in navigation which represents the most important difference from the detailed approach where the navigation operations can consists of three following modes: cruising, manoeuvring and hoteling. Usually, the calculations are made based upon real time data taken from automatic tracking system such as Automatic Identification System (AIS). These real time data methodologies use information such as position, route, speed and navigation mode of the ship [11, 13, 14]. For this paper, there was no cruise ship database available with technical information for each ship, such as main and auxiliary engine types, fuel oil type and sulphur content. Therefore, the implemented methodology included specific emission factors chosen in accordance with the specific technical and navigation details as well as linear regression equation of specific fuel oil consumption at full power according to the available gross tonnage data instead of real SFOC information [12] .

Thus, the used inventory represents simplification of detailed methodology in the way that some specific necessary data are replaced with adequate equations and assumptions gathered from recent study cases and research papers.

For this research, a methodology of Trozzi and Vaccaro [12] was used to estimate the exhaust gas emissions from cruise ships. These are obtained from the following equations:

$$E_i = \Sigma_{jklm} E_{ijklm} \tag{1}$$

with

$$E_{ijklm} = S_{jkm}(GT)^{*} t_{jklm}{}^{*} F_{ijlm} \tag{2}$$

where:

Table 3 Emission factors for different engine types in cruising mode (kg/ton of fuel) [12]

Engine type	NOx	CO	CO_2	VOC	PM	SOx
Steam turbine – residual oil	6.98	0.431	3,200	0.085	2.5	20s
Steam turbine – distillate oil	6.25	0.6	3,200	0.5	2.08	20s
High speed diesel engines	70	9	3,200	3	1.5	20s
Medium speed diesel engines	57	7.4	3,200	2.4	1.2	20s
Slow speed diesel engines	87	7.4	3,200	2.4	1.2	20s
Gas turbines	16	0.5	3,200	0.2	1.1	20s
Pleasure – inboard diesel	48	20	3,200	26	Neg.	20s
Pleasure – inboard gasoline	21.2	201	3,200	13.9	Neg.	20s
Outboard gasoline engines	1.07	540	3,000	176	Neg.	20s

i is the pollutant type,
j is the fuel type,
k is ship class for use in consumption classification,
l is the engine type,
E_i is the total emissions of pollutant i,
E_{ijklm} is total emissions of pollutant i from use of fuel j on ship class k with engines type l in mode m,
S_{jkm} (GT) is daily consumption of fuel j in ship class k in mode m as a function of gross tonnage,
GT is gross tonnage GT of the ship,
t_{jklm} is days in navigation of ships of class k with engines type l using fuel j in mode m.
F_{ijlm} is average emission factors of pollutant i from fuel j in engines type l in mode m (for SOx, taking into account average sulphur content of fuel).

According to Eqs. (1) and (2) exhaust emission estimation depends on the ship's class, fuel type, engine type, gross tonnage and time in adequate navigation mode.

Ship emission factors, as proposed by this methodology, depend on engine type, fuel type and navigation mode [15]. Tables 3, 4, and 5 present emission factors for different ship type and specific navigation modes [12].

Statistical analysis of the world's fleet data regarding the installed main engine type in 2010 shows that about 76.98% are driven by medium speed diesel engines which use heavy fuel oils, 5.68% are driven by medium speed diesel engines which use marine diesel or gas oils, 4.79% are driven by gas turbines which use marine diesel or gas oils, 3.81% are driven by slow speed diesel engines which use heavy fuel oils, 3.68% are driven by high speed diesel engines which use marine diesel or gas oils, 3.29% are driven by gas turbines which use heavy fuel oils, 1.76% are driven by high speed diesel engines which use diesel fuel oil and only 0.02% are driven by steam turbines which use heavy fuel oil [16]. Random analysis of specific ships berthed in the Port of Kotor corresponded to the presented statistics and based on the findings it is assumed that installed main engine power is medium speed diesel engine.

Table 4 Emission factors for different engine types in manoeuvring mode (kg/ton of fuel) [12]

Engine type	NOx	CO	CO_2	VOC	PM	SOx
Steam turbine – residual oil	6.11	0.19	3,200	0.85	2.5	20s
Steam turbine – distillate oil	5.47	0.27	3,200	5.0	2.08	20s
High speed diesel engines	63	34	3,200	4.5	1.5	20s
Medium speed diesel engines	51	28	3,200	3.6	1.2	20s
Slow speed diesel engines	78	28	3,200	3.6	1.2	20s
Gas turbines	14	1.9	3,200	0.3	1.1	20s
Pleasure – inboard diesel	48	20	3,200	26	Neg.	20s
Pleasure – inboard gasoline	21.2	201	3,200	13.9	Neg.	20s
Outboard gasoline engines	1.07	540	3,000	176	Neg.	20s

Table 5 Emission factors for different engine types in hoteling mode (kg/ton of fuel) [12]

Engine type	NOx	CO	CO_2	VOC	PM	SOx
Steam turbine – residual oil	4.55	0	3,200	0.85	2.5	20s
Steam turbine – distillate oil	3.11	0.6	3,200	5.0	2.11	20s
High speed diesel engines	28	120	3,200	4.5	1.5	20s
Medium speed diesel engines	23	99	3,200	3.6	1.2	20s
Slow speed diesel engines	35	99	3,200	3.6	1.2	20s
Gas turbines	6	7	3,200	0.3	1.1	20s
Pleasure – inboard diesel	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.
Pleasure – inboard gasoline	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.
Outboard gasoline engines	Neg.	Neg.	Neg.	neg.	Neg.	Neg.

Modern cruise ships use two types of fuels: heavy fuel oil having high sulphur content and marine distillate oils having low sulphur level. For purpose of this research, fuel samples from cruise ships were taken. Since it was not possible to take samples from each ship, median values of sulphur content from available fuel samples were taken for estimation of exhaust emission from cruise ships. Median value of sulphur content for HFO was 2.67% m/m, while for distillate diesel oil 0.0475% m/m. Majority of modern cruise ships during manoeuvring and hoteling use low sulphur fuels. Since there are no regulations for mandatory usage of low sulphur marine fuels in ports in Montenegro, neither any surveys were conducted among captains whether they use high or low sulphur fuels while manoeuvring and hoteling in the Boka Kotorska Bay, both situations will be taken into account – first the worst case scenario when ships burn high sulphur fuels and then the best case scenario where ships burn low sulphur fuels as the second.

Identification of specific navigation modes is a prerequisites for implementation of accepted methodology. Navigation operations are divided on next modes [15]:

(a) approaching and docking or mooring in ports;
(b) hoteling in ports;
(c) departing from the ports, and
(d) cruising.

Table 6 Categorization of cruise ships in the Port of Kotor in 2015 [17]

Cruise ship category	Gross tonnage	Number of cruse ships
Boutique ship	1,000–5,000	14
Small ship	5,000–25,000	12
Mid-size ship	25,000–50,000	19
Large resort ship	<50,000	21

For this paper, phase (d) is not considered because of the specific character of the navigation operations in the Boka Kotorska Bay. Accordingly, phase (a) starts when the ship enters the Boka Kotorska Bay. This phase ends at the moment of the mooring or docking in the Port of Kotor. Phase (b) includes the time spent at the dock or at anchor. Phase (c) starts with departure from the berth or from anchor and ends when cruising speed has been reached, which is in this case outside of bay area. Thus, from the exhaust emission aspects there are two manoeuvring phases (when ships arrive and depart from the Port of Kotor) and hoteling phase. In case of the Boka Kotorska Bay, there are two navigation modes divided into three phases as follows: manoeuvring and hoteling (Fig. 1). Based upon experience of port's pilots, it is assumed that the duration of manoeuvring operations (together for (a) and (c) phases) is approximately 4 h or 0.17 days, while hoteling phase is calculated based on information from ship's announcements.

The number of cruise calls in Port of Kotor was 411 in 2015 [3]. In total, there were 72 different cruise ships in that year. For implemented methodology, 66 cruise ships were included divided into three categories according its gross tonnage, Table 6. The most common categories were large resort and mid-size cruise ships. Smaller cruise ships with less than 1,000 GT were not taken into consideration.

4 Results and Discussion

Individual calculations were made for each visit of each ship in the period from January to December 2015, because there were some variations in the retention time in the Port of Kotor. In this sense, 406 different cases were considered in total and results obtained represent estimated quantitative values for nitrogen oxides (NOx), carbon monoxide (CO), carbon dioxide (CO_2), volatile organic compounds (VOCs), particulate matter (PM) and sulphur oxides (SOx). Estimations of exhaust emissions from cruise ships in the Boka Kotorska Bay are presented in Table 7.

Regarding navigation modes, 17% of total emission is referred to manoeuvring and 71% on hoteling. This means that majority of exhaust emission from cruise ships in Boka Kotorska Bay is emitted in the Port of Kotor, in vicinity of old town Kotor which is under UNESCO protection.

When only emission of pollutants are considered, Figs. 4 and 5 show distribution of each pollutant in both assumed cases, when low sulphur fuel and high sulphur

Table 7 Total annual exhaust emission from cruise ships in the Boka Kotorska Bay in 2015 (tons/year)

Month	NOx	CO	CO_2	VOC	PM	SOx[a]	SOx[b]
January	1.017	3.374	12.097	0.772	0.045	0.0378	2.021
February	1.54	5.122	183.622	1.172	0.069	0.0574	3.064
March	1.23	4.04	145.643	0.923	0.055	0.0455	2.43
April	13.469	32.13	1,348.232	7.101	0.506	0.4213	22.499
May	34.074	74.088	3,264.452	16.175	1.224	1.0201	54.476
June	40.071	92.154	3,941.245	20.272	1.478	1.2316	65.77
July	34.48	75.709	3,318.375	16.552	1.244	1.037	55.375
August	37.082	82.632	3,593.37	18.102	1.348	1.1229	59.964
September	42.686	94.137	4,116.418	20.593	1.544	1.2863	68.693
October	32.982	71.155	3,148.458	15.518	1.181	0.9839	52.54
November	17.127	36.393	1,623.624	7.92	0.609	0.5074	27.094
December	2.74	7.86	301.208	1.774	0.113	0.0941	5.026
Total (tons/year)	258.498	578.794	24,996.744	126.874	9.416	7.8453	418.952

[a]Estimation for average sulphur content in fuel of 0.0457% m/m
[b]Estimation for average sulphur content in fuel of 2.67% m/m

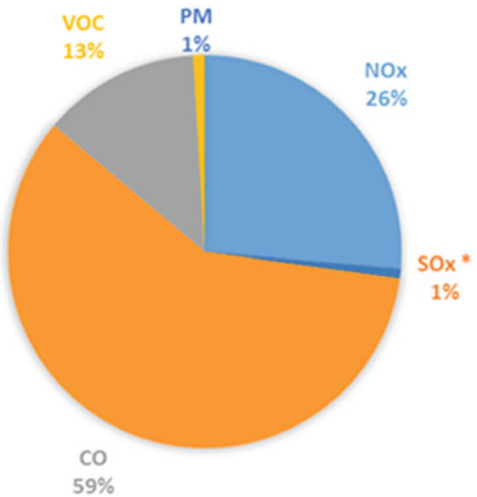

Fig. 4 Composition of pollutants in the best case scenario when assumed that a low sulphur fuels were used in 2015 [%]

fuels were used. In the low sulphur case, Fig. 4, majority of pollutant emission refers to CO (59%) and NOx (26%), while other pollutants represent smaller share VOC (13%), PM (1%) and SOx (1%). In the high sulphur case, Fig. 5, majority of pollutant emission refers to CO (59%) and NOx (26%), while other pollutants represent smaller share VOC (13%), PM (1%) and SOx (1%).

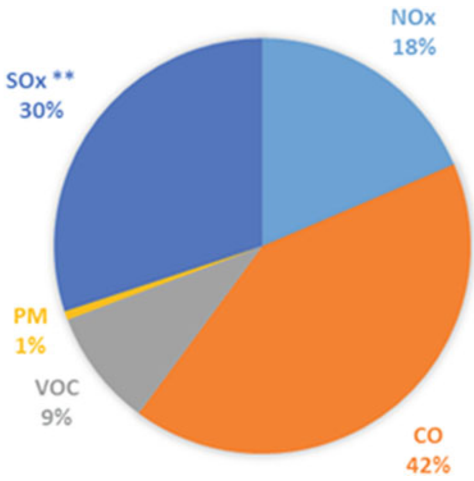

Fig. 5 Composition of pollutants in the worst case scenario when assumed that a high sulphur fuels were used in 2015 [%]

5 Conclusion

Emission from cruise ships accounts for majority of anthropogenic emissions of pollutants in Boka Kotorska Bay. The estimation of exhaust emissions of NOx, CO_2, SOx, CO, VOC and PM from cruise ships in the Bay was made by using Trozzi and Vacaro [12] methodology. Cruise ship's gross tonnage, marine engine types, marine fuel types and navigation modes of the ship in the Bay were taken into consideration in the study. Total emissions from cruise ships in the Boka Kotorska Bay area in 2015 were estimated as follows: NOx 258.50 t y^{-1} for NOx, 578.80 t y^{-1} for CO, CO_2 24,996.74 t y^{-1} for CO_2, 126.87 t y^{-1} for VOC, 9.42 t y^{-1} for PM and 7.84 t y^{-1} of SOx in case cruise ships burn low sulphur fuels and 418.95 t y^{-1} of SOx in case of high sulphur fuels. From total exhaust emission in the Bay, 71% is referred to hoteling mode, which means that majority of exhaust emission from cruise ships in Boka Kotorska Bay is emitted in the Port of Kotor.

References

1. IMO, "International Maritime Organization," (2016) [Online]. Available: http://www.imo.org/ Accessed 11 Apr 2016
2. IMO, Revised MARPOL Annex VI and NOx Technical Code 2008, London: International Maritime Organization, Albert Embankment, 2009 edition
3. Pallis T, Arapi K, Papachristou A (2016) Cruise activities in Medcruise Ports: statistics 2015. MedCruise Association, Piraeus
4. M. Traffic, "Marine Traffic," (2007) [Online]. Available: http://www.marinetraffic.com/. Accessed 11 Apr 2016
5. P. O. Kotor, "Port of Kotor," (2016) [Online]. Available: http://www.portofkotor.co.me/. Accessed 17 Apr 2016

6. Goodwin J (2013) Key category analysis and methodological choice, EMEP/EEA emission inventory guidebook 2013. Publications Office of the European Union, Luxembourg
7. Wang HC, Corbett JJ, Firestone J (2007) Modeling energy use and emissions from North American shipping: application of the ship traffic, energy, and environment model. Environ Sci Technol 41:3226–3232
8. Endresen Ø, Eide M (2008) The environmental impacts of increased international maritime shipping, past trends and future perspectives. In: Global forum on transport and environment in a Globalising World, Guadalajara, 2008
9. Georgakaki A, Coffey RA, Lock G, Sorenson SC (2005) Transport and environment database system (TRENDS): maritime air pollutant emission modelling. Atmos Environ 39:2357–2365
10. Cooper DA (2003) Exhaust emissions from ships at berth. Atmos Environ 37:3817–3830
11. Tichavska M, Tovar B (2015) Port-city exhaust emission model: an approach to Cruise and Ferry operations in Las Palmas Port. Transp Res Part A Policy Pract 78:347–360
12. Trozzi C, Vacaro R (1998) Methodologies for estimating air pollutant emissions from ships. Techne s.r.l, Roma
13. Jalkanen JP, Kukkonen J, Brink A, Kalli J, Stipa T (2012) Ship traffic emission assessment model-STEAM. 15th conference of the Global Emissions InitiAtive (GEIA)—emissions to address science and policy emission needs, Toulouse, June 2012
14. Jalkanen JP, Johansson L, Kukkonen L, Brink A, Kalli J, Stipa T (2012) Extension of an assessment model of ship traffic exhaust emissions for particulate matter and carbon monoxide. Atmos Chem Phys 12:2641–2659
15. Trozzi C, Vaccaro R (1998) Air pollutant emissions from ships: high Tyrrhenian Sea ports case study. In: First international conference PORTS 98 maritime engineering and ports, Genoa
16. Trozzi C (2010) Emission estimate methodology for maritime navigation. 19th annual international emission inventory conference “emissions inventories—informing emerging issues”, San Antonio, USA, September 2010
17. Ward D (2015) Berlitz Cruising & Cruise Ships 2015. Apa Publications Limited, UK

Metal Pollution and Ecotoxicology of the Boka Kotorska Bay

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Abstract Modern economic development of the Boka Kotorska Bay, known for its outstanding natural values, in terms of dynamics and size, is often not in line with the principles of environmental protection. As a consequence, over the recent decades, the Bay has been exposed to anthropogenic pollution. Marine sediment acts at the same time as a depositor and also the secondary source of pollutants, thus the analysis of pollutants in sediment is of vital importance for the estimation of its quality. Based on the results obtained over the past two decades, this paper considers characterization of sediment of the Boka Kotorska Bay in terms of heavy metal content and an assessment of heavy metal contamination in sediment and biota (*Mytilus galloprovincialis* and *Posidonia oceanica*), by applying environmental quality indexes: Enrichment Factor (EF), Metal Pollution Index (MPI), and Geo-accumulation Index (I_{geo}).

Since 2009, the Institute of Marine Biology Kotor has been conducting Biomonitoring in the framework of the Environmental Monitoring Programme for Montenegro – Program monitoring of the coastal sea ecosystem status of Montenegro, under the MED POL program. The main activities are aimed at determining the environmental status of the Boka Kotorska Bay marine ecosystem by analyzing the parameters and biomarkers described by MED POL program. Beside the recommended biomarkers (metallothioneins, acetilholinesterase,

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catalase test, glutathione S-transferase, micronuclei test) a new approach of seawater quality biomonitoring was established and it is based on physiological biomarkers of benthic invertebrates. Analysis of all biomarkers showed the pollution trends in Boka Kotorska Bay.

Keywords Biomarkers, Biomonitoring, Biota, Boka Kotorska Bay, Heavy metals, Pollution, Sediment

Contents

1 Introduction

In recent decades anthropogenic activities (agricultural, urban, and industrial) have led to increased pollution of marine ecosystems, especially in the bays. As a consequence of these actions, pollutants get into the water and often cause irreversible changes in marine ecosystem. Beside these pollutants, heavy metals are of the major concern due to their persistence and bio-accumulative nature [1]. Heavy metals can be introduced into the aquatic environment and accumulate in sediments by disposal of liquid effluents, chemical leachates, and runoff originating from domestic, industrial, and agricultural activities, as well as atmospheric deposition [2, 3].

In Europe, coastal waters are protected by the Water Framework Directive (WFD) and the seas are protected by the Marine Strategy Framework Directive (MSFD). Member States are required to achieve or maintain “good environmental statuses” within their marine waters by 2020 under the MSFD [4]. In order to do that Regional Conventions started to recommend specific sub-lethal biological responses (contaminant-related biomarkers) to be measured in marine organisms [5, 6]. MSFD (Directive 2008/56/EC) has put emphasis on the importance of assessing key biological responses to evaluate the health of organisms and to link any observed responses to contaminant exposure [7]. Marine pollution is defined by GESAMP (The Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection) as introduction by man, directly or indirectly, of substances or energy into the marine environment resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of sea water, and reduction of amenities.

The focus is therefore on humans, rather than natural inputs to the sea and damaging effects of the wastes. Bioavailability is an important aspect of environmental pollution studying. Current scientific knowledge regarding bioavailability, particularly of the microelements, with ecological risk assessment is relatively limited [8].

To assess the ecosystem health, fundamental approach is usage of biomarkers as indicators of pollution. Biomarkers are defined as "a xenobiotically induced variation in cellular or biochemical components, and in processes, structures, or functions, that are measurable in a biological system or sample" [9]. These biomarkers have been incorporated in several regional programs of biomonitoring carried out under international bodies (UNEP and OSPAR) [10]. Biomonitoring is a scientific technique for assessing the environment including human exposures to natural and synthetic chemicals, based on sampling and analysis of an individual organism's (biomarkers/bioindicators) tissues and fluids [11, 12].

Biomarkers allow the detection of early biological changes that can lead to long-term physiological disorders and can be used as early warning signals of environmental disturbance [12, 13]. Unlike the chemical monitoring that assesses only the presence of pollutants in the cells and tissues using chemical analysis, biomonitoring is not in use to assess the presence exclusively; organisms' response and impact of pollutants on molecules, cells, tissues/organs, and body of the animals are more important [12]. Biomonitoring cannot replace chemical monitoring but it integrates them and provides unique contribution in toxicity determination of pollutants, even in cases where they are present in low, sub-lethal concentrations.

EU Water Framework Directive (WFD, Directive 2000/60/EC) integrated chemical, biological, physicochemical, hydro-morphological parameters and ecological status in defining water quality [14]. WFD recommends monitoring programs that are necessary for the assessment to achieve good chemical and ecological status of water bodies and stresses the importance of biological monitoring to determine the water quality. Biomarkers, although not incorporated in the WFD, are among the emerging biological monitoring tools considered for use in monitoring programs necessary for the implementation of the WFD [15, 16].

2 Metal Pollution in Sediments in the Boka Kotorska Bay

Biogeochemical cycles of metals in the sea derive from equilibrium processes of chemical substances on the border between the atmosphere, sediment, and seawater. Trace metals enter the sea by different paths such as atmospheric deposition (rain, dust particles, and other precipitation), land erosion, or by rivers loaded with atmospheric and waste waters. Their bioavailability from sediments is affected by the complex relation of the factors: physicochemical features of microelements and sediments, and biological strategies of the organism involved. Considering biological systems complexity, simple relationship between the microelements concentration in the environment and their bioavailability to an organism cannot be expected.

However, biogeochemical cycle of certain natural constituents of seawater is exposed to negative anthropogenic impact. The additional metal quantities in the seawater are derived from industrial waste waters. Accordingly, coastal and industrialized areas are the most vulnerable regarding high metal content in the sea relative to natural content [17, 18]. The purpose and nature of sediment and biota monitoring differ from water monitoring. Sediment monitoring and its quality assessment are mainly conducted in order to determine to what extent sediment acts as a reservoir and secondary source of contaminants in surface waters.

These studies can be conducted in order to determine sediment quality status and its effect on the environment and human health by studying different interactions of the sediment-water system or for regulatory implications such as dredging and final disposal of dredged material.

Sediment quality assessment is mainly limited to chemical characterization. In general, determination of pollutants and their concentration cannot provide enough information in order to adequately determine antagonistic effects or interactions between pollutants or time-dependent availability of pollutants to aquatic organisms.

Sediment toxicity can be defined as an ecological and biological change caused by sediment contamination [19]. Even though, in the case when the contaminant concentrations can be measured precisely (such as metal ions measurement), chemical analyzes do not provide the information regarding their bioavailability or possible negative effects [20].

Certain pollutants are less bioavailable than others [21, 22]. For example, many metals are bound to sediment or water particles in quantities inert in terms of influence on organisms. Accordingly, particular metals measured in high levels can have minimal influence. On the other hand, some other compounds (chlorophenols) may be present in relatively low concentrations, but with high impact on organisms. Based on all that, it can be concluded that measuring only the total concentration of different chemical substances is not enough for determination of potential pollutions [22, 23].

In order to understand the distribution of contaminants and ecological value of sediments in a particular area, in addition to elemental composition, it is necessary to know the grain size distribution, mineralogical composition, carbonate content, and content of organic matter in sediment. Granulometric composition of the sediment is a very important indicator of sediment properties [24–26]. It provides data on the concentration of particles with different grain sizes in observed sediment, which means the percentage content of the gravel, sand, and clay in sediment [27].

Based on granulometric composition of the sediment, it is possible to assess its physical and chemical properties. Generally, higher concentrations of heavy metals can be found in the mud, muddy sand, silt, and their mixture compared to carbonated and pure sand sediment [24, 28–30].

Hydrodynamics of the Bay is conditioned by the shape and position of the bay, as well as by a large influx of fresh water from the land in certain periods of the year. The Bay is rich in submerged springs of fresh water, the so-called vrulje that contribute to sediment re-suspension and transport. These conditions in the Bay affect changes in temperature, salinity, and density of seawater, and indirectly the deposition and distribution of metals. Data related to the research on the content of heavy metals in sediment, which have been published in recent years, indicate that the sediment of the Boka Kotorska Bay is loaded with heavy metals and that certain locations, such as ports and marinas, are characterized by a high degree of sediment contamination by heavy metals [3]. Deposition of heavy metals in sediment of the Buy was the result of many years of inadequate treatment of industrial water and municipal water. Environmental risk is greater because the Bay is an almost closed water basin. Although now practically there is no industrial activity in the Bay, the former factory of soap and detergents *Riviera*, the manufacture and repair of bearings and *Jugopetrol* warehouses in Kotor, former repair shipyard *Arsenal* and *Avioservis* in Tivat, shipyard in Bijela, were in past decades the main sources of heavy metals in the Bay, some of which still have a negative impact on its aquatorium. The intensive marine transport in the Bay, large sailing cruisers, the presence of marinas and small ports, roads that are located along the coast, also contribute to the intake of metals in the waters of the Bay, especially during the tourist season. Due to the natural attractiveness and intense socioeconomic development, the Bay of Boka Kotorska is in recent years exposed to the pressure of rapid urbanization and increasing population, which makes its ecosystem extremely vulnerable to pollution.

Within the framework of monitoring the state of coastal ecosystem of Montenegro which has been implemented in accordance with international standards since 2008, the state of sediment quality is monitored in the Boka Kotorska Bay, especially on the so-called hot spots [3]. This monitoring includes also the analysis of sediment on the content of heavy metals: Cd, Hg, Cu, Ni, Fe, Mn, Pb, Zn, Cr, As. In addition, sediment is the subject of analysis within the national and international projects, the studies on the assessment of environmental impact, or after the contamination caused by accidents.

According to the results of particles' distribution relative to their size in sediment samples taken from nine locations in the Boka Kotorska Bay in 2014 (Fig. 1), it can be concluded that majority of the sediment samples have muddy consistency, consisted of grain size particles >0.063 mm that belong to clay and silt fractions. Exceptions are sediments in the locations in front of the former repair shipyard "Arsenal" (TV Porto MNE) with 22.35% mud and near the Lustica Peninsula, at the exit from the Bay of Kotor (with 7.10% mud), which mainly consist of different fractions of sand. Mud concentration (clay and silt) on other locations in the Boka Kotorska Bay was in the range 68.12–99.05% [31].

The content of the heavy metals in sediment was investigated at the same locations. Their concentrations in the sediment, expressed in mg/kg dw, were within the following ranges: Cd (0.11–0.36), Hg (0.05–4.40), Cu (12.5–121.5), Ni (68.3–161.7), Fe (12,200–36,000), Mn (341.0–1545.0), Pb (9.0–84.3), Zn

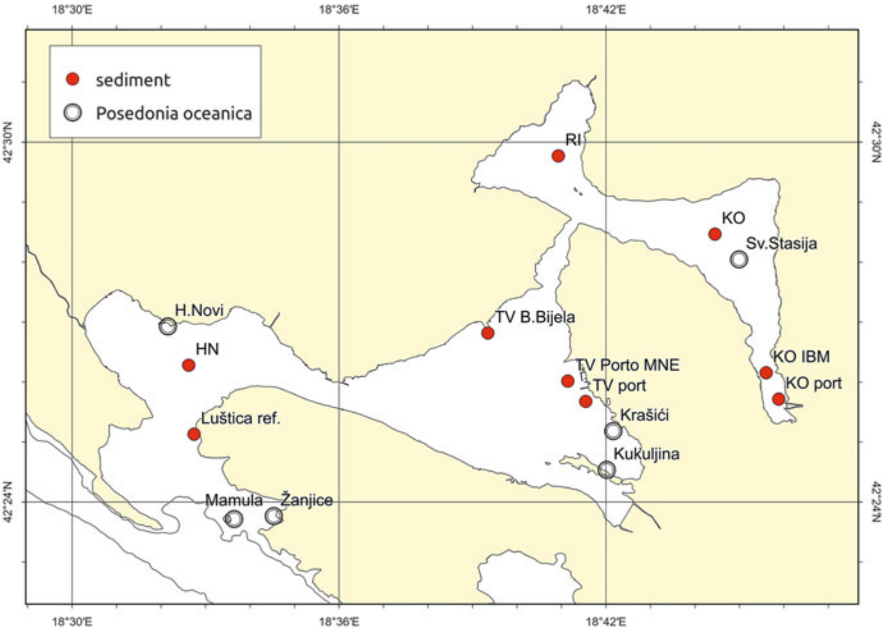

Fig. 1 The Boka Kotorska Bay – map of investigations: *red circles* are sediment stations; *open circles* are *Posidonia oceanica* stations

(34.5–241.0), Cr (44.9–95.8), As (11.0– 39.0). The presence of the investigated elements in the sediment, expressed on the basis of the average concentration, decreases in the series:

$$Fe > Mn > Zn > Ni > Cr > Pb > Cu > As > Hg > Cd.$$

In terms of the content of investigated heavy metals, the lowest mass fraction of Cd, Hg, Cu, Fe, Mn, Pb, Zn, Ni, Cr, As was measured at the reference location in the Lustica Peninsula. This location is close to the open sea where the dynamics of water is more intensive, away from direct sources of anthropogenic pollution, and with the low content of the mud in the composition of its sediment, which support the obtained results. On the other hand, higher concentrations deviations from the average values for specific metals and locations, such as Cu in sediment near the shipyard Bijela (TV B. Bijela), Hg, Pb, and As near former repair shipyard (TV Porto MNE), then Zn, Pb, and Cd in the port of Kotor (KO port), indicate a significant presence of anthropogenic sources of pollution in the aquatorium of the Tivat and Kotor Bays. The sources of these elements in the Bay might be activities in shipyards, discharges of untreated municipal and waste water, surrounding soil erosion, and nautical tourism. Cu, Zn, As, and Pb are constituents in antifouling paints and other marine coatings (corrosion, wood preservation, etc.), solid waste and waste water of different origin.

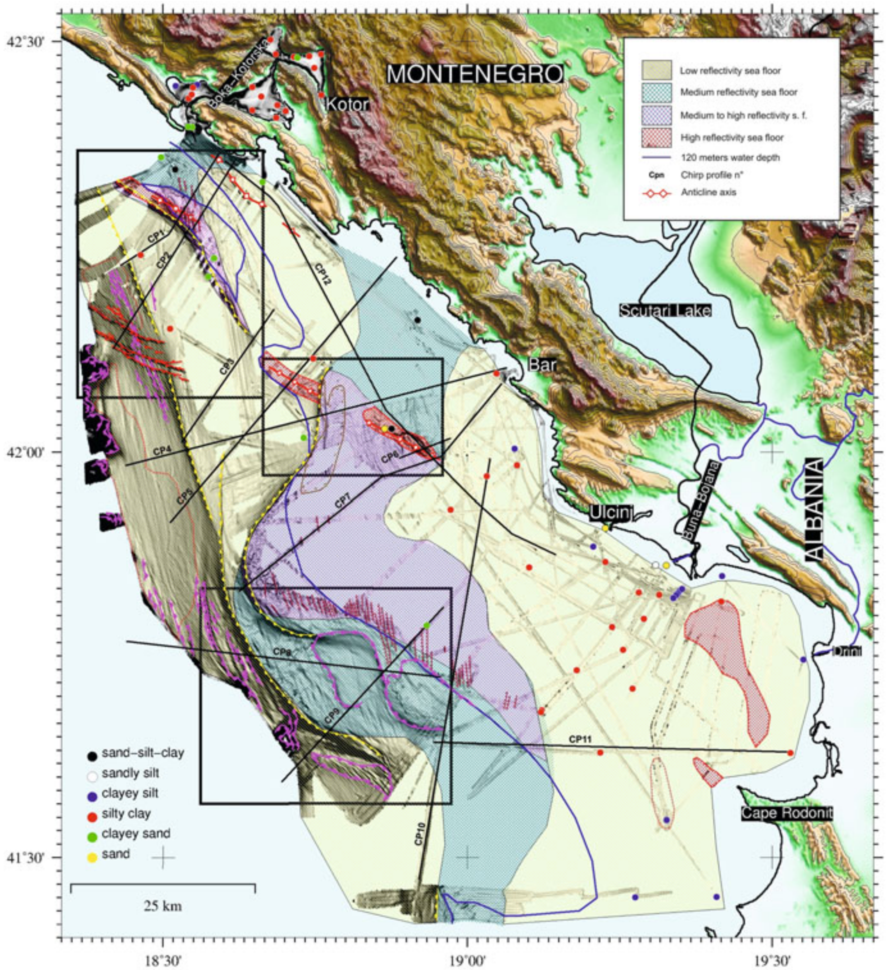

Fig. 2 Bathymetric contour map of the Montenegro/Northern Albania Continental Margin with indicated main morphologic features [32]

Most of the heavy metals, regardless the natural or anthropogenic origin, have higher affinity to fine particle material of sediment relative to coarse fraction.

The seabed the Boka Kotorska Bay is mostly covered with layers of fine mud, which further contributes to the accumulation of pollutants in their sediments [32] (Fig. 2). The affinity of heavy metals to the sediment is enhanced by ingredients such as organic matter and clay minerals [33].

Also, carbonates content is the indicator of heavy metal content in surface sediment. A smaller content of the organic matter and higher carbonate content indicates less presence of heavy metals in sediment [34].

The recent study [35] in the Boka Kotorska Bay has shown that the surface sediment is mostly composed of lithogenous material, impacted by biogenic and anthropogenic materials. The source of terrigenous fraction in sediments are rock weathering by rain and river erosion, while biological processes like secretion (growth) of skeletal materials by marine organisms feed up biological content in sediment. Sediment in the Boka Kotorska Bay is characterized by high content of organic matter and carbonates [35]. The organic matter contents ranged from 2.84 to 12.93% and carbonates from 10.94 to 37.29%. The source of organic matter are terrigenous materials and decomposition of marine organisms, while carbonate phase probably originates from biogenic precipitation of aquatic organisms, precipitation of the $CaCO_3$ from calcium-rich waters during photosynthesis with increase of pH and partly from natural carbonates [35]. The average content of investigated oxides in the same study of surface sediment in the Boka Kotorska Bay followed the order:

$$SiO_2 > CaO > Fe_2O_3 > Al_2O_3 > K_2O > MgO > TiO_2 > Na_2O > MnO > P_2O_5.$$

The results indicated positive relationship between heavy metals (Cu, Ni, Co, V, Mo, Rb, Zr, U, and Th) and majority of investigated oxides (K_2O, SiO_2, Al_2O_3, Fe_2O_3, MgO, and TiO_2). Accordingly, they have the same source and association with clayey sediments. Also, the results indicated association of elements Ni, Co, Cu, V, Mo, Rb, Zr, U, and Th with aluminosilicates minerals in the sediment. It was concluded that CaO mainly derives from marine biogenic carbonate in surface sediment of the Bay. This was based on the negative correlation between CaO and remaining investigated oxides and elements (Co, Ni, Cu, Rb, Zr, Mo, V, W, U, and Th) [35].

3 Assessment of Metal Contamination

To evaluate degree of contamination in the sediments and biota, we used three parameters: Enrichment Factor (EF), Metal Pollution Index (MPI), and Geo-accumulation Index (I_{geo}).

3.1 Enrichment Factor (EF)

The enrichment factor (EF) of metals is a useful indicator reflecting the status and degree of environmental contamination [36]. The EF calculations compare each value with a given background level, either from the local site, using older deposits formed under similar conditions, but without anthropogenic impact, or from a regional or global average composition [37, 38]. The EF was calculated using the method proposed by [39] as follows:

$$EF = (Me/Fe)\ sample/(Me/Fe)\ background,$$

where (Me/Fe) sample is metal to Fe ratio in the sample of interest; (Me/Fe) background is the natural background value of metal to Fe ratio. In the present study, average shale [40] was used as background or undisturbed value for those metals because no such data was available for the study area.

Elements can be divided into three major groups: elements without enrichment, $EF < 10$; elements with medium-level enrichment, $10 < EF < 100$; and finally highly enriched elements, $EF > 100$ [41].

In general, EF average values of sediment from autumn 2005 to spring 2007 in the Boka Kotorska indicate that Mn, Zn, Ni, Pb, Cu, Co, As, and Hg have enrichment factors less than 10, and they are in the group of elements without enrichment in surface sediment of the study area. The EF values suggest that metals originate entirely from crustal or natural weathering processes in the surface sediments, except Cd that was with medium-level enrichment in all investigated locations, except Kukuljina, where EF value was less than 10 [42].

Analyzing enrichments of investigated elements in seagrass *Posidonia oceanica*, the same equation was used to determine EF values as it was used for the sediment. EF average values in seagrass from autumn 2005 to spring 2007 show that Fe, Cu, and Mn in *P. oceanica* were derived from lithosphere mainly (lithogenic source), considering that EF values were lower than 10. The values were higher in other elements tested, Co and As were low or slightly elevated, Zn, Ni, Pb were high (medium-level enrichment). Cd and Hg were very high (more than 100) [42, 43]. Based on EF value, *P. oceanica* from location Mamula is enriched by majority of elements, particularly by Hg and Cd, except for As with the lowest value in Mamula.

According to an USEPA regulation [44], sediments with Hg contents below 0.3 mg kg–1 dw were considered as not polluted. This was the case for the analyzed sediments. Besides that, EF values for Hg indicated that Hg was not enriched in the sediments [42].

Accordingly, it is obvious that Hg found in the *P. oceanica* samples was not adsorbed from surface sediment. On the other hand, EF values for Cd were generally high both in sediment and seagrass samples. However, it was evidenced that sea weed accumulate Cd from water [45, 46].

3.2 Metal Pollution Index (MPI)

To compare the total content of metals at the different sampling stations, the Metal Pollution Index (MPI) was used. The MPI was obtained with the equation:

Table 1 I_{geo} index and MPI in sediments for the study area in autumn 2005/2006

Years	I_{geo}	Mamula	Žanjice	H. Novi	Kukuljina	S. Stasije
2005	Fe	−4.55	−1.83	−2.62	−1.67	−2.02
2006	Fe	−4.35	−4.23	−2.06	−1.61	−2.92
2005	Mn	−0.67	**0.14**	**0.77**	−0.46	−1.11
2006	Mn	−1.42	−1.53	−0.28	−0.14	−1.36
2005	Zn	−3.62	−2.25	−1.98	−1.06	−1.91
2006	Zn	−4.21	−3.02	−1.91	−1.02	−3.37
2005	Cu	−2.67	−1.96	−1.35	−1.06	−2.18
2006	Cu	−2.58	−2.58	−1.76	−2.09	−2.58
2005	Ni	−1.44	−1.07	−0.09	**1.11**	−0.92
2006	Ni	−1.04	−0.38	**0.42**	**1.05**	−0.74
2005	Pb	−2.63	−3.01	−3.08	−1.73	−2.17
2006	Pb	−4.39	−8.29	−2.71	−6.29	−6.71
2005	Cd	**0.15**	**1.15**	**1.15**	**0.47**	**1.15**
2006	Cd	−2.36	−2.84	−0.26	**3.79**	−2.84
2005	As	−2.41	−0.29	−2.65	−2.21	−2.32
2006	As	−3.74	−4.45	−3.82	−2.41	−2.44
2005	Hg	−2.70	−2.70	−1.28	−1.12	−1.70
2006	Hg	−4.28	−3.28	−2.28	−1.12	−2.28
2005	MPI	1.84	2.21	2.28	2.48	2.13
2006	MPI	1.47	1.46	1.97	2.32	1.57

$$\text{MPI} = (\text{Cf}1 \times \text{Cf}2 \times \ldots \text{Cf}n)^{1/n}$$

where: Cf1 = concentration value of the first metal; Cf2 = concentration value of the second metal; n is the number of metals; and CF is the contamination factor. The contamination can be calculated from: Contamination factor (CF) = metal concentration in sediments/Background values of the metal. The MPI > 1 is polluted whereas MPI < 1 indicates no pollution [47]. Based on the values obtained for MPI in sediment, it is obvious that pollution was present on all locations tested in the Boka Kotorska Bay in autumn 2005 and 2006 (Table 1). If we compare the seasons 2005 and 2006, MPI is higher in all location in 2005 (1.84–2.48) relative to 2006 (1.46–2.32). The location with the highest values of MPI in both examined seasons is Kukuljina (the Bay of Tivat), that corresponds with previous statements, because this location has the highest content of microelements in sediment. Although MPI values indicate the presence of pollution, in comparison with Mediterranean countries [47–49], Montenegrin coast is classified in areas with the lowest content of microelements in sediment.

Mapping the spatial distribution of contaminants in soils is the basis of pollution evaluation and risk control. Spatial distribution and concentrations of heavy metals in the bottom sediments are effected by both natural environment factors and anthropogenic factors. Spatial distribution of MPI in surface sediments from the Boka Kotorska Bay was showed to using Ocean DataView 4 (Fig. 3a, b).

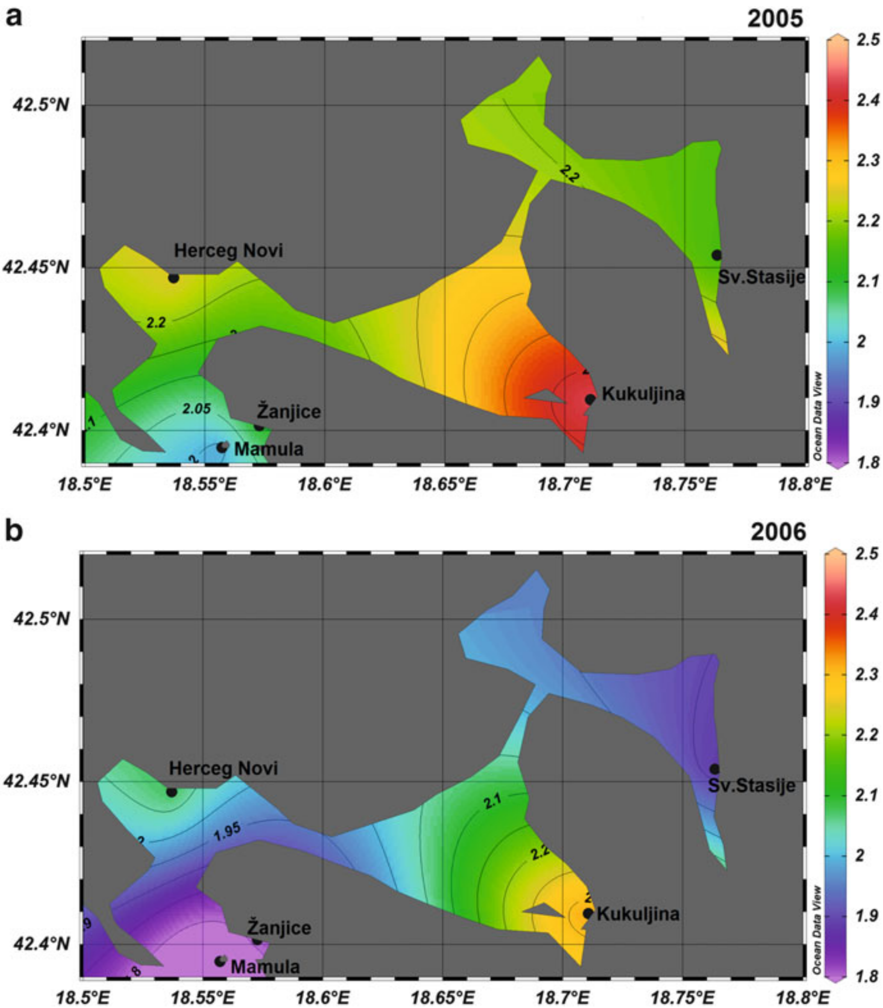

Fig. 3 The spatial distribution of metal pollution index in the Boka Kotorska Bay. (**a**) MPI (2005); (**b**) MPI (2006)

If we compare MPI values obtained for sediment and seagrass *P. oceanica* for autumn 2005 to spring 2007, we can say that Mamula was the least polluted location in the Boka Kotorska Bay. In general, MPI values for *P. oceanica* were higher than MPI values for sediment on the same locations, the highest MPI average values for this seagrass were on the locations Sveti Stasije and Kukuljina [42, 43].

It can be said that the locations in the Bay of Tivat, particularly Tivat center, are the locations with the highest pollution index, based on MPI values for mussels (*Mytilus galloprovincialis)* in autumn 2007 to autumn 2009 (5.50–18.50). This is not surprising taking into account that this is the bay with the highest number of anthropogenic sources of pollution (airport, military port, shipyard, agricultural activities). On the other hand, Sveti Stasije in the Kotor Bay is the location with the lowest MPI values in all seasons (3.7–10.00). The highest MPI values were obtained during winter and autumn, while the lowest values were observed in spring for both years tested. On the basis of the MPI values determined for marine seagrass for the same period (autumn 2007 to autumn 2009), it can be said that there is no location with maximum or minimum values. MPI values vary in relation to the investigated locations, seasons, and years. Obviously, in the case of *P. oceanica*, metals pollution index is the indicator of pollution of both marine water and sediment, because here the physical-chemical parameters of water and sediment [50] play an important role in the bioavailability and accumulation of heavy metals.

Based on continuous monitoring of MPI values of mussels (*Mytilus galloprovincialis*) growing in the sea grass meadows vicinity, pollution level of selected location can be determined and adequate actions can be undertaken in the case of elevated MPI values. Accordingly, it is possible to decrease destruction and withdrawal of these unique and very useful marine species *P. oceanica* [50, 51].

3.3 Geo-Accumulation Index (I_{geo})

A common criterion to evaluate the heavy metal pollution in sediments is the geo-accumulation index (I_{geo}), which was originally defined by Müller [52] to determine metals contamination in sediments, by comparing current concentrations with pre-industrial levels and can be calculated by the following equation [52]:

$$I_{\text{geo}} = \log 2Cn/1.5Bn,$$

where C_n is the concentration of element n and B_n is the geochemical background value. In this study, consider $B_n =$ world surface rock average given by Martin and Meybeck [53]. The factor 1.5 is incorporated in the relationship to account for possible variation in background data due to lithogenic effect. Muller has classified I_{geo} in relation to contamination levels into seven classes: unpolluted (Class 0, $I_{\text{geo}} < 0$), unpolluted to moderately polluted (Class 1, $0 < I_{\text{geo}} < 1$), moderately polluted (Class 2, $1 < I_{\text{geo}} < 2$), moderately to highly polluted (Class3, $2 < I_{\text{geo}} < 3$), highly polluted (Class 4, $3 < I_{\text{geo}} < 4$), highly to extremely polluted (Class 5, $4 < I_{\text{geo}} < 5$), and extremely polluted (Class 6, $I_{\text{geo}} > 5$), the highest grade reflecting a 100-fold enrichment above baseline values.

According to the categorization based on the obtained I_{geo} values, locations Žanjice and Herceg Novi are categorized as unpolluted to moderately polluted locations by manganese (0.14 respectively 0.77), while the same can be said for nickel (0.42 respectively 1.11) in the case of Herceg Novi and Kukuljina. Kukuljina (Tivat Bay) is location with the highest geoaccumulation index value for Cd, with I_{geo} value for Cd 3.79 in autumn 2006 that represents highly polluted area (Table 1). High contamination of this area by Cd is a consequence of the anthropogenic influence from the land, including waste waters, port activities, and usage of anticorrosive paints for ships and boats [54]. Interestingly, the toxic elements such as mercury, lead and arsenic, as well as the essential elements iron, copper and zinc have such I_{geo} values that all investigated locations are classified practically as non-polluted areas.

Comparing the results of geo-accumulation index to other authors [54], we can conclude that obtained values are significantly lower than those from the data from reference works and that they appear in locations with elevated concentrations of metals.

4 Biomonitoring and Biomarkers in Boka Kotorska Bay

In the framework of the MED POL Program since 2009 in Montenegro is implementing a National Biomonitoring of the coastal waters in Boka Kotorska Bay in order to fulfill the obligations set out in the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention, entered into force 2007). Following the Manual on the biomarkers recommended for the MED POL Biomonitoring programme [5] the Institute of Marine Biology conducted in the period from 2009 to 2015 a research of various biomarkers in order to assess the level and to determine the types of pollution in Boka Kotorska Bay.

The research included biomarkers of effect and biomarkers of exposure. For the detection and assessment of pollution levels in Boka Kotorska Bay the following biomarkers were determined: (a) the content of metallothioneins (MT) in response to exposure to heavy metals, (b) activity of Acetilholinesterase (AChE) in response to exposure to organophosphate and carbamate pesticides, (c) glutathione S-transferase (GST) in response to exposure to organic pollutants (PCB, PAHs), (d) evaluation of the oxidative stress using the Catalase test (CAT), and (e) presence of micronuclei (MN) as a marker of effects of mutagenic and clastogenic substances from the environment on organisms. Also to define the well-being of the animals the Condition (CI) and Gonadosomic (GSI) Indexes were determined.

As a sentinel species the mussel *Mytillus galloprovincialis* L. was used for monitoring. The mussels are desirable as bioindicators since they have the ability to accumulate water contaminants, have a broad geographical distribution, and can be easily grown in cages. With the parallel use of wild and mussels from the cage we can get information about the long-term and short-term effects of pollution in the areas where they are naturally present.

Biomarker responses were measured in mussels collected in their natural habitat at the location Kotor and the mussels taken from the mussel farm, the location Bijela. Both locations have different levels of pollution and ecological characteristics and are under great anthropogenic pressures due to the outflow of waste water, small shipyard, maritime transport, tourism, etc.

One of the first researches on biomarkers was done in 2008. Biological effects were investigated analyzing both generic and specific biomarkers at cellular level (metallothionein content, lysosomal membrane stability, lipofuscin and neutral lipid accumulation, lysosomal structural changes) [55].

Comparing the data from 2009 to 2015 for CI and GSI shows the decrease in the conditional index in both locations, which may be an indication that some adverse effect on mussels exists. CI values ranged from 10.78 g/cm^3 in the location Kotor in 2015 up to 19.95 g/cm^3 also in the location Kotor in 2013 [31].

The location Kotor has a higher CI than the location Bijela. The reason for this is the fact that the location Bijela sustains a larger anthropogenic impact (load of industrial pollution, shipbuilding, port activities), while the location Kotor is affected mainly by the waste water from households. Reduced nutritional status of mussels in both locations can lead to increased stress in mussels.

The content of metallothionein is determined in response to exposure to heavy metals. Metallothionein are a group of proteins of low molecular weight with a high content of thiol groups and metal atoms embedded in a relatively stable molecule tetrathionate cluster configuration type. The content of MT which is found in a particular tissue or cell is a direct reflection of the state of equilibrium that is established between the MT synthesis process and its degradation. Violation of this balance was due to the slow decomposition or due to increased synthesis leading to increased concentrations of MT in the cell. Although a variety of substances can cause the synthesis of MT, only some metals (Zn, Cd, Cu) and glucocorticoids are considered as primary inducers. Metallothionein concentration was highest in 2014 in the location Bijela (165.15 mg/g wet weight), and the lowest also was recorded in 2014 in the location Kotor (33.74 mg/g wet weight) [31]. In comparison to the Southern Adriatic (Slovenian coastal waters) the MT levels are lower in Southern Adriatic [56]. The essential difference between the heavy metal pollutions is the concentration of some metals. The location Bijela has higher levels of arsenic and lead with low capacity of binding to MT. On the other hand, it was found that the concentration of total Hg was ten times higher in the northern Adriatic than in other parts. A higher level of MT in the northern locations may be due to the high binding affinity for Hg MT, despite its low induction ability [57].

Acetylcholinesterase (AChE) is an enzyme involved in the transmission of nerve impulses, and its inhibition leads to neurotoxicity that occurs due to exposure of the body to organophosphorus and carbamate pesticides. Activity of acetylcholinesterase is inhibited by many pesticides (organophosphorus and carbamate pesticides) and metals such as cadmium (Cd) and chromium (Cr). Lately, there has been increasing evidence that different pollutants inhibit AChE and is therefore considered that the AChE biomarker of general stress. Activity of AChE was measured in whole mussel tissue and it ranged from 1.093 in the location Kotor (2013) to 12.63 nmol/min/mg in the location Bijela (2009) [31]. These concentrations were in the same range at the northern and southern stations [57].

Glutathione S-transferase (GST) is a detoxification enzyme which catalyzes the reaction of detoxification of numerous toxic compounds using glutathione. In this way, it prevents any interaction between the reactive products and cellular proteins or nucleic acids. If the organism is an animal under the influence of high oxidative stress, that would result in high activity of the enzyme glutathione S-transferase.

The average specific activity of GST was the highest in the location Bijela in 2013 (8.179 nmol/mg protein/min) while the lowest value was in the location Kotor (4.390 nmol/mg protein/min) [31]. The activity of GST at the location Bijela was also higher than in Eastern Mediterranean [58].

Catalase (CAT) is an enzyme that is mainly found in the digestive tract (hepatopancreas) of animals and is a part of the antioxidant protection of the organism. Catalase breaks down toxic hydrogen peroxide to oxygen and water molecules. If there is no decomposition of hydrogen peroxide, then the oxidative stress induced by hydrogen peroxide leads to the cell death. If the animal is exposed to oxidative stress, hydrogen peroxide concentration value is increased resulting in higher activity of the enzyme catalase. Average maximum and minimum values are obtained in the location Kotor and ranged from 0.952 μmol/min/mg of protein in 2013 to 4.185 μmol/min/mg in 2015 [31]. There were no difference in the activity of the enzyme between the south of Adriatic and Eastern Mediterranean [58].

The application of genotoxicity biomarkers in sentinel organisms allows for the assessment of mutagenic hazards and/or for the identification of the sources and fate of the contaminants. Micronucleus (MN) test as an index of accumulated genetic damage during the lifespan of the cells is one of the most appropriate techniques for identification of the integrated response to the complex mixture of contaminants [59]. MN are formed in the process of cell division and their expression can occur at different times after the DNA damage event, depending on the cell cycle kinetics and the mechanism of induction [59]. During 2009 and 2010 MN test was done for the two sampling sites in the Boka Kotorska Bay. The MN frequencies were detected in the stations Kotor (3 ± 1) and Bijela (4 ± 1). Comparing the obtained results with the results from other sampling locations indicates that the test results do not differ and that there is an increased frequency of micronuclei. In July 2011, the Comet test was performed and it confirmed the results of the micronucleus test. The comet assay measured the levels of DNA damage molecules in the gills, hemolymph, and hepatopancreas caused by mutagenic and genotoxic substances. The level of DNA damage was significantly higher at the site Bijela [60].

In the cooperation framework between the University of Montenegro with Environmental Protection Agency of Montenegro and Saint-Petersburg Scientific Research Centre for Ecological Safety, Russian Academy of Sciences from Russia, at Institute of Marine Biology (IMB) Kotor, Montenegro established a new approach of seawater quality biomonitoring based on physiological biomarkers of benthic invertebrates. There are two monitoring types in use: active biomonitoring has been conducted since 2012 while passive biomonitoring has been implemented since 2016. The collaboration is aimed to improve the existing methodology of sea water quality assessment in the Boka Kotorska Bay by the integration of procedure already validated in Russia [61].

Due to specific seasonal variations in salinity and temperature of seawater surface in the BokaKotorska Bay [62], to overcome these environmental conditions and survive, intertidal animals attached to one location almost their entire life cycle are forced to activate protective physiological mechanisms. It was suggested that disruption of any physiological process of an organism will surely decrease its

Fig. 4 Experimental unit for cardiac activity recording of aquatic invertebrates

ability to survive, if the problem would occur on population level; it is not difficult to conclude that physiological biomarkers have direct relevance to entire population [63]. The physiological biomarkers of Mytilid mussels such as heart rate, clearance rate, condition indices, scope for metabolic arrest, scope for growth, shell growth, and byssus thread production were reviewed in the study of [64].

Recently, preliminary study of seawater quality assessment by active biomonitoring based on cardiac activity of the Mediterranean mussel *Mytilus galloprovincialis* L. as physiological biomarker has been conducted in a part of the Boka Kotorska Bay [65]. Since the heart rate (Hr) is a reliable indicator of general health condition of an organism, Hr recovery time and the coefficient of variation (CV) within a group of *M. galloprovincialis* L. are calculated after the stress, induced by the addition of distilled water in seawater aquarium. The method was developed by S. V. Kholodkevich and it is based on non-invasive recording of cardiac activity of invertebrates with hard skeletons by means of photoplethismograph technology with infrared laser fiber-optic sensors [66]. Experimental unit is presented in Fig. 4. Photoplethismographs are widely used as medical devices in optical detection of blood volume changes derived from contractile activity of the heart [67]. The usage of optical sensors in cardiac activity recording of aquatic invertebrates is innovative and reliable, also animal stress during handling is minimized. To avoid drilling a hole in shell valves to obtain Hr signal, small sensors are attached by waterproof glue above the heart area.

Beside the active biomonitoring of seawater quality including the addition of distilled water as functional loading in static system, passive biomonitoring of sea water quality based on Hr of *M. galloprovincialis* L. in the Boka Kotorska Bay is conducted. Experimental procedure was described in [61], whereby crayfish *Pontascus leptodactylus* was used as a model organism. Briefly, procedure requires permanent circulation of water directly from the sea through aquaria with mussels connected to a System for Industrial Biological Water Quality Monitoring (SIBWQM). For example, if potentially polluted seawater induced significant Hr variation within a group of mussels, the system would rapidly activate the alarm signal and seawater that caused the reaction would be sampled and used for physical-chemical analyses to reveal the source of pollution. Accordingly, this biomonitoring approach can be considered as reliable early warning system in detection of different pollution types in the aquatic ecosystems. Since the environmental pollution incidents are caused by human factor in most cases, there is an opportunity for implementation of "Polluter Pays Principle" [68], particularly in the inner part of the Boka Kotorska Bay, characterized by low level of water exchange and intensive maritime transport in relatively small area during the summer season. The application of aforementioned early warning system for biomonitoring enables detection of pollution on the initial phase and prevents further contamination of aquatic ecosystem.

Experimental unit for cardiac activity recording of aquatic invertebrates is also used for testing the toxicity of different chemical pollutants to cardiac physiology of mussels sampled in the Boka Kotorska Bay. The study [69] indicated high toxicity of cadmium-chloride to Hr of *M. galloprovincialis* L. In spite of washing out polluted seawater from the system after the exposure to toxicant, cardiac activity was at the low level a few hours later, suggesting possible inhibition of neurophysiological pathways.

In areas with intensive marine traffic, release of oil and oil derivatives in the seawater is inevitable [70]. Recently, in the Boka Kotorska Bay, 32.7 m ship has sunk, consequently, dispersed diesel fuel droplets were detected in the whole water column [71]. Intertidal animals and filter feeders were particularly endangered. The impact of diesel oil, dispersed diesel oil, and oil dispersant (Superdispersant-25) on Hr and level of DNA damage in haemocytes of *M. galloprovincialis* from the same area was investigated in studies [72, 73]. The results indicated high susceptibility of *M. galloprovincialis*to oil related pollution. Superdispersant-25 induced impairment of cardiac activity despite low concentrations. In parallel with Hr, level of DNA molecule damage in haemocytes of the same species was analyzed by single-cell gel electrophoresis (SCGE), known as comet assay. In general, genotoxic effect of diesel oil was not significantly expressed while exposure to Superdispersant-25 induced significant increase of tail intensity parameter (TI%) indicating on genotoxic potential of oil dispersant. Accordingly, chemical dispersion of oil should not be applied in partly closed systems such as the Boka Kotorska Bay. Previously, the evaluation of comet assay on three tissues of *M. galloprovincials* L. sampled on different locations in the Boka Kotorska Bay was conducted [60].

The studies including genotoxicity assessment are implemented in cooperation between the IMB Kotor, Department of Microbiology Faculty of Biology and Institute for Multidisciplinary Research, University of Belgrade, Serbia. The aim of the further collaboration is to integrate environmental toxicology methods and reinforce capacities for future participation in international projects regarding environmental protection.

5 Conclusion

Over the past few decades, the Boka Kotorska Bay with its extraordinary natural and socioeconomic values, distinct both in the historical and contemporary context, has been undergoing a dynamic economic development that implies a number of risks related to the protection of the marine ecosystem. The specific character of this Bay in terms of geological, hydrological, and hydrographic characteristics and limited communication with the open sea increases the pressure of its exposure to the anthropogenic pollution above all. This complicates research and monitoring of the state of environmental quality in the Bay and establishing of a connection between the degree of contamination of the bay on one side and the response and rehabilitation capacity of its ecosystem on the other side. In addition to regular monitoring based on internationally agreed standards, which our country has accepted as binding, there are, depending on the context, also other approaches in assessing the contamination of water, sediment, and biota. Data reported in this paper in terms of the heavy metals content in sediment indicate that the Bay of Tivat and the Bay of Kotor are more exposed to anthropogenic sources of contamination, which is related to more intensive economic activities in these two Bays. The indexes of environmental quality as a powerful tool for assessing the degree of contamination with heavy metals were applied for sediment and biota (*P. oceanica* and *M. galloprovincialis*) through the Enrichment Factor (EF), Metal Pollution Index (MPI), and Geo-accumulation Index (I_{geo}E). They pointed out the seasonal and annual variability of assessment results, especially the assessment of the degree of contamination in biota, and indicated the Tivat Bay as the most contaminated. Also, available data and their comparison show that it is necessary to continuously monitor the degree of heavy metals contamination in sediment and biota in the long term, and to determine the trend of contamination the Boka Kotorska Bay in terms of heavy metal content in these environments.

Biomonitoring activities based on the analysis of all mentioned biomarkers and indexes have showed that the location Bijela is under the higher pressure from human activities than the location Kotor (industrial pollution load, shipbuilding, port activities, etc.) while the location Kotor is most affected by the waste water from households. This assertion is supported by the fact that the inhibition of the enzyme was higher in the location Bijela (caused by oxidative stress, pollution with organophosphate pesticide, carbamate pesticides and metals), and also that the maximum load of metals was in the location Bijela.

Active biomonitoring method has major potential in seawater monitoring of the Montenegrin coast; however, it should be further tested and elaborated. Furthermore, since the Town of Kotor in the Boka Kotorska Bay is an important destination for large touristic ships – cruisers – passive biomonitoring of sea water quality will significantly contribute to environmental protection and sustainable development of this part of the Adriatic Sea.

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References

1. Kaushik A, Kansal A, Santosh et al (2009) Heavy metal contamination of river Yamuna, Haryana, India: assessment by metal enrichment factor of the sediment. J Hazard Mater 164:265–270
2. Stanković S, Cantaluppi C, Mandić S, Degetto S (2002) The environmental state of aquatic systems through sediments analysis: radiochemical approach. Stud Mar 23:57–64
3. Tanaskovski B, Petrovic M, Kljajic Z, Degetto S, Stankovic S (2014) Analysis of major, minor and trace elements in surface sediments by X-ray fluorescence spectrometry for assessment of possible contamination of Boka Kotorska Bay, Montenegro. Maced J Chem Chem Eng 33:139–150
4. Schettino T, Caricato R, Calisi A et al (2012) Biomarker approach in marine monitoring and assessment: new insights and perspectives. Open Environ Sci 6:20–27
5. UNEP/RAMOGE: Manual on the biomarkers recommended for the MED POL biomonitoring programme (1999) UNEP, Athens
6. OSPAR Commission (2008) Coordinated environmental monitoring programme – assessment manual for contaminants in sediment and biota, publication no. 379/2008, p 39
7. Law R, Hanke G, Angelidis M et al (2010) Marine strategy framework directive – task group 8 report contaminants and pollution effects. Scientific and Technical Research Series, vol 161. EUR 24335 EN – Joint Research Centre Scientific and Technical Reports. Office for Official 622 Publications of the European Communities, Luxembourg
8. Peijenenburg WJGM, Posthuma L, Eijsacheis HJP et al (1997) A conceptual frame work of implementation of bioavailability of metals for environmental management purposes. Ecotoxicol Environ Saf 37:163–172
9. Committee on Biological Markers of the National Research Council (1987) Biological markers in environmental health research. Environ Health Perspect 74:3–9
10. Ramsak A, Scancar J, Horvat M (2012) Evaluation of metallothioneins in blue mussels (Mytilus galloprovincialis) as a biomarker of mercury and cadmium exposure in the Slovenian waters (Gulf of Trieste): a long-term field study. Acta Adriat 53(1):71–86
11. Zhou Q, Zhang J, Fu J et al (2008) Biomonitoring: an appealing tool for assessment of metal pollution in the aquatic ecosystem. Anal Chim Acta 606:135–150
12. Stankovic S, Kalaba P, Stankovic RA (2014) Biota as toxic metals indicators. A review. Environ Chem Lett 12:63–84
13. Walker CH, Hopkin SP, Sibly RM et al (2006) Principles of ecotoxicology. CRC Presss, Taylor & Francis Group, Boca Raton, FL
14. Vincent C, Heinrich H, Edwards A et al (2002) Guidance on typology, reference conditions and classification systems for transitional and coastal waters. CIS Working Group 2.4 (COAST). Common Implementation Strategy of the Water Framework Directive, European Commision, p 119

15. Allan IJ, Vrana B, Greenwood R et al (2006) "Toolbox" for biological and chemical monitoring requirements for the European Union's Water Framework Directive. Talanta 69:302–322
16. Mills GA, Greenwood R, Gonzalez C (2007) Environmental monitoring within the Water Framework Directive (WFD). Trends Anal Chem 26:450–453
17. Libes SM (1992) An introduction to marine biogeochemistry. Wiley, New York
18. Phillips DJH, Rainbow PS (1993) Biomonitoring of trace aquatic contaminants. Elsevier Applied Science, London
19. Balkis N, Çağatay MN (2001) Factors controlling metal distribution in the surface sediment in the Erdek Bay, Sea of Marmara, Turkey. Environ Int 27:1–13
20. Chapman PM (2007) Determining when contamination is pollution – weight of evidence determinations for sediments and effluents. Environ Int 33:492–501
21. Cenci RM, Basset A, Sena F et al (2002) Trace elements in sediment cores of Lake Alimini (Lecce Italy). Fresenius Environ Bull 11:681–685
22. Ansari TM, Marr L, Tariq N (2004) Heavy metals in marine pollution perspective-A: mini review. J Appl Sci 4:1–20
23. Papatheodorou G, Hotos G, Gerada M et al (2002) Heavy metal concentrations in sediments of Klisova lagoon (Southeast Mesalonghi-Aetolikon lagoon complex), W. Greece. Fresenius Environ Bull 11:951–956
24. Zabetoglou K, Voutsa D, Samara C (2002) Toxicity and heavy metal contamination of surficial sediment from the Bay of Thessaloniki (Northwestern Aegean Sea) Greece. Chemosphere 49:17–26
25. Ünlü S, Topcuoğlu S, Alpar B et al (2008) Heavy metal pollution in surface sediments and mussel samples in the Gulf of Gemlik. Environ Monit Assess 144:169–178
26. Ujević I, Kljaković-Gašpić Z, Bogner D (2010) Influence of suspended matter on cadmium accumulation in sediment from Kaštela Bay, Adriatic Sea, Croatia. Acta Adriat 51:79–88
27. Dugalić JG, Gajić AB (2005) Pedologija – praktikum. Agronomski fakultet, Čačak
28. UNEP/IOC/IAEA (1995). Manual for the geochemical analyses of marine sediments and suspended particulate matter. Reference Methods for Marine Pollution Studies No.63, UNEP
29. Tam NFY, Wong YS (2000) Spatial variation of heavy metals in surface sediments of Hong Kong mangrove swamps. Environ Pollut 10:195–205
30. Aloupi M, Angelidis MO, Gabriel A et al (2007) Marine monitoring along the eastern coastal area of the island of Lesvos, Greece during 2004 in the framework of MedPol III. J Global Nest 9:83–97
31. Joksimovic D (2015) Complex research of the ecosystem of coastal sea of Montenegro. University of Montenegro, Final study of the KOTOR project. Institute of Marine Biology, pp 1–145
32. Del Bianco F, Gasperini L, Giglio F et al (2014) Seafloor morphology of the Montenegro/N. Albania Continental Margin (Adriatic Sea—Central Mediterranean). Geomorphology 226:202–216
33. ICES (2009) Report of the Working Group on Marine Sediments in Relation to Pollution (WGMS). ICES CM 2009/MHC:02, p 59
34. Dolenec T, Faganeli J, Pirc S (1998) Major, minor and trace elements in surficial sediments from the open Adriatic Sea: a regional geochemical study. Geol Croatica 51:59–73. doi:10.4154/GC.1998.08
35. Tanaskovski B, Jovic M, Milicic L et al (2016) The geochemistry model of the surface sediment determined by using ED-XRF technique: a case study of the Boka Kotorska bay, Adriatic Sea. Environ Sci Pollut Res 1–13. doi: 10.1007/s11356-016-6353-6
36. Feng H, Han X, Zhang WG et al (2004) A preliminary study of heavy metal contamination in Yangtze River Intertidal Zone Due to urbanization. Mar Pollut Bull 49(11–12):910–915. doi:10.1016/j.marpolbul.2004.06.014
37. Cato I (1977) Recent sedimentological and geochemical conditions and pollution problems in two marine areas in Southwestern Sweden. Striae 6:1–150

38. Choi K, Kim S, Hong G et al (2012) Distribution of heavy metals in the sediments of South Korean harbours. Environ Geochem Health 34:71–82. doi:10.1007/s10653-011-9413-3
39. Sinex S, Helz G (1981) Regional geochemistry of trace elements in Chesapeak Bay sediments. Environ Geol 3(6):315–323. doi:10.1007/BF02473521
40. Turekian KK, Wedepohl KH (1961) Distribution of the elements in some major units of the earth's crust. Geol Soc Am Bull 72:175–92
41. Pekey H (2006) The distribution and sources of heavy metals in Izmit Bay surface sediments affected by a polluted stream. Mar Pollut Bull 52:1197–1208
42. Stanković S, Jović M, Tanaskovski B et al (2015) Can the origin of some metals in the seagrass Posidonia oceanica be determined by the indexes of metals pollutions? Environ Sci Pollut Res 22(11):8253–8263. doi:10.1007/s11356-014-3953-x
43. Stanković S, Jović M, Mihajlović ML et al (2015) Metal pollution determined by pollution indices for sea grass P. oceanica and surface sediments. Arch Biol Sci 67(1):91–101
44. Ligero RA, Barrera M, Casas-Ruiz M et al (2002) Dating of marine sediments and time evolution of heavy metal concentrations in the Bay of Cadiz, Spain. Environ Pollut 118:97–108
45. Lee WY, Wang XW (2001) Metal accumulation in the green macroalgae Ulva fasciata: effect of nitrate, ammonium and phosphate. Sci Total Environ 278:11–22
46. Joksimović D, Stanković S (2012) Accumulation of trace metals in marine organisms of the southeastern Adriatic coast, Montenegro. J Serb Chem Soc 77:105–117
47. Usero J, Morillo J, Gracia I (2005) Heavy metal concentrations in molluscs from the Atlantic coast of southern Spain. Chemosphere 59:1175–1181
48. Rodríguez-Barroso MR, Benhamou Y, El Moumni B (2009) Evaluation of metal contamination in sediments from North of Morocco: geochemical and statistical approaches. Environ Monit Assess 159:169–181
49. Uluturhan E (2010) Heavy metal concentrations in surface sediments from two regions (Saros and Gökova Gulfs) of the Eastern Aegean Sea. Environ Monit Assess 165:657–684
50. Stanković S, Jović M, Petrović M et al (2012) Trace elements concentrations in the seagrass Posidonia oceanica and surface sediments samples at the southeastern Adriatic coast. Int Conf Mar Coast Ecos, Tirana, Albania 25–28:89
51. Jović M, Stanković S (2014) Determination of marine pollution by comparative analysis of metal pollution indices. Arch Biol Sci 66(3):1205–1215
52. Müller G (1981) Die Schwemetallbelastungder sedimente des Neckars und seiner Nebenflusse: eine Bestandsaufnahme. Chem Ztg 105:157–164
53. Martin JM, Meybeck M (1979) Elemental mass balance of materials carried by major world rivers. Mar Chem 7:173–206
54. Buccolieri A, Buccolieri G, Cardellicchio N et al (2006) Heavy metals in marine sediments of Taranto Gulf (Ionian Sea, Southern Italy). Mar Chem 99:227–235
55. Da Ros L, Moschino V, Macic V et al (2011) An ecotoxicological approach for the Boka Kotorska Bay (south-eastern Adriatic Sea): first evaluation of lysosomal responses and metallothionein induction in mussels. Mar Pollut Bull 63:326–333
56. Kristan U, Kanduc T, Osterc A et al (2014) Assessment of pollution level using Mytilus galloprovincialis as a bioindicator species: The case of the Gulf of Trieste. Mar Pollut Bull 89 (1–2):455–63
57. Ramsak A, Tkalcic B, Kljajic Z (2010) Evaluation of biomarkers response at the SE Gulf of Trieste (Slovenia) and Boka Kotorska (Montenegro). CIESM - 39th Congress, Venezia, 10-14May 2010
58. Tsangaris C, Moschino V, Strogyloudi E et al (2016) Biochemical biomarker responses to pollution in selected sentinel organisms across the Eastern Mediterranean and the Black Sea. Environ Sci Pollut Res 23:1789–1804
59. Bolognesi C, Hayashi M (2011) Micronucleus assay in aquatic animals. Mutagenesis 26 (1):205–213

60. Heberger K, Kolarevic S, Kracun-Kolarevic M et al (2014) Evaluation of single-cell gel electrophoresis data: Combination of variance analysis with sum of ranking differences. Mutat Res 771:15–22
61. Kholodkevich SV, Ivanov AV, Kurakin AS et al (2008) Real time biomonitoring of surface water toxicity level at water supply stations. Environ Bioindic 3(1):23–34
62. Bellafiore D, Guarnieri A, Grilli F et al (2011) Study of the hydrodynamical processes in the Boka Kotorska Bay with a finite element model. Dyn Atmos Oceans 52(1):298–321
63. Depledge MH, Aagaard A, Györkös P (1995) Assessment of trace metal toxicity using molecular, physiological and behavioural biomarkers. Mar Pollut Bull 31(1):19–27
64. Nicholson S, Lam PKS (2005) Pollution monitoring in Southeast Asia using biomarkers in the mytilid mussel Perna viridis (Mytilidae: Bivalvia). Environ Int 31(1):121–132
65. Martinović R, Kurakin AS, Kholodkevich SV et al (2013a) Preliminary results of sea water quality assessment based on physiological biomarkers in part of the Boka Kotorska Bay. Water Resour Manag 3(1):31–34
66. Fedotov VP, Kholodkevich SV, Strochilo AG (2000) Study of contractile activity of the crayfish heart with the aid of a new non-invasive technique. J Evol Biochem Physiol 36 (3):288–293
67. Allen J (2007) Photoplethysmography and its application in clinical physiological measurement. Physiol Meas 28(3):R1
68. Gaines SE (1991) Polluter-pays principle: from economic equity to environmental ethos. Tex Int'l LJ 26:463
69. Martinović R, Gacic Z, Kljajic Z (2013) Heart rate changes of the Mediterranean mussel (Mytilus galloprovincialis L.). Stud Mar 26(1):111–118
70. Etkin DS (2011) Spill occurrences: a world overview. In: Fingas M (ed) Oil spill science and technology: prevention, response and clean up, 1st edn. Gulf Professional Publishing, Burlington, pp 7–48
71. DeNardis NI, Svetličić V, Pletikapić G et al (2014) Presence of dispersed diesel fuel in the water column of the Boka Kotorska Bay: a case study. Stud Mar 27(1):43–64
72. Martinovic R, Gacic Z, Kljajic Z (2015a) The influence of oil, dispersed oil and the oil dispersant SD-25 on the heart rate of the mediterranean mussel (M.galloprvincialis L.). In: Stylios C et al (eds) Sustainable development of sea-corridors and coastal waters. Springer, Switzerland, pp 21–27. doi:10.1007/978-3-319-11385-2_2
73. Martinović R, Kolarević S, Kračun-Kolarević M et al (2015b) Genotoxic potential and heart rate disorders in the Mediterranean mussel Mytilus galloprovincialis exposed to Superdispersant-25 and dispersed diesel oil. Mar Environ Res 108:83–90

Bacterial Diversity of the Boka Kotorska Bay

Sandra Jokanović, Aleksandra Huter, and Sandi Orlić

Abstract This chapter provides an overview on the results of bacterial diversity studies conducted in the Boka Kotorska Bay using flow cytometry, epifluorescence microscopy as well as CARD FISH methods. Preliminary results of bacterial communities in sediment using next generation sequencing are presented as well. The Boka Kotorska Bay represents a semi-closed basin with specific hydrographic characteristics where it is very important to investigate bacterioplankton structure and highlight their significance. Average results of heterotrophic bacteria showed that Boka Kotorska Bay during 2009 and 2010 belonged to oligotrophic area. In the course of 2011 and 2012 Kotor and Risan represented mesoeutrophic area while Tivat, Herceg Novi and Mamula belonged to oligotrophic area. Analysis of seasonal distribution of LNA and HNA groups in the area of Boka Kotorska Bay showed prevalence of the LNA bacteria during spring, summer and autumn, while prevalence of the HNA bacterial group was occurred only in winter time. Bacterioplankton abundance obtained by CARD FISH showed variations among different part of Bay. Abundance of all bacterial groups decreased going from the inner (Kotor and Risan Bay) to the outer part (Herceg Novi and Mamula). In inner part of the Bay dominated *Gammaproteobacteria* and *Cytophaga*/*Flavobacter*, typical chemoorganotrophs. This part of investigated area was affected by inflow of fresh waters, nutrients as well as under great influence of contamination taking account bacterial faecal indicators. Preliminary results of sediment analysis showed dominance of *Proteobacteria*, *Firmicutes*, and *Actinobacteria* in surface sediment layers especially *Gammaproteobacteria* in the most polluted sites.

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Contents

1 Introduction

Microorganisms play a crucial role in the most biogeochemical cycles in marine ecosystems, taking part in the decomposition of organic matter and the cycling of nutrients. Their activity has a major impact on ecosystem metabolism and function [1]. Bacteria harvest energy from variety of sources, ranging from solar radiation to chemosynthesis. Therefore they are divided into different functional groups: photoautotrophs, photoheterotrophs, heterotrophs, nitrogen fixing, nitrifying and denitrifying bacteria [2]. Taking into account their high growth potential and the response to all changes in the ecosystem, variation in abundance and diversity of bacterial communities can be used as a measure in assessing the harmful effects on the ecosystem [3, 4]. Prokaryotic organism identification in the past was based on the methods of growing in pure culture. It has been found that there is a large discrepancy between the numbers of organisms counted using direct microscopic observation and those recovered on culture media [5].

During the 1990s flow cytometry was introduced in oceanography [6, 7] what has resulted in the discovery of several groups of bacterioplankton on the basis of different proportions of deoxyribonucleic acid [8]. Groups with more DNA are called high nucleic acid (HNA) content bacterial groups, whereas groups with a small amount of DNA are called low nucleic acid (LNA) content groups of bacteria [9]. Development of molecular methods based primarily on ribosomal ribonucleic acid (rRNA) nucleotide sequence of small ribosomal subunits resulted in identification of new microbial communities [10]. It is currently thought that less than 1% of marine prokaryotes have been cultured [11]. Most of techniques are based on bacterial DNA isolation, cloning and sequencing of specific marker genes [10]. Besides, fluorescence hybridization technique enabled in situ detection of certain microbial groups [12].

Research conducted in the Boka Kotorska Bay based mainly on the assessment of the sanitary quality of the seawater and sediment using the membrane filtration

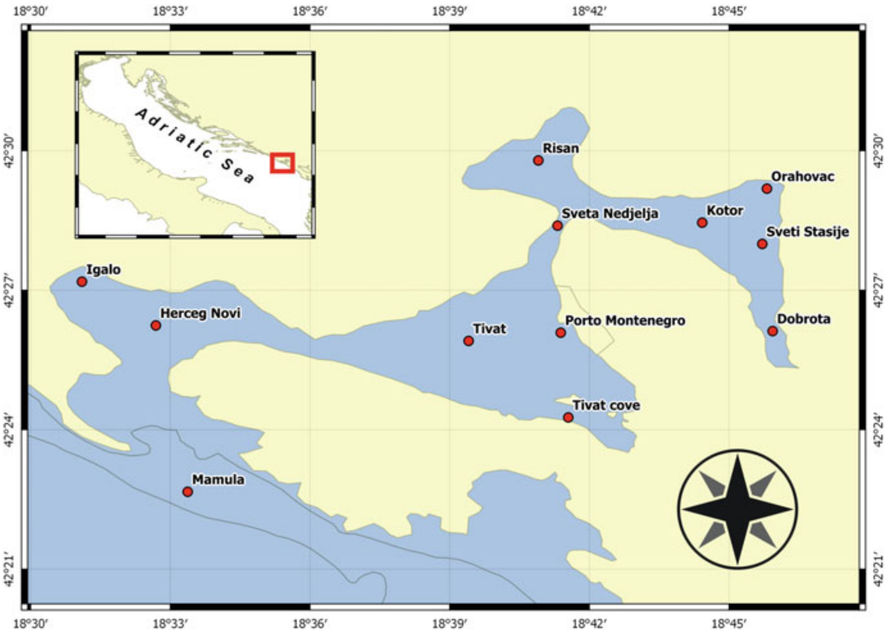

Fig. 1 Study area and sampling stations in the Boka Kotorska Bay

method. Over the last few years, the first data on the abundance of heterotrophic bacteria were obtained using the epifluorescence microscopy and flow cytometry as well as identification of microbial community by CARD FISH (*Catalyzed Reporter Deposition Fluorescence* In Situ *Hybridization*) method. The preliminary results of bacterial communities in sediment were obtained by next generation sequencing (NGS) method. The aim of this chapter is to provide an overview of the results on microbial communities in the Boka Kotorska Bay (Fig. 1) and their environmental significance. Geographic position and specific ecological conditions make Boka Kotorska Bay a specific biotope, thus it is very important to investigate bacterioplankton structure.

2 Flow Cytometry Analysis of Heterotrophic Communities

Non-pigmented bacteria are the most abundant component of the 0.2–2 μm size fraction and a major pathway in the flux of material and energy in pelagic marine ecosystems [13, 14].

In this study the abundances of non-pigmented bacteria were determined using flow cytometry [15]. The two groups of bacteria were distinguished according to their relative green fluorescence as a proxy for the nucleic acid content [16], referred to as HNA and LNA bacteria and light scattering.

Recent research showed that the HNA bacteria comprise an active group of heterotrophic bacteria in different marine ecosystems [17]; while in oligotrophic environments, LNA bacteria may represent the most active and predominating bacterioplankton community [18–20]. Research in oligotrophic systems and oceans show that LNA has a significant impact in the total heterotrophic metabolism and may have metabolic activity and growth rate similar to HNA bacteria [18]. According to the recent research, the dominance of LNA group in oligotrophic areas can be explained by the fact that LNA bacteria have a high surface–volume ratio and therefore better adaptation to poorer environmental conditions [19, 21].

Bacterial abundance in the marine ecosystem is a result of the trophic status of a specific area. Abundances of heterotrophic bacteria less than 1×10^6 cells mL^{-1} are considered to be typical for oligotrophic seas [22] and the values of heterotrophic bacteria in most parts of the study area (Fig. 1) were lower than 10^6 cells mL^{-1}.

During 2009 and 2010 bacterial abundance in the Kotor Bay ranged from 0.05×10^6 to 1.98×10^6 cells mL^{-1}, in the Tivat Bay ranged from 0.05×10^6 to 1.46×10^6 cells mL^{-1} and in the Herceg Novi Bay ranged from 0.15×10^6 to 1.39×10^6 cells mL^{-1}.

The seasonal distribution of non-pigmented bacteria in investigated area has shown an increased abundance during warmer seasons, summer season during 2009 and summer–autumn season with maximum abundance in October during 2010. Lower abundance of non-pigmented bacteria was occurred during the colder seasons. That confirms previous reports of non-pigmented bacteria distribution for coastal areas on the central and southern Adriatic Sea [23, 24]. The relationships among embayments in terms of bacterial abundance are analysed using PCA analysis. In terms of bacterial abundance, PCA analysis shows a three-layer structure in the Bay of Kotor – surface, subsurface and bottom layer [25]. The subsurface layer spreads from 5 m to 10 m and the bottom layer lies at 20 m for coastal stations and from 20 m to 30 m for the deeper central bay station. In Tivat Bay according to current patterns [26] there is a three-layer structure that does not maintain estuarine flow but registers an inflow in the bay, both from the surface and the bottom layers. According to PCA analysis of bacterial abundance, the water column is stratified into two layers. The surface layer for coastal station extends to 10 m, which is coincident with salinity of surface layer due to the strong influence of surface outflow circulation through the Verige Channel from Kotor Bay into Tivat Bay. In Herceg Novi Bay according to bacterial abundance there is a three-layer structure. Surface and bottom layer are similar according to bacterial abundance while the subsurface layer is different from the other two [21].

Analysis of seasonal distribution of LNA and HNA groups in the area of the Boka Kotorska Bay showed prevalence of the LNA bacteria during spring, summer and autumn, while prevalence of the HNA bacterial group was occurred only in winter [25]. Comparing all the data with the annual average, variations in the proportion of HNA bacteria were the most pronounced at coastal station in the Kotor Bay, which is under the strongest influence of the river Škurda. For other stations the annual average showed a percentage of HNA bacteria of less than 50%. The research conducted in the Central and Southern Adriatic Sea showed domination of LNA group in spring and summer, and dominance of HNA bacterial group during colder seasons. Thus, our findings are consistent with other research that found predominance of the LNA group over HNA for other oligotrophic areas such as the Celtic Sea, Gulf of Mexico and open Adriatic Sea [18, 19, 23], as well as dominance of the HNA group during the colder seasons [27, 28]. Furthermore, although rarely, LNA bacterial group are known to dominate in nutrient rich environments [29] which can be assumed also for the Boka Kotorska Bay during periodically more intensive river inflow and more intensive runoff.

The wide ranges of average monthly percentage of both groups in the Boka Kotorska Bay that ranged from 21% to 91% for HNA in the surface layer and from 21% to 82% HNA in the subsurface layer [25] confirmed the possible response of HNA as well as LNA bacterial groups to physical and chemical changes in the environment [27, 30]. Our results showed statistically significant correlation between the HNA and LNA bacterial groups with changes in temperature and salinity, which is consistent with previous reports with the coastal and open part of the Central and Southern Adriatic Sea [31, 32]. Also similar data for the average monthly percentage of HNA in the surface (from 24% to 63%) and in subsurface layer (from 20% to 68%) were obtained for the open part of the Southern Adriatic Sea.

3 Determination of Heterotrophic Bacteria Abundance by Epifluorescence Microscopy

Epifluorescence microscopy method is based on sample staining (most frequently using 4,5 diamidino-2-phenylindole DAPI) fluorescing under the UV light [33]. Heterotrophic bacteria samplings were performed with seasonal frequency: summer and autumn 2011 and winter–summer 2012. Samples were collected at the following stations: Kotor, Risan, Tivat, Herceg Novi and Mamula (Fig. 1). Bacterial abundance is associated with enrichment of nutrients in particular aquatic area. Any change in quantity of organic matter in the sea affects the bacterial abundance, their metabolic activity and qualitative composition. Heterotrophic bacteria are a good indicator of extent of eutrophication [21].

Heterotrophic bacteria abundance determined by DAPI counting in the Boka Kotorska Bay varied from 0.1×10^6 cells mL^{-1} to 2×10^6 cells mL^{-1} [34, 35]. The highest values were detected at Kotor station in spring when phytoplankton abundance reached maximum values [36]. Phytoplankton cells attract higher bacteria concentrations in their vicinity, probably due to excretion of polysaccharides that remain linked to cell membrane. That polysaccharide capsule can be enriched with diluted nitrogen and phosphorus from the seawater [37]. The abundance of heterotrophic bacteria decreased in summer. Previous studies [38] showed that bacterial abundance was growing from April to mid-June when it reached its maximum, and then decreased in summer which is also correlated with the main bacterial

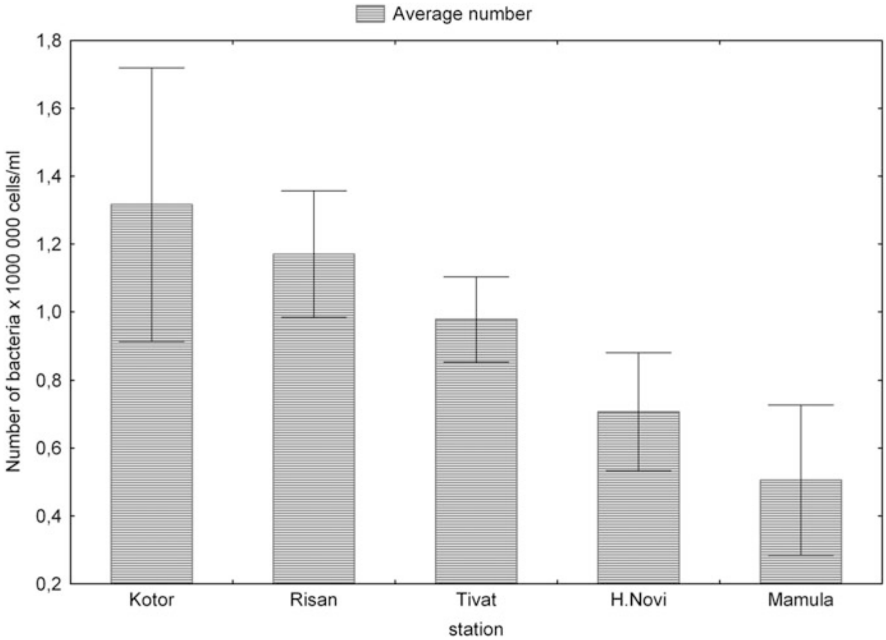

Fig. 2 Average number of heterotrophic bacteria in investigated area

consumers – *Cladocera*. In autumn, bacterial abundance didn't grow significantly in Boka Bay, and then increased again in winter, with higher inflow of nutrients coming from rainfall. Changes in bacterial population may depend not only on the biomass of microzooplankton and phytoplankton production, but also on the nutrient availability. Results of heterotrophic bacteria in surface layers varied from 0.5 x 10^6 cells mL^{-1} to 2.0×10^6 cells mL^{-1}, at the depth of 10 m from 0.5×10^6 cells mL^{-1} to 1.45 cells mL^{-1} while in bottom layers varied from 0.1×10^6 cells mL^{-1} to 1.1×10^6 cells mL^{-1} [34, 35]. Abundances of heterotrophic bacteria of less than 1×10^6 cells mL^{-1} [21] are considered to be typical for oligotrophic areas, while values between 1.2×10^6 cells mL^{-1} and 7.0×10^6 cells mL^{-1} indicate mesotrophic characteristics [39]. Consequently, based on average results (Fig. 2) Kotor and Risan Bays represented mesotrophic area during investigated period, while Tivat, Herceg Novi and Mamula belonged to oligotrophic areas [34, 35].

Detected abundance in our study is similar to results obtained in the Central and the Northern part of the Adriatic Sea where average values varied from 0.21×10^6 cells mL^{-1} to 2.39×10^6 cells mL^{-1} in the coastal region and from 0.23×10^6 cells mL^{-1} to 0.63×10^6 cells mL^{-1} in the open sea [40]. In the northern part of the Adriatic Sea maximum values exceed 7×10^6 cells mL^{-1} [41]. Significant correlation was noted between heterotrophic bacteria and chlorophyll *a* ($r^2 = 0.70$, $p < 0.01$) suggesting that a significant part of dissolved organic carbon in the sea originates from phytoplankton. Positive correlation was established between the number of heterotrophic bacteria and inorganic nutrients ($r^2 = 0.84$, $p < 0.01$ for nitrates, $r^2 = 0.71$, $p < 0.01$ for ammonia and $r^2 = 0.71$, $p < 0.01$ for phosphates) [34]. Experiments with marine cultures indicate the importance of NH_4^+ suggesting that a large portion of bacterial production is based on dissolved inorganic nitrogen and ammonia [42, 43]. Bacteria need large quantities of phosphorous since it is the main constituent of nucleic acids and cell membrane [44].

4 Bacteria Analysed by CARD FISH Method

The first data using CARD FISH method in the Boka Kotorska Bay were obtained in the course of 2011 and 2012 at the following stations: Kotor, Risan, Tivat, Herceg Novi and Mamula (Fig. 1). Samples were collected at 10 m in winter and summer months.

CARD FISH has proved a useful tool for monitoring spatial and temporal dynamics of different microbial groups in seawater and sediments. This technique permits an investigator to 'fish' for a specific nucleic acid sequence in a 'pool' of unrelated sequences. Fluorescence oligonucleotide probes with covalently bound horseradish peroxidase enzyme can be designed to recognize and hybridize to complementary 16S rRNA sequences, that are unique to specific microbial groups. Individual cell detection is enabled by tyramide, which contributes to signal amplification [11, 45].

Eubacteria as detected by the probe mix of EUB 338 I-III [46] dominated the microbial community. The average number of target cells ranged from 71% to 81%.

Relative abundance reached maximum of 90% in June at Kotor station [34, 35] which is correlated with the phytoplankton growth. Sampling time coincided with late spring, when phytoplankton abundance in the Bay is higher [36]. The minimum abundance of 60% was recorded at Mamula station.

We compared our results with other findings using CARD FISH method. In the North Adriatic, EUB 338 hybridizing cells ranged from 60% to 98% [47], in the Central part of the Adriatic Sea these values ranged from 55% to 92% [48], in the South Adriatic was 60% [47], while in Catalan Sea of the South-west Mediterranean coast (SW) ranged from 63% to 91% [49]. Changes in the composition of the bacterial community depend on the seasonal cycle and dissolved organic matter [50].

The largest and physiologically most diverse bacterial group belongs to the *Proteobacteria* phylum. The group is further divided into five classes, namely alpha (α), beta (β), gamma (γ), delta (δ) and epsilon (ε) *Proteobacteria* based on 16S rRNA sequences. The most important marine bacterioplankton are α-Proteobacteria and γ-*Proteobacteria* class. The α-*Proteobacteria* were among the most dominant bacteria in marine waters based on molecular analysis. Conversely, members of the γ-*Proteobacteria* were the most common when culture methods are used [45].

The abundance of γ-Proteobacteria ranged from 5% in Mamula to 42% in Kotor Bay (on average 12.6% of DAPI stained cell in June and 15.5% in February). It was noticed that relative abundance of γ-*Proteobacteria* was significantly higher in February in Kotor Bay compared with other investigated stations. The Kotor Bay area is largely affected by river inputs that provide the basin with large flow of fresh water and land-derived nutrients [35].

Most of γ-*Proteobacteria* are chemoorganotrophs, but they also include some phototrophs and chemolithotrophs. This group includes representatives of *Enterobacteriaceae* family that are well known as commensals and pathogens in intestines of warm-blooded organisms, so their presence affects the sanitary quality of seawater. The most widely known and easily grown genera are *E. coli, Enterobacter*, *Alteromonas, Pseudoalteromonas, Marinomonas, Vibrio* and *Schewanella* [51]. Previous investigations showed that γ-*Proteobacteria* had average higher population densities outside the oligotrophic regions [52] which was confirmed also in our study. The highest nitrates concentration of 7.134 μmol/L was also recorded at Kotor station in February, resulting from the increased inflow of nutrients through rainfall and rivulets. Significant positive correlation was established between this bacterial group and nitrate ($r = 0.84$, $p < 0.01$) as well as ammonia ($r = 0.74$, $p < 0.01$) [34]. We compared the results of our study with similar investigations. Thus, γ-*Proteobacteria* abundance in the North Adriatic can reach up to 42% [47] (ecosystem similar to Boka Kotorska Bay), in the Central Adriatic they account for 13% of the total bacteria [48], in the South Adriatic from 7.4% to 12% [46], while in the SW Mediterranean varied from 2% to 50% [49].

The abundance of α-*Proteobacteria* class ranged from 5% in Mamula to 26% in Kotor. Slightly higher concentration of this bacterial group was found in February [34] compared to summer season.

α-*Proteobacteria* is dominated by two lineages: the SAR 11 clade and *Roseobacter* clade. The SAR 11 clade prefers oligotrophic environmental conditions and their cells size is less than 1 μm. It was detected in almost all pelagic environments, from surface waters to the depth of 3,000 m.

The *Roseobacter* clade constitutes a significant fraction of α-*proteobacteria* and are widely distributed in plankton. They occur in a wide range of associations with other marine organisms. The diverse metabolic properties of this group play a large part in nutrient cycling. For example, they have a major role in the breakdown of dimethylsulfoniopropionate (DMSP) which is produced by algae. Products from its breakdown affect community structure, marine ecology and contribute to climate change [45, 53]. The values using CARD FISH in the North Adriatic showed significant variability, ranging from 6.4% to 50%, while in the South Adriatic it was up to 12% [47]. In the Central Adriatic, the abundance of this group ranged from 28% to 43% [48].

Representatives of the *Bacterioidetes* phylum (previously known as the *Cytophaga–Flavobacteria–Bacterioidetes* group) are an environmentally important and diverse group of the prokaryotic community, whose representatives were found in lakes, pelagic habitats of the seas and oceans, sediments, hydrothermal springs, as well as the digestive system of mammals [45].

Cytophaga–Flavobacterium abundance in the Boka Kotorska Bay varied from 3% in Mamula to 22% in Risan and 18% in Kotor. This group at all investigated

Table 1 Average numbers of microbial communities analysed by CARD FISH technique at investigated locations

Location	Microbial communities (%)			
	EUB I-III	*Gam42a*	*Alpha968*	*CF319a*
Kotor	86	30	24	16
Risan	80	14	19	18
Tivat	74	10	15	13
Herceg Novi	73	9	13	10
Mamula	66	5	5	3

EUB I-III Eubacteria, *Gam42a* Gammaproteobacteria, *Alpha968 Alphaproteobacteria*, *CF319a Cytophaga/Flavobacter*

station dominated the spring period when the chlorophyll *a* value was highest 4.16 mg/m^3 with significant positive correlation ($r = 0.90$; $p < 0.05$) [34]. High percentages of *Cytophaga–Flavobacterium* at high chlorophyll *a* concentrations during algal blooms may have been caused by high phytoplankton exudation rates related to nutrient depletion [54]. Most notably *Cytophaga–Flavobacterium* are chemoorganotrophic and are especially proficient in degrading biomacromolecules such as cellulose and chitin [55]. It is important to note that a negative correlation was established between this group and salinity. This is the reason why their abundance was higher in the inner parts of Bay (Kotor and Risan), since the salinity is lower compared to Herceg Novi and Mamula. Previous studies conducted in the Mediterranean showed similar results with our study. *Bacterioidetes* abundance in the North Adriatic reaches its maximum of up to 25% during periods of higher chlorophyll *a* concentration, 7.5% in the South Adriatic [47], and 6–16% along the SW Mediterranean [49].

It is obvious that abundance of all bacterial groups decreased going from the inner part (Kotor and Risan Bays) to the outer part (Herceg Novi and Mamula). The highest average number of *Eubacteria*, *Gammaproteobacteria* and *Alphaproteobacteria* was found in the Kotor Bay, while *Cytophaga/Flavobacteria* dominated in the Risan Bay. The lowest number of these bacteria was recorded in Mamula (Table 1). The oligotrophic characteristics of Mamula and low freshwater influence were correlated with low abundance of investigated bacterioplankton.

5 Microbial Communities in Sediment Analysed by Next Generation Sequencing

NGS gives several thousand to several hundred thousands of nucleotide sequences per sample which is required for the analysis and taxonomic classification. NGS methods that are widespread in marine microbial ecology are: 454 pyrosequencing and Illumina [45]. Sediment samples from the Boka Kotorska Bay were analysed by Illumina sequencing platform and were collected from nine different stations (Table 2; Fig. 1).

Table 2 Overview of sediment investigated stations in the Boka Kotorska Bay and their significance

Location	Location significance
Port of Kotor	The most indented part of the Bay. Great influence of freshwaters and wastewaters, risk of oil spills due to intensive maritime activities. Former detergent soap and rubber industry facilities
Risan	Influence of fresh water and organic matter by submerged springs Sopot and Morinj. Exposed to eutrophication. Tugboat sank in 2013
Sveta Neđelja	Strait. Pollution risks due to maritime activities
Bijela	The largest shipyard in the Southern Adriatic. Pollution risk – PAHs, PCBs, heavy metals.
Tivat	Influence of Porto M. marine and Shipyard Bijela
Porto M.	Yacht marine replaced former shipyard. Risk of faecal waste and PAHs pollution
Tivat cove	The shallowest part of the Tivat Bay. Two mussels farming sites. Influence from the shore through rivulets. Former saltworks in the hinterland
Herceg Novi	Lack of main sewer, but closer to the open sea
Igalo	Influence of the Sutorina River. Lack of main sewer. Sites with healing mud

The DNA to be sequenced is fragmented into about 200 base pairs. Adapters are ligated onto the ends of the fragments and one of these adapters is hybridized on a flow cell. Illumina utilizes a unique 'bridge' amplification reaction that occurs on the surface of the flow cell and four fluorescently labelled nucleotides to sequence the tens of millions of clusters on the flow cell surface in parallel. During each sequencing cycle, a single labelled deoxynucleoside triphosphate (dNTP) is added to nucleic chain. The nucleotide label serves as a terminator for polymerization. Emission light shows which base was incorporated on each one of those cluster [56]. Sediment is a complex environment, comprising both organic and inorganic particles surrounded by interstitial water and it is a phylogenetically diverse ecosystem [57]. The microbial degradation and transformation of particulate and dissolved organic matter in the sediment are key processes with regard to the carbon cycling in aquatic systems [58].

Distribution of bacteria in sediment, responsible for certain biogeochemical processes, is quite variable since it depends on numerous abiotic factors (sediment type, sediment depth, redox conditions and chemical properties of sedimenting particles) and relations with other members of the benthic microbial chain.

It should be noted that all these mineralizing bacteria are heterotrophic and their activity is far more limited by availability of energy (carbon), than by presence of other nutrients such as nitrogen and phosphorus. The quantity of energy that bacteria can utilize from the substrate decreases with increasing sediment depth [59].

Investigations showed that microbial communities' structures are ecologically relevant indicator of changes in ecosystem functioning. Implementation of significant molecular techniques contributes to the diversity of bacterial communities used to estimate the effect of various stressors on aquatic ecosystems. The input and accumulation of pollutant compounds is also a major threat for the Boka Bay ecosystem. Many pollutants, for example, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) and heavy metals, accumulate in marine sediments due to their recalcitrance to biodegradation. These are toxic, mutagenic and carcinogenic substances. Depending on the chemical structure and environmental factors, some compounds can be trapped in micropores and form strong bonds with sediment particles [60].

In locations with long-term exposure to aromatic hydrocarbons pollution, dominant bacterial populations utilize hydrocarbons as carbon and energy source for growth [61]. In the Boka Kotorska Bay there are the so-called hot spots, such as the Port of Kotor, Porto Montenegro marina and the Shipyard in Bijela, where sediment analysis from both microbiological and chemical aspect is of particular importance. Preliminary results of microbial communities in sediments in Boka Kotorska Bay showed dominance of some bacterial groups such as *Proteobacteria* phylum (*Alphaproteobacteria, Gammaproteobacteria* and *Deltaproteobacteria* class), *Actinobacteria* phylum and *Firmicutes* phylum. *Bacterioidetes* phylum, *Planctomycetes* and *Verrucomicrobia* phylum were present in a lesser number. There were no significant variations in qualitative composition of bacterial communities.

Proteobacteria are the most abundant bacterial communities in the sea sediment, especially *Gammaproteobacteria*. *Gammaproteobacteria* class is present in all sediment types, but it occurs more frequently in coastal sediments than in deep sediments [62]. They have a prominent role in biodegradation and bioremediation, particularly *Pseudomonas* and *Marinobacter* genus [61]. A larger number of *Gammaproteobacteria* were recorded in marinas and Port of Kotor in the Boka Kotorska Bay, where larger quantities of PAHs and PCBs were detected.

Alphaproteobacteria class is a very diverse community present in both marine and freshwater sediments. *Alphaproteobacteria* were more abundant at stations with lower quantities of hydrocarbon compounds – Risan, Tivat cove. In these locations, larger content of total phosphorous and nitrogen was detected. Previous research [62] showed that α-*Proteobacteria* richness is correlated to productivity levels in aquatic ecosystem. Some *Alphaproteobacteria* groups have the ability to degrade high molecular weight PAHs such as phenanthrene, naphthalene and pyrene [61]. Important representatives of *Deltaproteobacteria* in marine coastal and productive sediments are *Desulfobacteraceae* family [61] – important sulphate-reducing bacteria, which are also found in the most polluted areas with PAHs such as Port of Kotor, Bijela and Porto Montenegro.

Firmicutes phylum are Gram-positive heterotrophs capable of fermenting a broad range of organic substrates, such as cellulose, lignin and other carbohydrates [63] and are present in larger numbers at Risan, Port of Kotor and Tivat cove stations. The most widely spread classes within this group are *Clostridia* and *Bacilli*. Some *Bacillus* strains have the ability to degrade various hydrocarbon compounds [61] and bind metals such as manganese and copper, thus they have applications in remediation of polluted marine sediments [45].

Presence of *Actinobacteria* phylum is mainly linked with sediments, and they belong to aerobic Gram-positive bacteria. They are primarily saprophytes, taking part in degradation of complex biopolymers, some groups are also nitrogen-fixing bacteria and their presence is connected with areas with larger quantity of total organic carbon (TOC). They are important from both the biotechnological and medicinal aspects. They also form symbiotic relations with different marine organisms such as sponges, tunicates, bryozoa [62]. Significant TOC concentration was recorded at Port of Kotor, Bijela, Igalo, Sveta Neđelja and Tivat Centre stations. In these locations higher abundance of *Actinobacteria* is expected.

A large number of bacteria have the ability to degrade organic matters using oxygen molecule as an electron acceptor. However, many species such as *Pseudomonas*, *Bacillus* degrade organic matter under anaerobic conditions, or are using alternative acceptor – nitrates. Chemolithotrophs, which receive energy from oxidation of inorganic compounds, are present in deeper sediment layers as well as deep sea habitats, where anaerobic conditions prevail [63]. Further research activities will be based on vertical sediment profile that will show distribution of bacterial population in different sediment layers as well as characterization of bacterial communities degrading petroleum products.

6 Indicators of Faecal Contamination in the Sea

Marine coasts, especially near urban areas, are often subject of pollution from sewage and industrial discharges. Allochthonous microorganisms in the sea can be derived from a wide variety of sources including wastewaters, rivers and soil. Some of them are pathogenic and cause various infections and diseases. Presence of such organisms in the sea represents pollution.

The need to define sanitary quality indicators of seawaters is derived from several facts: hundred of pathogen bacteria can be isolated from wastewaters, with each having a different probability of causing disease, depending of concentration; also for some pathogens methods for isolation and determination from marine environment have not been yet developed. In fact, it is of great importance to determine whether of pathogens are present in sufficient quantities to represent an unacceptable risk to human health [64].

E. coli and other coliform bacteria exist in large numbers (over 10^8 per gram) in the gut of warm-blooded organisms and their faeces, therefore they became the standard indicator for faecal pollution of water. Obligatory anaerobic bacteria, such as *Lactobacillus*, *Bifidobacterium* and *Clostridium*, are more abundant in the human gut, but these have not been used so extensively until recently indicators, because they are more difficult to cultivate. Total coliforms may be used as faecal pollution indicator, but they include also bacteria of non-faecal origin. The well-known strains are *Escherichia, Citrobacter, Klebsiella, Enterobacter, Serratia*, etc. Coliform bacteria are facultative anaerobic organisms characterized by sensitivity to bile salts and the ability to ferment lactose at 37°C. These bacteria can be derived from a wide variety of sources, including plants and soil, so they often reflect runoff from the land as well as faecal pollution.

The faecal coliforms are a subset of the coliforms originally distinguished by their ability to grow and ferment lactose at 44°C; the main member of this group is *E. coli* showing high correlation with the level of faecal pollution.

Intestinal enterococci might be an alternative indicator for monitoring environmental water quality. These bacteria are consistently associated with the intestines of humans and warm-blooded animals and include the species *Enterococcus faecalis*, *Enterococcus faecium* and *Enterococcus durans*. Their presence also indicates faecal pollution. Generally they have longer survival times in marine medium than coliforms and *E. coli*. It should be noted that alternative indicators are still being explored. One of preferred alternative indicator is *Clostridium perfrigens* because it forms resistant endospores that survive for long periods in the environment [45].

The Boka Kotorska Bay, as a specific semi-closed ecosystem, is increasingly exposed to anthropogenic impact as a result of maritime transport development and intensive urbanization. In accordance with MED POL (Programme for the assessment and control of marine pollution in the Mediterranean), recommendations with the European Environment Agency and Barcelona Convention, sanitary control of seawater is performed regularly [65]. The monitoring programme includes quantitative assessment of total coliforms, faecal coliforms and intestinal enterococci. Most of pollution indicators are registered in the inner parts of Bay (Kotor and Risan), mainly in summer months, which is expected, taking into account the absence of wind, reduced seawater circulation as well as more organic waste caused by increase of population in the narrow coastal strip. In these parts of Bay, the highest nutrient values were detected as well as TRIX index, showing good trophic state [66–69]. In winter, number of total coliform increased as a result of heavy rainfall and inflow of freshwater through submerged springs. Due to high concentration of organic matter, numbers of bacteria in sediment samples were twice higher when compared to the number of bacteria in surrounding water [70]. The values of total coliforms and intestinal enterococci are presented in the area of Kotor (Orahovac, Dobrota, Sveti Stasije, Port of Kotor – Fig. 1) in August 2012 (Fig. 3). The results were converted to logarithm for easier overview.

This significant increase in survival times in sediment had at first been attributed to the absence of light and presence of organic matter, although sediment includes a large number of micro- and macro predators, and antibiotic producing microorganisms. Recent studies have shown that marine sediment contains osmolytes that enable bacterial cells to regulate turgor (intracellular pressure) and renew metabolism in marine conditions. Positive effect of sediment on microorganism survival compared to surrounding marine water is reflected also in reduced effects of solar radiation, higher content of nutrients that enhance bacterial growth [64].

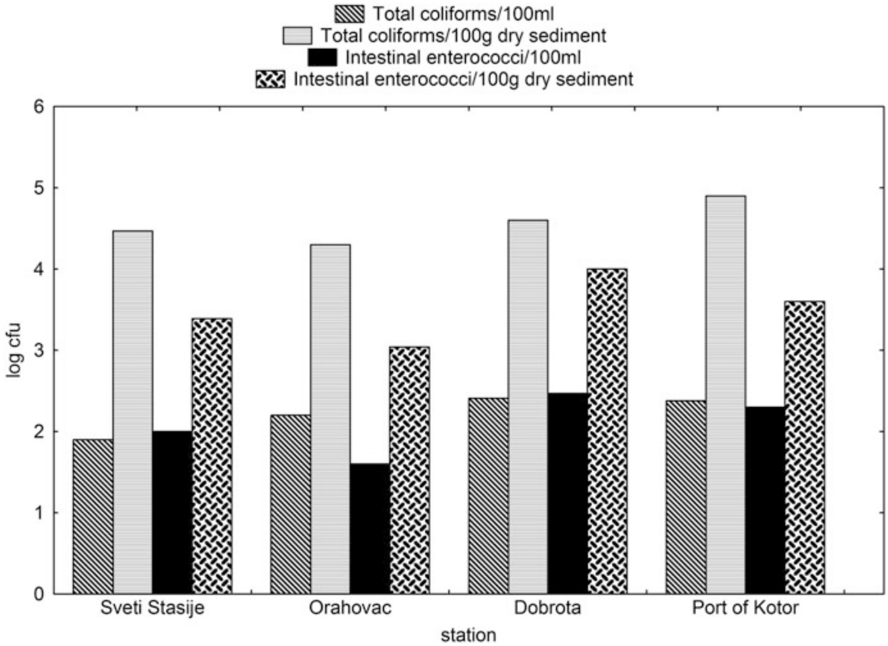

Fig. 3 Comparison of the number of total coliforms and intestinal enterococci in sediment and surrounding water in Kotor Bay

7 Conclusions

Based on average results of heterotrophic bacteria Boka Kotorska Bay represented oligotrophic area in 2009 and 2010. In the course of 2011 and 2012 Kotor and Risan Bay belonged to mesotrophic area, while Tivat, Herceg Novi and Mamula belonged to oligotrophic area. Analysis of seasonal distribution of LNA and HNA groups in the area of the Boka Kotorska Bay showed prevalence of the LNA bacteria during spring, summer and autumn, while prevalence of the HNA bacterial group was occurred only in winter.

Abundance of all bacterial groups decreased going from the inner part (Kotor and Risan Bay) to the outer part (Herceg Novi and Mamula). The highest abundance of *Eubacteria*, *Gammaproteobacteria* and *Alphaproteobacteria* was detected in Kotor while *Cytophaga*/*Flavobacteria* reached maximum values in Risan Bay. *Cytophaga*/*Flavobacteria* dominated in spring season, which is correlated with phytoplankton bloom and higher chlorophyll *a* concentration. γ-*Proteobacteria* had average higher population in February resulting from the increased inflow of nutrients through rainfall and rivulets. The lowest number of these bacteria was recorded in Mamula.

According to preliminary results *Proteobacteria* phylum (*Alphaproteobacteria, Gammaproteobacteria, Deltaproteobacteria* class), *Actinobacteria* phylum and

Firmicutes phylum dominated in surface sediment of Boka Kotorska Bay. *Bacterioidetes*, *Planctomyces* and *Verrucomicrobia* were present in a lesser number. There were no significant variations in qualitative composition of bacterial communities.

Taking into account of faecal indicators, Kotor Bay is under greater influence of contamination. Coliforms and intestinal enterococci showed higher concentrations in sediment compared with surrounding water.

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References

1. Sieburth JM, Smetacek V, Lenz J (1978) Pelagic ecosystem structure: heterotrophic compartments and their relationship to plankton size fractions. Limnol Oceanogr 23:1256–1263
2. Whitman WB, Coleman DC, Wiebe WJ (1998) Prokaryotes: the unseen majority. Proc Natl Acad Sci 95:6578–6583
3. Atlas RM (1984) Petroleum microbiology. MacMillan Pub. Co., New York
4. Lachmund C, Köcher B, Manz W et al (2003) Chemical and microbiological in situ characterization of benthic communities in sediments with different contamination levels. J Soil Sediment 3(3):188–196
5. Fuhrman JA, Hagström Â (2008) Bacterial and archaeal community structure and its patterns. In: Kirchman DL (ed) Microbial ecology of the oceans, 2nd edn. Wiley-Blackwell, New Jersey, pp 45–90
6. Davey H, Kell D (1996) Flow cytometry and cell sorting of heterogeneous microbial populations: the importance of single-cell analysis. Microbiol Rev 60:641–696
7. Collier JL, Campbell L (1999) Flow cytometry in molecular aquatic ecology. Hydrobiologia 401:33–53
8. Li WKW, Jellett JF, Dickie PM (1995) DNA distribution in planktonic bacteria stained with TOTO or TO-PRO. Limnol Oceanogr 40:1485–1495
9. Gasol JM, Zweifel UL, Peters F et al (1999) Significance of size and nucleic acid content heterogeneity as assessed by flow cytometry in natural planktonic bacteria. Appl Environ Microbiol 65:4475–4483
10. Pace N, Stahl D, Lane D et al (1985) Analyzing natural microbial populations by rRNA sequences. Am Soc Microbiol News 51:4–12
11. Amann RI, Ludwig W, Schleifer KH (1995) Phylogenetic identification and in situ detection of individual microbial cells without cultivation. Microbiol Rev 59(1):143–169
12. Pernthaler A, Pernthaler J, Amann R (2002) Fluorescence in situ hybridization and catalyzed reporter deposition for the identification of marine bacteria. Appl Environ Microbiol 68 (6):3094–3101
13. Azam F, Cho BC (1987) Bacterial utilization of organic matter in the sea. In: Ecology of microbial communities. Cambridge University Press, Cambridge, pp 261–281
14. Gasol JM, Del Giorgio PA, Duarte C (1997) Biomass distribution in marine planktonic communities. Limnol Oceanogr 42:1353–1363
15. Marie D, Partensky F, Jacquet S et al (1997) Enumeration and cell cycle analysis of natural populations of marine picoplankton by flow cytometry using the nucleic acid stain SYBR green I. Appl Environ Microbiol 63:186–193

16. Jochem FJ (2001) Morphology and DNA content of bacterioplankton in the northern Gulf of Mexico: analysis by epifluorescence microscopy and flow cytometry. Aquat Microb Ecol 25:179–194
17. Gasol JM, Del Giorgio PA (2000) Using flow cytometry for counting natural planktonic bacteria and understanding the structure of planktonic bacterial communities. Sci Mar 64:197–224
18. Zubkov MV, Fuchs BM, Burkill PH et al (2001) Comparison of cellular and biomass specific activities of dominant bacterioplankton groups in stratified waters of the Celtic Sea. Appl Environ Microbiol 67:5210–5218
19. Jochem FJ, Lavrentyev PJ, First MR (2004) Growth and grazing rates of bacteria groups with different apparent DNA content in the Gulf of Mexico. Mar Biol 145:1213–1225
20. Longnecker K, Sherr BF, Sherr EB (2005) Activity and phylogenetic diversity of bacterial cells with high and low nucleic acid content and electron transport system activity in an upwelling ecosystem. Appl Environ Microbiol 71:7737–7749
21. Button DK (1998) Nutrient uptake by microorganisms according to kinetic parameters from theory as related to cytoarchitecture. Microbiol Mol Biol Rev 62:636–645
22. Cotner JB, Biddanda BA (2002) Small players, large role: microbial influence on autoheterotrophic coupling and biogeochemical processes in aquatic ecosystem. Ecosystem 5:105–121
23. Šantić D, Krstulović N, Šolić M et al (2013) Dynamics of prokaryotic picoplankton community in the central and southern Adriatic Sea (Croatia). Helgol Mar Res 67:471–481
24. Šolić M, Krstulović N, Šestanović S (2001) The role of predation, substrate supply and temperature in controlling bacterial abundance: interaction between spatial and seasonal scale. Acta Adriat 42:35–48
25. Redžić A, Krstulović N, Šolić M et al (2015) Dynamics of prokaryotic community in Boka Kotorska Bay (South-eastern Adriatic Sea). Acta Adriat 56(2):157–170
26. Bellafiore D, Guarnierib A, Grillia F et al (2011) Study of the hydrodynamical processes in the Bokakotorska Bay with a finite element model. Dyn Atmos Oceans 52:298–321
27. Calvo-Díaz A, Morán XAG, Suárez LÁ (2008) Seasonality of picophytoplankton chlorophyll a and biomass in the central Cantabrian Sea, southern Bay of Biscay. J Mar Syst 72:271–281
28. Šantić D, Krstulović N (2012) Identification and characterisation of microbial populations using flow cytometry in the Adriatic Sea. In: Schmid I (ed) Flow cytometry – recent perspectives. InTech, Croatia, pp 29–42
29. Andrade L, Gonzalez AM, Rezende CE et al (2007) Distribution of HNA and LNA bacterial groups in the Southwest Atlantic Ocean. Braz J Microbiol 38:330–336
30. Morán XAG, Bode A, Suárez LÁ et al (2007) Assessing the relevance of nucleic acid content as an indicator of marine bacterial activity. Aquat Microb Ecol 46:141–152
31. Šolić M, Krstulović N, Vilibić I et al (2009) Variability in the bottom-up and top-down control of bacteria on trophic and temporal scale in the middle Adriatic Sea. Aquat Microb Ecol 58:15–19
32. Šantić D (2010) Distribution and activity of prokaryotic microorganisms in middle and southern Adriatic Sea. Dissertation, University of Zagreb (in Croatian)
33. Porter KG, Feig YS (1980) The use of DAPI for identifying and counting aquatic microflora. Limnol Oceanogr 25:943–948
34. Marković S (2014) Estimation number of bacterial communities in Boka Kotorska Bay by CARD FISH method and epifluorescence microscopy. Dissertation, University of Montenegro (in Montenegrin)
35. Marković S, Paliaga P, Kljaić Z et al (2013) Identification and quantification of microbial community by CARD FISH method in Boka Kotorska Bay. Stud Mar 26(1):83–98
36. Drakulović D, Vuksanović N, Joksimović D (2011) Dynamics of phytoplankton in Bokakotorska Bay. Stud Mar 25(1):1–20

37. Azam F, Smith DC (1991) Bacterial influence on the variability in the oceans biogeochemical state: a mechanistic view. In: Demers S (ed) Particles analyses in oceanography. Ecological science, vol 27. Springer, Berlin, pp 213–236
38. Jardillier L, Basset M, Domaizon I et al (2004) Bottom-up and top-down control of bacterial community composition in the euphotic zone of a reservoir. Aquat Microb Ecol 35:259–273
39. Glöckner FO, Fuchs BM, Amann R (1999) Bacterioplankton compositions of lakes and oceans: a first comparison based on fluorescence in situ hybridization. Appl Environ Microbiol 65(8):3721–2726
40. Šantić D, Krstulović N, Šolić M (2007) Comparison of flow cytometric an epifluorescent counting methods for marine heterotrophic bacteria. Acta Adriatic 48:107–114
41. Fuks DI, Ivančić I, Najdek M et al (2012) Changes in the planktonic community structure related to trophic conditions: the case study of the northern Adriatic Sea. J Mar Syst 96–97:95–102
42. Jørgensen NOG (1987) Free amino acid in lakes: concentrations and assimilation rates in relation to phytoplankton and bacteria production. Limnol Oceanogr 32:97–111
43. Keil RG, Kirchman DL (1991) Contribution energetics of a polluted stream. Limnol Oceanogr 12:27–33
44. Toolan T, Wehr JD, Findlay S (1991) Inorganic phosphorus stimulation of bacterioplankton production in a meso-eutrophic lake. Appl Environ Microbiol 57:2074–2078
45. Munn C (2011) Marine microbiology, ecology and applications. Garland Science, New York and London
46. Amann R, Krumholz L, Stahl A (1990) Fluorescent-oligonucleotide probing of whole cells for determinative, phylogenetic and environmental studies in microbiology. J Bacteriol 172 (2):762–770
47. Korlević M (2015) In-depth analysis of the Adriatic Sea bacterial diversity. Dissertation, University of Zagreb (in Croatian)
48. Manti A, Boi P, Semprucci F et al (2012) Picoplankton community composition by CARD FISH and flow cytometric techniques: a preliminary study in Central Adriatic Sea water. Int J Oceanogr doi:10.1155/2012/909718
49. Alonso-Sáez AL, Balaqué V, Sà EL et al (2007) Seasonality in bacterial diversity in north-west Mediterranean coastal waters: assessment through clone libraries, fingerprinting and FISH. FEMS Microbiol Ecol 60(1):98–112
50. Crump BC, Kling GW, Bahr M (2003) Bacterioplankton community shifts in an arctic lake correlate with seasonal changes in organic matter source. Appl Environ Microbiol 69:2253–2268
51. Worden AZ, Not F (2008) Ecology and diversity of picoeukaryotes. In: Kirchman DL (ed) Microbial ecology of the oceans, 2nd edn. Wiley-Blackwell, New Jersey, pp 234–295
52. Schattenhofer M, Fuchs BM, Amann R et al (2009) Latitudinal distribution of prokaryotic picoplankton populations in the Atlantic Ocean. Environ Microbiol 11(8):2078–2093
53. Mary I, Cummings DG, Zubkov MV et al (2006) Seasonal dynamics of bacterioplankton community structure at the coastal station in the western English channel. Aquat Microb Ecol 42:119–126
54. Lancelot C (1983) Factors affecting phytoplankton extracellular release in the Southern Bight of the North Sea. Mar Ecol Prog Ser 12:115–121
55. Fandino LB, Reimann L, Steward GF et al (2005) Population dynamics of *Cytophaga-Flavobacteria* during marine phytoplankton blooms analyzed by real-time quantitative PCR. Aquat Microb Ecol 40:251–257
56. Mardis ER (2008) Next-generation DNA methods. Ann Rev Genomics Hum Genet 9:387–402
57. Harayama S, Yuki K, Akihiro H (2004) Microbial communities in oil-contaminated seawater. Curr Opin Biotechnol 15(3):205–214
58. Wobus A, Bleul C, Maassen S et al (2003) Microbial diversity and functional characterization of sediments from reservoirs of different trophic state. FEMS Microbiol Ecol 46(3):331–347

59. De Flaun MF, Mayer LM (1983) Relationships between bacteria and grain surfaces in intertidal sediments. Limnol Oceanogr 28:873–881
60. Edlund A (2007) Microbial diversity in Baltic Sea sediments. Dissertation, Swedish University of Agricultural Sciences
61. Amer RA, Fattah YRA (2014) Hydrocarbonoclastic marine bacteria in Mediterranean Sea, El-Max, Egypt: isolation, identification and site characterization. Jökull J 64(4):223–249
62. Polymenakou PN, Bertilsson S, Tselepides A et al (2005) Bacterial community composition in different sediments from the Eastern Mediterranean Sea: a comparison of four 16S ribosomal DNA clone libraries. Microb Ecol 50(3):447–462
63. Giovanelli D (2013) Microbial life in extreme environments. Dissertation, University of Napoli
64. Krstulović N, Šolić M (2006) Microbiology of the sea. Institute of Oceanography and Fisheries, Split (in Croatian)
65. Kljajić Z, Marković S, Žmukić J et al (2012) Montenegrin coastal sea monitoring. In: Conference proceedings “Water 2012”, 41st annual conference of the Serbian Water Pollution Control Society, Divčibare, 5–7 June 2012 (in Serbian)
66. Stjepčević B (1983) Quantitative variation of coliforms and heterotrophic bacteria in Kotor and Risan Bay. Stud Mar 13–14(1):142–148 (in Serbian)
67. Stjepčević B, Ivanović A (2001) Some indicators of anthropogenic pollution of the sea water in Kotor and Risan Bays. Stud Mar 23(1):65–70
68. Huter A (2012) The ecological status of mussel farms (*Mytilus galloprovicialis*) in Kotor–Risan Bay during summer months of 2010 and 2011. In: Conference proceedings “Water 2012”, 41st annual conference of the Serbian Water Pollution Control Society, Divčibare, 5–7 June 2012 (in Serbian)
69. Marković S, Mitrić M, Martinović R et al (2015) Monitoring of seawater in the Bokakotorska Bay. In: Conference proceedings “Water 2015”, 44th annual conference of the Serbian Water Pollution Control Society, Kopaonik, 2–4 June 2015 (in Serbian)
70. Marković S, Kolarević S, Vuković-Gačić B et al (2012) Influence of waste water on seawater and sediment quality in the Bokakotorska Bay. In: Conference proceedings “Water 2012”, 41st annual conference of the Serbian Water Pollution Control Society, Divčibare, 5–7 June 2012 (in Serbian)

Phytoplankton Community and Trophic State in Boka Kotorska Bay

Dragana Drakulović, Branka Pestorić, Romina Kraus, Stijepo Ljubimir, and Slađana Krivokapić

Abstract Compiling the available data collected over many years of research of Boka Kotorska Bay showed variability in terms of dynamics and abundance of phytoplankton organisms. The Boka Kotorska Bay is a relatively large (87 km^2), semi-enclosed bay, located in the south-eastern part of the Adriatic Sea. In addition to human impact, significant inflow of freshwater from numerous karstic streams and submarine springs contributes to the unique ecological characteristics of the Bay, particularly in its inner part (the Kotor Bay). Based on the data presented for the Boka Kotorska Bay (the Kotor Bay) phytoplankton abundance reaches up to 10^7 cells/l. Diatoms are the phytoplankton group present throughout the year. In some researches conducted in the Boka Kotorska Bay diatoms abundance reaching up to 10^7 cells/l was recorded. Dominant species are typical of areas with higher eutrophication that prefer nutrient rich areas and are very good indicators of ecosystem conditions. Dinoflagellates are the second important group of microplankton, frequently found in the aquatorium of the Boka Kotorska Bay. Dinoflagellates are generally less represented than diatoms, both quantitatively and qualitatively.

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The maximal recorded phytoplankton values indicate changes that may lead to eutrophic conditions in the Bay; however, it can be concluded that the Bay is still moderately trophic. According to the two trophic indices TRIX and Fp ratio natural eutrophication is still dominant over anthropogenic eutrophication in Boka Kotorska Bay.

Keywords Coccolithophorids, Diatoms, Dinoflagellates, Phytoplankton assemblages, Silicoflagellates, South Adriatic, Trophic level

Contents

1 Introduction

Primary production encompasses the process of organic matter generation, which, in the marine ecosystem, takes place mainly through photosynthesis by phytoplankton, including macroalgae, although to a lesser extent. The organic matter generated is the first link in the food chain and hence supports the sea life in entirety. However, too low or too high concentrations of essential nutrients necessary for primary production (phosphorous and nitrogen, above all) cause imbalances in ecosystem that may result in either oligotrophication or eutrophication. Oligotrophication will result in reduced secondary production, i.e. an area poorer in marine flora and fauna. The other extreme, eutrophication, due to oversupply of nutritive substances, would cause far more significant distortions in the ecosystem. Excessive primary production will encourage secondary (excessive production of flora and fauna) and quite often even bacterial production (significant quantity of available organic matter enables intensive bacterial degradation activity), and sometimes also harmful algal blooms, with numerous harmful consequences for other marine organisms caused by excretion of toxic substances and, indirectly, to human population using various marine organisms in its diet.

Eutrophication, in most cases caused by inflow of nutritive substances from the land through rivers or runoff caused by precipitation, can be natural; however, it is becoming increasingly anthropogenic, enhanced by human activity and over the last few decades has become a significant problem along the coast, in channels and in bays [1–4]. The Mediterranean Sea, oligotrophic for the most part, is increasingly influenced by anthropogenic eutrophication in its coastal regions [5, 6]. Demographic development of Mediterranean countries, including the seasonal influx of tourists, estimated at 100 million per annum [7], and related economic activities (agriculture, industry) doubtlessly have either a direct or an indirect effect on the inflow of freshwaters from the shore into the lagoons and coastal ecosystems of the Mediterranean. The objective of the framework of the European Union Directive – Eutrophication in Europe's coastal waters [8] is to improve the ecological quality of coastal waters, since eutrophication has become a widespread issue in European coastal waters, the Mediterranean and the Black Sea included [9]. Therefore, reduction in nutrients, and hence the chlorophyll *a* concentration, is necessary in those zones. The problem of eutrophication in the Mediterranean was identified as early as in 1970s, and for that reason, it was the first region included in the EU programme (UNEP), where the Regional Sea Program, launched in 1974, grew into the Action Plan 1975 [10]. In 2003, UNEP [11] adopted the Mediterranean Action Plan on mandatory monitoring of eutrophication processes in the region.

The Boka Kotorska Bay is a relatively large (87 km^2), semi-enclosed bay, located in the south-eastern part of the Adriatic Sea. It is surrounded by high karstic mountains, with a population of approximately 50,000 inhabitants living along its coast. Intensive urbanization of the coastal zone, absence of a developmental strategy and lack of spatial planning, as well as disrespect of applicable building legislation resulted in destruction of the coastal zone and significant increase of nutrient load through marine outfalls. In addition to human impact, significant inflow of freshwater from numerous karstic streams and submarine springs contributes to the unique ecological characteristics of the Bay, particularly in its inner part (the Kotor Bay). Considering that this is one of the most interesting transition areas of the Adriatic Sea, in terms of its environment and strategic characteristics, it is necessary to intensify the researches on the influence of the hydrographical conditions on the biological communities [12, 13] (Fig. 1).

It is quite difficult to monitor changes in the marine environment due to the absence of historical data on marine biological communities [14]. There are numerous reference works explaining how limiting nutrients affect the phytoplankton growth and development in the Mediterranean [15, 16]. There are suggestions that productivity in south-east Mediterranean might be limited by phosphorus availability [17, 18]. Furthermore, phosphorus limitation was identified in coastal areas of the Adriatic Sea [19]. Identification of limiting nutrients is of essential importance for the selection of appropriate measures to control nutritive substances in order to mitigate the eutrophication effects.

In terms of availability of nutrients and increase in phytoplankton abundance, sea water can be assigned a specific trophic state. Oligotrophic zones are characterized by 'few nutrients and phytoplankton', 'nutrient enriched' waters are

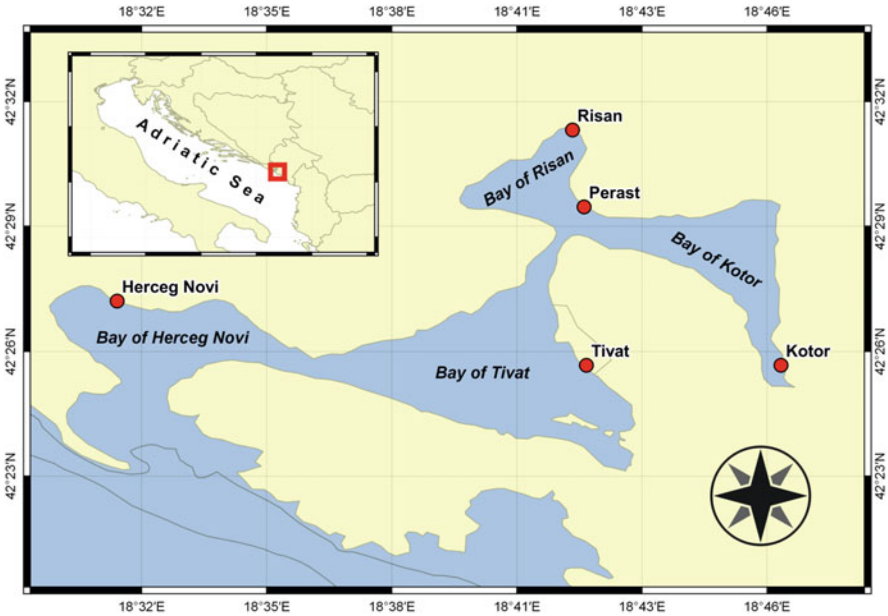


Fig. 1 Investigated area (Boka Kotorska Bay)

described as mesotrophic, while waters 'rich in nutrients and algal biomass' are characterized as eutrophic. Seasonal changes represent the main difficulty in setting the scale of nutrient and phytoplankton concentrations [20]. Certainly, reference works describe numerous attempts to determine the trophic state based on biological and physico-chemical indicators: EPA NCA Water Quality Index [21], TRIX [18], LWQI/TWQI [22], ASSETS [23], OSPAR COMPP [24], IFREMER [25] and STI [26]. Vollenweider et al. [18] introduced a complex trophic index (TRIX) for the Adriatic, based on biological (chlorophyll *a* concentration) and physico-chemical parameters (oxygen saturation, total nitrogen and phosphorus). Claustre [19] proposed Fp ratio, which takes into account only biological parameters such as photosynthetic pigments. The Fp is the ratio of phytoplankton mass (diatoms and dinoflagellates) to total diagnostic pigments biomass [19], and it indicates the ratio between the new production and the total production [27]. Both indices present complementary information, since Fp indicates the influence of environmental conditions on phytoplankton community composition, while TRIX indicates the general trophic state.

The part of the Adriatic that is most exposed to eutrophication processes is the north Adriatic, which is also its shallowest part (with average depth of approximately 30 m). However, some researches of the north Adriatic [28], based on chlorophyll *a* concentrations, show also presence of oligotrophic periods in the north Adriatic. The north Adriatic is under the greatest influence of freshwater and nutrients originating primarily from the river Po [29, 30]. The significance of the Po and other rivers in northern Italy for the north Adriatic is reflected in the fact that it is believed that these rivers account for around 20% of the total freshwater discharge in the Mediterranean [31]. The entire area of the north Adriatic had for long been considered one of the most productive areas in the Mediterranean [32]. However, researches conducted in the 1990s show that only the western part is eutrophic [33], which is confirmed also by higher phytoplankton abundances registered in that area [34]. However, the typical west-east gradient of phytoplankton abundance in the north Adriatic disappears under certain conditions and in such cases intensive phytoplankton blooms are widespread also in its eastern part [35–37]. These specific conditions, when nutrients are spread to the eastern coast, enabling intensive primary production in the entire area of the north Adriatic, are connected with the closing of the circulation encouraged by appearance of the Istrian Coastal Countercurrent, ICCC [38, 39]. Open circulation is quite common, when nutrients introduced with freshwater discharged from the Po river are retained in the western part due to currents that transport them southward along the western coast, while the eastern region is mainly oligotrophic, due to influence of the east Adriatic currents [40, 41] and oligotrophic karstic rivers [42]. These currents, flowing northward along the eastern coast bring high-salinity nutrient-poor waters from the Ionian and Levantine Seas into the eastern Adriatic [43]. Nevertheless, analysis of years' long set of data on chlorophyll *a* (1970–2007) from the entire Adriatic shows a global tendency of decrease in chl *a* concentration, particularly in the fourth research decade, which is most significant in the eutrophic part of the north Adriatic. These results are in concordance with the recorded reduction in phosphate and ammonia concentrations over the last 20 years [44] probably resulting from the ban on use of phosphorus in detergents in Italy introduced in mid-1980s and better wastewater treatment resulting in reduction in nutrients in the river Po [45]. It seems that reduced river discharge and more intensive inflow of Levantine waters contribute further to such situation [44].

Central Adriatic is deeper than the north Adriatic, with maximum depth of 270 m [46]. In this part of the Adriatic, eutrophication processes are less noticeable than in the north Adriatic, but eutrophication is present. Marasović [47], and Marasović et al. [48], found that due to intensive eutrophication, phytoplankton blooming is pronounced, along with toxic species growth. Oligotrophic character of the central Adriatic, reflected in nanoplankton dominance (mainly phytoflagellates), was pronounced during the research period, from May 1995 to February 1996. However, microplankton abundance recorded (up to 10^6 cells/l along Italian coast, since the research covered the transect from the Croatian to the Italian coast along the central Adriatic basin) also shows presence of eutrophication in the central Adriatic [46]. Vukadin and Stojanski [49] conducted a research on identification of the nutrient that is the limiting factor in the central Adriatic, taking into account that nitrogen and phosphorus are essential elements of the primary production. The result of their research is that phosphorus is the main limiting factor in the central Adriatic, limiting the phytoplankton growth.

South Adriatic is under the influence of two coastal currents flowing, one from the north along the western coast and the other from the south, along the eastern coast [50]. The current along the western (Italian) side originates from the northern part of the Adriatic, one of the most productive areas of the Mediterranean. The current along the eastern (Balkan) coast originates from the central Mediterranean (Ionian Sea), the most oligotrophic area worldwide [51]. As a result, the south Adriatic is extremely oligotrophic, except for the Italian coastal areas that are under the influence of the northern, nutrient-enriched waters [52]. South Adriatic has been characterized as highly oligotrophic. However, despite its general oligotrophic character, the coastal part is under an increasing anthropogenic impact and eutrophication [53]. Under INTERREG II Albania–Italy Project a research was conducted in the northern part of the Albanian coast (Drin Bay) and the northern part of the Italian coast (Manfredonia Bay), situated on the opposite sides of the south Adriatic. On both sides of the south Adriatic phytoplankton values were quite low (which is typical of oligotrophic areas); however, they were higher on the Italian coast as a result of effect of the current arriving from the north Adriatic, brining nutrient rich water [54]. Under the said project, exploration of the phytoplankton composition along the entire Albanian coast and oligotrophic character of the region under research was confirmed, which is the main cause of nanoplankton dominance, mainly of phytoflagellates [55]. Eutrophication signs (phytoplankton abundance of up to 10^6 cells/l, presence of species preferring nutrient rich areas) have become increasingly frequent also along the Montenegrin coast, the Boka Kotorska Bay in particular [56–65].

In this chapter we will present phytoplankton distribution and assess the trophic state using two trophic indices, TRIX and the Fp ratio in the Boka Kotorska Bay.

2 Phytoplankton Dynamics in the Boka Kotorska Bay

The first, mainly taxonomic investigation, of phytoplankton in the Boka Kotorska Bay was conducted in the period 1914–1928 [66]. Determination of influence of physico-chemical properties and determination of phytoplankton species in the Bay were conducted in autumn 1937 [67]. Exploration of the phytoplankton composition and ratio of phytoplankton groups in the Bay, done in spring 1967, revealed greater diatoms and coccolithophorids frequency [68]. In the period from July 1966 until June 1967, the share of phytoplankton group and phytoplankton composition was investigated, and greater frequency of diatoms was established in most of investigated locations [69]. During a 1-year research – 1973–1974 – phytoplankton abundance of up to 10^7 cells/l [70] was recorded. Intensive development of dinoflagellate species from the *Prorocentrum* genus was recorded during the research conducted in the Bay in summer 1975 [71]. Seasonal phytoplankton researches in the period 1980–1981 recorded a large share of diatoms in three seasons, except for summer, when their share was still the highest, but lower than in other three seasons [72]. During a 1-year research from December 1981 to December 1982, phytoplankton abundance and volume were investigated and phytoplankton abundance reached values of up to 10^6 cells/l [53, 73]. In the period 1981–1982, Viličić [74] studied the phytoplankton abundance and biomass and based on those parameters, the Bay fell under the category IV – eutrophic area. Exploration of bio-physiological state of the phytoplankton in the Kotor Bay was conducted using the fast fluorescence method, whereby high level of photosynthetic activity was determined even in low salinity waters (river mouths) [75]. Vukanić et al. [76] point to ecological characteristics of the Kotor Bay with particular emphasis on representative plankton species in this area. Analysis of influence of ecological factors in the period from 1983 to 1984 on plankton community in the phytoplankton blooming period revealed high number of specimens and lower species diversity [77]. An overview of the phytoplankton community in 1985, with particular emphasis on the diatom group in the period of summer stratification of the water column in the Kotor Bay, was given by Vuksanović et al. [78], as well as temporal distribution of phytoplankton in the Tivat Bay, with particular emphasis on phytoplankton size fractions [79]. In the period from January to June 1984 and in the period from July to December 1991, partial researches were conducted in the bay, covering quantitative and qualitative phytoplankton analysis [80]. The researches on phytoplankton communities conducted in the period 2000–2006 concerned the checks of the quality of waters for bathing and recreation were partial and focused mainly on determining the phytoplankton abundance and presence of dominant species.

Drakulović et al. [64] gave an overview of the composition and abundance of phytoplankton along the Montenegrin coast, during the partial research. The dynamics and the composition of the phytoplankton in the Boka Kotorska Bay were also studied by Drakulović et al. [65, 81–85]. Bosak et al. [86] contributed to the determination of phytoplankton composition as a trophic indicator in the Boka Kotorska Bay through seasonal researches of the phytoplankton community in the period 2008–2009. Contribution to determination of the trophic state of the Boka Kotorska Bay (the Kotor Bay) was given also by Krivokapić [87, 88] who explored the trophic state by TRIX index and Fp ratio, in the period from March 2008 to February 2009, and in the period from April 2008 to March 2009.

3 Phytoplankton

Based on the data presented for the Boka Kotorska Bay (the Kotor Bay) by Vuksanović [80] for the research period from January to June 1984 and from July to December 1991, phytoplankton abundance reached up to 10^7 cells/l. These values are in concordance with the results of the researches conducted in the period 2003–2004 [89]. Seasonal dynamics of the research conducted in the period from 2008 to 2009 [86] and 1-year research period from 2009 to 2010 [82] recorded values of up to 10^6 cells/l. The maximum phytoplankton values recorded indicate changes that may lead to eutrophic conditions in the Bay; however, it can be concluded that the Bay is still moderately trophic.

Phytoplankton researches in the Boka Kotorska Bay, in the period January–June 1984 and July–December 1991 [80], showed increased abundance in summer and spring periods. Phytoplankton distribution in the bay was explored in 2008–2009, and the highest phytoplankton abundance was recorded at the end of winter, and the lowest in spring [81]. In the period 2009–2010, researches showed higher abundance in summer [82]. Seasonal phytoplankton researches from April 2008 until March 2009 showed the highest phytoplankton abundance in spring, with the lowest abundance recorded in autumn [86].

During partial researches [80] conducted in 1984 and 1991, 225 taxa were recorded, while in researches conducted in 2008 and 2009 [81] 109 taxa were identified, and in the period from 2009 to 2010, 192 taxa [82].

3.1 Diatoms

Diatoms are the phytoplankton group present throughout the year in the Boka Kotorska Bay, accounting for the highest microplankton share.

The highest diatom abundance in the Boka Kotorska Bay (the Kotor Bay) recorded during the research in the period from July to December 1991 [80] ranged up to 10^6 cells/l, which corresponds with the diatoms abundance data recorded in 2008–2009 [86] and 2009–2010 [82]. Vuksanović [80] in the research conducted from January to June 1984 and Krivokapić [89] from 2003 to 2004 recorded diatoms abundance reaching up to 10^7 cells/l, with *Skeletonema costatum* as a dominant species, accounting for almost entire diatoms abundance. Researches conducted in 2008 and 2009 [81] recorded lower diatoms abundance (up to 10^5 cells/l) than results of researches of above mentioned authors, who recorded higher diatoms abundance in the Boka Kotorska Bay.

In some research periods in the Bay, diatoms were dominant, as well as in summer 2009, and in the period February to June 2010 [82]. Although they were not dominant in a number of research periods, they were always present. This is explained by their ability to adjust to different environmental conditions, since they are eurivalent organism group. Although adaptable to various conditions, they typically occur in the colder periods (late winter, early spring) probably due to the diatoms ability to adjust to quite turbulent environmental conditions [90]. Diatoms dominance was confirmed in numerous researches (Vuksanović [80], Krivokapić [89], Bosak et al. [86] and Drakulović et al. [85]).

When results from the Bay are compared to the Adriatic, diatom dominance in phytoplankton composition in summer and autumn was recorded also in the north Adriatic [91] with its highest abundance smaller than the highest abundance recorded in the Bay in summer [82]. In the central Adriatic [90] diatoms dominance was recorded in late winter – early spring, but, highest values did not differ from the highest abundance value recorded in the Bay [82]. In the Boka Kotorska Bay, Bosak et al. [86] note the highest diatom value of up to 10^6 cells/l in spring and winter. Similar diatoms abundance is recorded for the south Adriatic [92], with the highest values recorded in winter.

In his researches, Vuksanović [80] recorded as dominant the following diatom species: *Cerataulina pelagica*, *Chaetoceros affinis*, *Leptocylindrus danicus*, *Navicula* spp., *Proboscia alata, Pseudo-nitzschia delicatissima*, *P. seriata*, *Skeletonema costatum* and *Thalassionema nitzschioides*. Vuksanović [80] notes the *Skeletonema costatum* species, which reached abundance of up to 10^7 cells/l and *Leptocylindrus danicus* up to 10^6 cells/l. In the period 2003–2004, the dominant and most abundant diatom species was *Skeletonema costatum*, with 10^7 cells/l [89]. Dominance of diatoms *Skeletonema marinoi*, *Pseudo-nitzschia pseudodelicatissima* and *Thalassionema frauenfeldii* was recorded in researches conducted in 2008 and 2009. Dominance of *Skeletonema marinoi* species was noted in winter/spring increase of phytoplankton abundance [86]. Increased abundance of *Skeletonema marinoi* species was noted in winter in the northern Adriatic [34, 93]. In the north Adriatic [92], *Skeletonema costatum* species was dominant in winter. In south Adriatic [94], broader temporal distribution and lesser dependence on external factors were recorded for *Pseudo-nitzschia delicatissima* species than for *P. calliantha*. Increased abundance of *Pseudo-nitzschia pseudodelicatissima* was recorded in the Bay in summer period of up to 10^5 cells/l [86]. *Skeletonema marinoi* and *Pseudo-nitzschia pseudodelicatissima* species were recorded for the first time in Boka Kotorska Bay by Bosak et al. [86].

Of the total of 109 taxa recorded by Drakulović et al. [81], 48 taxa belong to diatoms, while Bosak et al. [86] identified 104 taxa of which 61 taxa belong to diatoms.

In the period 2009–2010, [82] 192 taxa were identified, of which 90 belong to diatoms (46.88%). Of all diatom genera, the most abundant were the following: *Chaetoceros* (8 species) and *Nitzschia* (6 species). Among dominant species with abundance above 10^3 cells/l present in more than 10% of samples, 35 species were identified during the research. Among diatoms, the dominant species were *Chaetoceros affinis* (13.16%), *Lioloma pacificum* (10.05%), *Lithodesmium undulatum* (16.51%), *Navicula* spp. (32.06%), *Pseudo-nitzschia* spp. (65.31%), *Thalassionema frauenfeldii* (11.48%), *T. nitzschioides* (95.69%) and *Thalassiosira* sp. (24.40%). The species from diatom group present almost throughout the research process was *Thalassionema nitzschioides* and this species was determined as dominant [65]. During the research period, the phytoplankton peak was recorded in July 2009, reaching up to 10^6 cells/l, comprising this diatom species.

When data from the research carried out in 2009–2010 [82] are compared with the data from the period 2008–2009 [86] for this same bay, the diatom dominance periods are identical. Bosak et al. [86] noted dominance of diatoms from *Pseudo-nitzschia* genus and *Thalassionema* in summer period, which is the same as recorded in the research conducted by Drakulović [82], the only difference being that in the research 2009–2010 [82] *Thalassionema nitzschioides* species was dominant, and during the researches in 2008 and 2009 [86] it was *Thalassionema frauenfeldii*. In the Velebit and Pag Channels – north Adriatic, dominance of *Thalassionema nitzschioides* species was recorded [95]. Dominant species in researches are typical of areas with higher eutrophication that prefer nutrient rich areas and are very good indicators of ecosystem conditions [96]. In the northern

Table 1 Diatoms species recorded in the Boka Kotorska Bay

Diatoms	
Achnanthes brevipes Agardh	Vuksanović [80]; Drakulović [82]
A. longipes Agardh	Vuksanović [80]; Drakulović [82]
Achnanthes sp.	Drakulović [82]; Bosak et al. [86]
Amphiprora gigantea var. sulcata (O'Meara) Cleve	Drakulović [82]
Amphiprora sp.	Drakulović [82]
Amphora grevilleana Gregory	Drakulović et al. [81]
A. laevis Gregory	Vuksanović [80]
A. ostrearia Brébisson	Vuksanović [80]; Drakulović [82]
Amphora sp.	Drakulović [82]
Asterionellopsis glacialis (Castracane) Round	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
Asterolampra grevillei (Wallich) Grev	Vuksanović [80]; Drakulović [82]
A.marylandica Ehrenberg	Vuksanović [80]; Drakulović [82]
Asteromphalus flabellatus (Brébisson) Grev.	Vuksanović [80]; Drakulović [82]
Aulacoseira distans (Ehrenberg) Simonsen	Vuksanović [80]
Bacillaria paxillifera (Müller) Marsson	Drakulović [82]
Bacillaria sp.	Bosak et al. [86]
Bacteriastrum biconicum Pavillard	Vuksanović [80]
B. delicatulum Cleve	Vuksanović [80]
B. elegans Pavillard	Vuksanović [80]
B. elongatum Cleve	Vuksanović [80]
B. hyalinum Lauder	Vuksanović [80]; Drakulović et al. [81]; Drakulović [82]; Bosak et al. [86]
B. mediterraneum Pavillard	Vuksanović [80]
Bacteriastrum sp.	Drakulović [82]; Bosak et al. [86]
Chaetoceros affinis Lauder	Vuksanović [80]; Drakulović et al. [81]; Drakulović [82]; Bosak et al. [86]
C. anastomosans Grunow	Vuksanović [80]
C. atlanticus var. neapolitanus (Schroeder) Hustedt	Vuksanović [80]
C. brevis Schütt	Vuksanović [80]; Drakulović et al. [81]
C. compressus Lauder	Vuksanović [80]; Drakulović et al. [81]; Drakulović [82]
C. contortus Schütt	Bosak et al. [86]
C. costatus Pavillard	Vuksanović [80]; Bosak et al. [86]
C. convolutus Castracane	Vuksanović [80]
C. curvisetus Cleve	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
C. dadayi Pavillard	Vuksanović [80]
C. danicus Cleve	Vuksanović [80]; Bosak et al. [86]
C. decipiens Cleve	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
C. delicatulus Ostenfeld	Vuksanović [80]

(continued)

Table 1 (continued)

Diatoms	
C. densus	Bosak et al. [86]
C. didymus Ehrenberg	Vuksanović [80]
C. diversus Cleve	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
C. laciniosus Schutt	Vuksanović [80]
C. lauderi Ralfs	Vuksanović [80]
C. peruvianus Brightwell	Vuksanović [80]; Bosak et al. [86]
C. protuberans Lauder	Drakulović et al. [81]
C. rostratus Ralfs	Vuksanović [80]
Chaetoceros spp.	Drakulović et al. [81], Drakulović [82]; Bosak et al. [86]
C. simplex Ostenfeld	Vuksanović [80]; Bosak et al. [86]
C. subsecundus (Grunow ex Van Heurck.) Hustedt	Vuksanović [80]
C. tenuissimus Meunier	Drakulović et al. [81]; Bosak et al. [86]
C. tetrastichon Cleve	Vuksanović [80]
C. throndsenii (Marino, Montresor and Zingone) Marino, Montresor and Zingone	Bosak et al. [86]
C. tortissimus Gran	Vuksanović [80]; Drakulović [82]
C. wighamii Brightwell	Vuksanović [80], Bosak et al. [86]
C. willei Gran	Vuksanović [80]
C. vixvisibilis Schiller	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81];
Cerataulina pelagica (Cleve) Hendey	Vuksanović [80]; Drakulović [82]; Bosak et al. [86]
Ceratoneis closterium Ehrenberg	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81] Bosak et al. [86]
Cocconeis scutellum Ehrenberg	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
Cocconeis sp.	Drakulović [82]
Coscinodiscus janischii Schmidt	Drakulović [82]
C. perforatus Ehrenberg	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81],
Coscinodiscus spp.	Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
C. radiatus Ehrenberg	Vuksanović [80]
C. thorii Pavillard	Drakulović [82]
Cyclotella striata (Kützing) Grunow	Drakulović [82]; Drakulović et al. [81]
Cyclotella sp.	Vuksanović [80]; Bosak et al. [86]
Dactyliosolen blavyanus (Peragallo) Hasle	Vuksanović [80]; Drakulović [82]
D. fragilissimus (Bergon) Hasle	Vuksanović [80]; Bosak et al. [86]
Diploneis crabro (Ehrenberg) Ehrenberg	Drakulović [82]
D. bombus (Ehrenberg) Ehrenberg	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]

(continued)

Table 1 (continued)

Diatoms	
Diploneis sp.	Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
Ditylum brightwelli (West) Grunow	Vuksanović [80]; Drakulović [82]
Detonula pumila (Castracane) Gran	Vuksanović [80]; Drakulović et al. [81]; Bosak et al. [86]
Eucampia cornuta (Cleve) Grunow	Vuksanović [80]; Drakulović et al. [81]; Bosak et al. [86]
E. zoodiacus Ehrenberg	Vuksanović [80]
Grammatophora angulosa Ehrenberg	Vuksanović [80]
G.oceanica Ehrenberg	Drakulović [82]
Grammatophora sp.	Drakulović [82]
G. undulata Ehrenberg	Vuksanović [80]
Guinardia flaccida (Castracane) Peragallo	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
G. striata (Stolterfoth) Hasle	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
G. delicatula (Cleve) Hasle	Vuksanović [80]
Gyrosigma balticum (Ehrenberg) Rabenhorst	Drakulović [82]
Halamphora costata (W. Smith) Levkov	Vuksanović [80]
Haslea wawrikae (Hustedt) Simonsen	Bosak et al. [86]
Hemiaulus hauckii Grunow ex Van Heureck	Vuksanović [80]; Drakulović [82]; Bosak et al. [86]
H. sinensis Greville	Vuksanović [80]; Drakulović [82]
Fragilaria hyalina (Kützing) Grunow ex Van Heureck	Vuksanović [80]
F. striatula Lyngbye	Vuksanović [80]
Lampriscus kittonii Schmidt	Drakulović [82]
Lauderia anulata Cleve	Vuksanović [80]
Leptocylindrus adriaticus Schroder	Vuksanović [80]
L. danicus Cleve	Vuksanović [80]; Drakulović [82], Drakulović et al. [81]; Bosak et al. [86]
L. mediterraneus (Peragallo) Hasle	Vuksanović [80]; Drakulović [82]; Bosak et al. [86]
L.minimus Gran	Vuksanović [80]; Drakulović [82]; Bosak et al. [86]
Licmophora argenescens Agardh	Drakulović [82]
L. communis (Heiberg) Grunow	Vuksanović [80]
L. dalmatica (Kützing) Grunow	Vuksanović [80]
L. ehrenbergii (Kützing) Grunow	Vuksanović [80]
L. flabellata (Greville) Agardh	Drakulović [82]
L. grandis (Kützing) Grunow	Vuksanović [80]
L. paradoxa (Lyngbye) Agardh	Vuksanović [80]; Drakulović [82]
L. reichardtii Grunow	Drakulović [82]

(continued)

Table 1 (continued)

Diatoms	
Licmophora spp.	Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
Lioloma pacificum (Cupp) Hasle	Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
Lithodesmium undulatum Ehrenberg	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
M. dubia Kützing	Vuksanović [80]; Drakulović [82]
M. lineata (Dillwyn) Agardh	Vuksanović [80]; Drakulović [82]
M. moniliformis (Müller) Agardh	Vuksanović [80]; Drakulović et al. [81]; Drakulović [82]
M. nummuloides Agardh	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
Melosira spp.	Drakulović [82]; Drakulović et al. [81]
Navicula spp.	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
Neocalyptrella robusta (Norman ex Ralfs) Hernández Becerril et Meave	Vuksanović [80]; Drakulović [82]
Nitzschia incerta (Grunow) Peragallo	Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
N. sicula (Castracane) Hustedt	Drakulović [82]
N. sigma (Kützing) W. Smith	Vuksanović [80]; Drakulović [82]
N. habirshawii Febiger ex Smith	Vuksanović [80]; Drakulović [82]
N. longissima (Brébisson) Ralfs	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
Nitzschia spp.	Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
Odontella aurita (Lyngbye) Agardh	Drakulović [82]
Paralia sulcata (Ehrenberg) Cleve	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81],
Petrodictyon gemma (Ehrenberg) Mann	Drakulović [82]
Petrodictyon sp.	Drakulović [82]
Plagiogramma interruptum (Gregory) Ralfs	Vuksanović [80]
Pleurosigma angulatum (Quekett) W. Smith	Vuksanović [80]; Drakulović [82]
P. formosum W. Smith	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
P. elongatum W. Smith	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
Pleurosigma spp.	Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
Proboscia alata (Brightwell) Sundström	Drakulović et al. [81]; Vuksanović [80]; Drakulović [82]; Bosak et al. [86]
P. indica (Peragallo) Hernández-Becerril	Vuksanović [80]; Drakulović [82]
Psammodictyon panduriforme (Gregory) Mann	Vuksanović [80]; Bosak et al. [86]
Pseudo-nitzschia delicatissima (Cleve) Heiden	Vuksanović [80]
P. seriata (Cleve) Peragallo	Vuksanović [80]; Bosak et al. [86]

(continued)

Table 1 (continued)

Diatoms	
Pseudo-nitzschia pseudodelicatissima (Hasle) Hasle	Bosak et al. [86]
Pseudo-nitzschia spp.	Drakulović [82]; Drakulović et al. [81];
Rhabdonema adriaticum Kützing	Vuksanović [80]
Rhizosolenia calcar-avis Schultze	Vuksanović [80]; Drakulović [82]; Bosak et al. [86]
R. decipiens Sundström	Bosak et al. [86]
R. imbricata Brightwell	Vuksanović [80]; Drakulović et al. [81]; Bosak et al. [86]
R. setigera Brightwell	Vuksanović [80]
Rhizosolenia sp.	Bosak et al. [86]
Skeletonema costatum (Greville) Cleve	Vuksanović [80]
S. marinoi Sarno and Zingone	Bosak et al. [86]
Skeletonema spp.	Drakulović [82]; Drakulović et al. [81]
Stellarima stellaris (Roper) Hasle et Sims	Drakulović [82]
Striatella unipunctata (Lyngbye) Agardh	Drakulović [82]; Bosak et al. [86]
Surirella sp.	Drakulović [82]
Synedra crystalina (Agardh) Kützing	Vuksanović [80]; Drakulović [82]
S. fulgens (Greville) W. Smith	Drakulović [82]
Synedra spp.	Drakulović [82]; Drakulović et al. [81]
Tabularia fasciculata (Agardh) Williams and Round	Vuksanović [80]
T. gailloni (Bory de Saint Vincent) Bukhtiyarova	Vuksanović [80]
Thalassionema frauenfeldii (Grunow) Tempère and Peragallo	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
T. nitzschioides (Grunow) Mereschkowsky	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
Thalassiotrix mediterranea Pavillard	Vuksanović [80]
Thalassiosira decipiens (Grunow ex Van Heureck) Jörgensen	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81],
T. eccentrica (Ehrenberg) Cleve	Vuksanović [80]; Drakulović [82]
T. leptopus (Grunow ex Van Heurck) Hasle and Fryxell	Vuksanović [80]
Thalassiosira rotula Meunier	Bosak et al. [86]
Thalassiosira sp.	Drakulović [82]; Bosak et al. [86]
Trieres mobiliensis (Bailey) Ashworth and Theriot	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81];
Trieres regia (Schultze) Ashworth and Theriot	Vuksanović [80]

[34] and central Adriatic [46] high abundance of diatoms from the *Pseudo-nitzschia* genus was noted in spring and autumn periods. Burić et al. [97] reported blooming of potentially toxic species – diatom *Pseudo-nitzschia* spp. – in Zrmanja estuary,

central Adriatic. During a research in the Boka Kotorska Bay, Campanelli et al. [13] also found this species as dominant in summer, but its abundance was lower than previously recorded [82, 86]. Presence of this species as a dominant one indicates high eutrophication level [98] (Table 1).

3.2 Dinoflagellates

Dinoflagellates are the second group of organisms belonging to microplankton group, frequently found in the aquatorium of the Boka Kotorska Bay. Dinoflagellates are generally less represented than diatoms, both quantitatively and qualitatively.

During his researches conducted from June to December 1981 and from July to December 1994, Vuksanović [80] noted lower dinoflagellates values of up to 10^4 cells/l, while in researches conducted in the period 2003–2004 [89] and 2008 and 2009 [81] higher values were recorded, reaching up to 10^6 cells/l. Drakulović [82], during the research conducted in the period 2009–2010, noted the highest dinoflagellates abundance in September 2009 (up to 10^5 cells/l), and the same abundance was also recorded during the research conducted in 2008–2009 [86]. The highest dinoflagellates abundance recorded in September (summer period) is explained by reduction in nutrient concentration and reduced nutrient supply favours dinoflagellates development in summer [90, 99]. In the researches conducted, the highest values of dinoflagellates in the Boka Kotorska Bay were recorded during the warm season [86, 89].

In the north Adriatic, the dinoflagellates peak occurred in June–July, following the diatoms development [99]. The highest dinoflagellates values for the Bay differ from the data for the Stella Maris (northern Adriatic) [91], where the highest dinoflagellates abundance was noted in spring, with values not exceeding 10^4 cells/l. In the central Adriatic, higher dinoflagellates abundance was noted in summer [90].

Drakulović et al. [81] recorded somewhat higher share of dinoflagellates compared to diatoms, while in other researches, diatoms dominated (Vuksanović [80], Krivokapić [89] and Bosak et al. [86]).

During the research conducted from January to June 1984 and from July to December 1991 [80], 103 dinoflagellates taxa were recorded. The following dinoflagellate species were recorded as dominant: *Amphidinium* spp., *Gymnodinium* spp., *Gyrodinium fusiforme, Gyrodinium* spp., *Oxytoxum scolopax, Protoperidinium diabolus, Protoperidinium* spp., *Prorocentrum scutellum* and *Torodinium robustum*. Species *Gymnodinium* spp., *Prorocentrum micans* and *P. scutellum* had higher abundance of up to 10^4 cells/l [80]. During the research conducted in 2003–2004, Krivokapić [89] notes *Gymnodinium* spp. as a dominant and numerous dinoflagellate species, with abundance reaching up to 10^6 cells/l, while abundance of species *Prorocentrum micans* and *P. cordatum* were up to 10^5 cells/l – all species in warmer period. Drakulović [82] recorded 83 dinoflagellates

Table 2 Dinoflagellates species recorded in the Boka Kotorska Bay

Dinoflagellates	
Amphidinium spp.	Vuksanović [80]; Drakulović [82], Drakulović et al. [81]
Amphidinium acutissimum Schiller	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
A.acutum Lohmann	Vuksanović [80]
A. lanceolatum Schröder	Vuksanović [80]; Drakulović [82]
A. flagellans Schiller	Vuksanović [80]
A. operculatum Claparede and Lachmann	Vuksanović [80]
A. stigmatum Schiller	Vuksanović [80]
Amphidinium spp.	Vuksanović [80]
Corythodinium constrictum (Stein) Taylor	Vuksanović [80]; Drakulović [82]
C. tesselatum (Stein) Loeblich Jr. and Loeblich III	Vuksanović [80]; Drakulović [82]
Cochlodinium pulchellum Lebour	Vuksanović [80]
Ceratocorys armata (Schütt) Kofoid	Vuksanović [80]
Ceratoperidinium falcatum (Kofid and Swezy) de Salas	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
Ceratium inflatum (Kofoid) Jørgensen	Vuksanović [80]
C. fusus var. seta (Ehrenberg) Sournia	Vuksanović [80]
C. longirostrum Gourret	Vuksanović [80]
C. setaceum Jørgensen	Vuksanović [80]; Drakulović et al. [81]
C. teres Kofoid	Vuksanović [80]
Dinophysis acuminata Claparede et Lachmann	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
D. acuta Ehrenberg	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
D. caudata Seville-Kent	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
D. dens Pavillard	Vuksanović [80];
D. fortii Pavillard	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
D. hastata Stein	Vuksanović [80]; Drakulović [82]
D.ovum (Schütt) Abé	Vuksanović [80];
D. parvula (Schütt) Balech	Vuksanović [80];
D. sacculus Stein	Vuksanović [80]; Bosak et al. [86]
D. schroederi Pavillard	Vuksanović [80];
D. sphaerica Stein	Vuksanović [80]; Drakulović [82]
Dinophysis sp.	Drakulović [82]
D. tripos Gourret	Vuksanović [80]
Diplopsalis lenticula Bergh	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
Diplopsalis sp.	Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
Ebria tripartita (Schumann) Lemmermann	Vuksanović [80]; Drakulović [82]

(continued)

Table 2 (continued)

Dinoflagellates	
Glenodinium obliquum Pouchet	Vuksanović [80]
Glenodinium spp.	Drakulović et al. [81]
Gonyaulax digitale (Pouchet) Kofoid	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
G. polygramma Stein	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
G. hyalina Ostenfeld et Schmidt	Drakulović [82]
G. monacantha Pavillard	Vuksanović [80]
G. spinifera (Claparede et Lachmann) Diesing	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
Gonyaulax spp.	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81] Bosak et al. [86]
G. verior Sournia	Drakulović [82]; Drakulović et al. [81]
Goniodoma sphaericum (Murray and Whitting) Dodge	Vuksanović [80]
Gymnodinium cucumis Schütt	Drakulović [82]
Gymnodinium spp.	Vuksanović [80]; Drakulović [82]; Drakulović et al.; [81]; Bosak et al. [86]
Gyrodinium fusiforme Kofoid et Swezy	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
Gyrodinium spp.	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
Hermesinum adriaticum Zacharias	Vuksanović [80]
Heterodinium milneri (Murray and Whitting) Kofoid	Drakulović [82]
Lingulodinium polyedra (Stein) Dodge	Vuksanović [80]
Mesoporos perforatus (Gran) Lillick	Bosak et al. [86]
N. hexacantum (Gourret) Gomez, Moreira and Lopez-Garcia	Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
Noctiluca scintillans (Macartney) Kofoid et Swezy	Vuksanović [80]; Drakulović [82]
Ornithocercus heteroporus Kofoid	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
Oxytoxum adriaticum Schiller	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
O. caudatum Schiller	Vuksanović [80]; Drakulović [82]
O. crassum Schiller	Vuksanović [80]
O. gladiolus Stein	Vuksanović [80]
O. laticeps Schiller	Vuksanović [80]; Drakulović [82]
O. mediterraneum Schiller	Vuksanović [80]
O. sceptrum (Stein) Schröder	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
O. sphaeroideum Stein	Drakulović [82]
O. scolopax Stein	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]

(continued)

Table 2 (continued)

Dinoflagellates	
Oxytoxum sp.	Drakulović [82]; Bosak et al. [86]
O. variabile Schiller	Vuksanović [80]; Drakulović [82]
Phalacroma ovum Schütt	Vuksanović [80]
Phalacroma rotundatum (Claparede et Lachmann) Kofoid et Michener	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
Podolampas elegans Schütt	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
Preperidinium meunieri (Pavillard) Elbrächter	Vuksanović [80]
Prororcentrum cordatum (Ostenfeld) Dodge	Bosak et al. [86] Drakulović [82]; Drakulović et al. [81]
P. dactylus (Stein) Dodge	Vuksanović [80]
P. gracile Schütt	Vuksanović [80]; Bosak et al. [86]
P. lima (Ehrenberg) Stein	Vuksanović [80]
P. micans Ehrenberg	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
P. scutellum Schröder	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
Prorocentrum sp.	Drakulović [82]
P. triestinum Schiller	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
Prosoaulax lacustris (Stein) Calado and Moestrup	Vuksanović [80]
Protoperidinium breve Paulsen	Vuksanović [80]
P. brochi (Kofoid et Swezy) Balech	Vuksanović [80]
P. crassipes (Kofoid) Balech	Vuksanović [80]; Drakulović [82] Drakulović et al. [81]
P. conicum (Gran) Balech	Vuksanović [80]; Drakulović [82]
P. depressum (Bailey) Balech	Vuksanović [80]; Drakulović [82]
P. diabolum (Cleve) Balech	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
P.divergens (Ehrenberg) Balech	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
P. elegans (Cleve) Balech	Vuksanović [80]
P. globulum (Stein) Balech	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
P. leonis (Pavillard) Balech	Vuksanović [80]; Drakulović [82]
P. oceanicum (Vanhöffen) Balech	Vuksanović [80]; Drakulović [82]
P. pallidum (Ostenfeld) Balech	Drakulović [82]
P. paulsenii (Pavillard) Balech	Vuksanović [80]; Drakulović [82]
P. pedunculatum (Schütt) Balech	Vuksanović [80]
P. pellucidum Bergh	Vuksanović [80], Drakulović et al. [81]
P. pentagonum (Gran) Balech	Vuksanović [80]
Protoperidinium spp.	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]

(continued)

Table 2 (continued)

Dinoflagellates	
P. sphaericum (Murray and Whitting) Balech	Vuksanović [80]
P. steinii (Jørgensen) Balech	Drakulović [82]
P. trochoideum (Stein) Lemmermann	Vuksanović [80]
P. tuba (Schiller) Balech	Drakulović [82]; Drakulović et al. [81]
Pyrocystis elegans (Pavillard) Matzenauer	Vuksanović [80]; Drakulović [82]
P. lunula (Schütt) Schütt	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
Pyrocystis sp.	Drakulović et al. [81]
Pyrophacus horologium (Stein)	Drakulović et al. [81]
P.steinii (Schiller) Wall et Dale	Drakulović [82]
Scrippsiella sp.	Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
Triadinum polyedricum (Pouchet) Jørgensen	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
Torodinium robustum Kofoid et Swezy	Vuksanović [80]; Drakulović [82]
Torodinium sp.	Drakulović [82]
Tryblionella compressa (Bailey) Poulin	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
Tripos buceros (Zacharias) Gómez	Vuksanović [80]
T. candelabrus (Ehrenberg) Gómez	Vuksanović [80]; Drakulović [82]
T. carriensis (Gourret) Gómez	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
T. contortus (Gourret) Gómez	Drakulović [82]; Drakulović et al. [81]
T. declinatus (Karsten) Gómez	Vuksanović [80]
T. denticulatus (Jörgenen) Gómez	Vuksanović [80]
T. extensus (Gourret) Gómez	Vuksanović [80]
*T. furca (*Ehrenberg) Gómez	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
T. fusus (Ehrenberg) Gómez	Drakulović [82] Drakulović et al. [81]; Bosak et al. [86]
*T. gravidus (*Gourret) Gómez	Drakulović [82]
T. giberrus (Gourret) Gómez	Drakulović [82]
T. horridus (Cleve) Gómez	Drakulović [82]; Drakulović et al. [81]
T. kofoidii (Jörgenen) Gómez	Vuksanović [80]; Drakulović [82]
T. lineatus (Ehrenberg) Gómez	Vuksanović [80]; Drakulović [82]
T. macroceros (Ehrenberg) Gómez	Vuksanović [80]; Drakulović [82]
T. massiliensis (Gourret) Gómez	Vuksanović [80]; Drakulović [82]; Bosak et al. [86]
T. mollis (Kofoid) Gómez	Vuksanović [80]
T. muelleri Bory de Saint-Vincent	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
T. pentagonus (Gourret) Gómez	Vuksanović [80]; Drakulović [82] Drakulović et al. [81]; Bosak et al. [86]
T. pulchellus (Schröder) Gómez	Vuksanović [80]

(continued)

Table 2 (continued)

Dinoflagellates	
T. symmetricus (Pavillard) Gómez	Vuksanović [80]
Tripos spp.	Drakulović [82]; Bosak et al. [86]
T. trichoceros (Ehrenberg) Gómez	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]

taxa (43.23%). Among dinoflagellates, the most abundant genera were the following: *Tripos* (16 species), *Protoperidinium* (13 species), *Dinophysis* (7 species), *Oxytoxum* (8 species), *Gonyaulax* (6 species) and *Prorocentrum* (5 species). Among dinoflagellates, dominant were the following species: *Dinophysis fortii* (22.97%), *Diplopsalis lenticula* (16.51%), *Gonyaulax* spp. (30.38%), *Gymnodinium* spp. (69.38%), *Gyrodinium fusiforme* (22.97%), *Oxytoxum sceptrum* (11.00%), *Prorocentrum micans* (62.92%), *P. cordatum* (16.03%), *Protoperidinium crassipes* (17.22%), *P. diabolum* (13.88%), *P. globulum* (11.48%), *Protoperidinium* spp. (24.64%), *Scrippsiella* sp. (20.10%), *Tripos furca* (16.03%), *T. fusus* (11.96%), *T. horridus* (15.55%), *T. muelleri* (15.79%) and *Tryblionella compressa* (12.92%). In the period 2008–2009 [81], 51 dinoflagellates taxa were recorded, while in seasonal research conducted in the period 2008–2009 [86], 24 taxa were noted. Drakulović et al. [81] state the highest abundance of *Prorocentrum micans* dinoflagellate, accounting for the largest share of the peak values in the summer period. Bosak et al. [86] recorded dominance of dinoflagellates *Prorocentrum micans* and *P. cordatum* in summer. In the northern and central Adriatic, *Prorocentrum cordatum* species was noted as frequently occurring [34, 100] (Table 2).

3.3 Coccolithophorids

Coccolithophorids are a phytoplankton group that is generally less represented in the Boka Kotorska Bay than diatoms and dinoflagellates.

In the Bay, Vuksanović [80] notes coccolithophorids abundance of up to 10^4 cells/l, like Bosak et al. [86] who also note the highest coccolithophorids abundance of 10^4 cells/l, mainly in winter. The highest coccolithophorids abundance recorded by Drakulović [82] was in September 2009, reaching up to 10^5 cells/l.

During the research conducted in the period January–June 1984, the dominant species was *Calyptrosphaaera oblonga*, while in the period from July to December 1991, species *Helicosphaera wallichii* and *Rhabdosphaera tignifer* were recorded [80]. In the research period from 2009 to 2010, the total of 14 coccolithophorids taxa (7.29%) were recorded [82]. Among coccolithophorids, the following species were recorded as dominant: *Calciosolenia brasiliensis* (15.31%), *Calyptrosphaera oblonga* (28.23%), *Helicosphaera walichii* (28.23%) and *Syracosphaera pulchra*

(45.65%). During the research, Drakulović et al. [81] recorded 8 coccolithophorids taxa, while Bosak et al. [86] noted 10 taxa among which *Ophiaster* spp. occurred frequently.

In the lagoon of Stella Maris, north Adriatic [91], higher coccolithophorids abundance of up to 10^5 cells/l occurred in March, with June and August values reaching up to 10^4 cells/l. In the Bay of Trieste, increase in coccolithophorids abundance was recorded in January [101]. In Pag and Velebit channels – north-eastern Adriatic – higher coccolithophorids abundances were recorded in oligotrophic locations than in eutrophic [95]. Bernardi-Aubry et al. [99] noted the highest coccolithophorids abundance in winter, in deeper layers. They linked their distribution with higher salinity and cold waters, which was proved by positive correlation with salinity and negative correlation with temperature. The highest coccolithophorids value recorded in the north Adriatic was similar to that in the Bay, which reached up to 10^5 cells/l [34], while in the central Adriatic abundance (10^6 cells/l) was higher [90] and was recorded in autumn. The similar situation was noted in the central Adriatic [46] – the highest coccolithophorids abundance as in spring, with lower values in autumn. Higher autumn coccolithophorids concentrations in the central Adriatic, which is under the influence of waters from the Ionian Sea, might be the result of a more intensive inflow of saltier water from the south Adriatic [46, 102]. Svensen et al. [100] noted high coccolithophorids abundance in the Krka estuary – central Adriatic – which is the result of influence from the Port of Šibenik that contributes to the increase of nutrient supply. Generally, coccolithophorids are more abundant in the south Adriatic, in winter [102] (Table 3).

3.4 Silicoflagellates

Silicoflagellates are a phytoplankton group that is not highly represented in the Boka Kotorska Bay either quantitatively or qualitatively. Vuksanović [80] recorded silicoflagellates abundance of up to 10^4 cells/l. Drakulović [82] notes that in certain periods, mainly warmer, presence of silicoflagellates was not recorded, since they develop better in colder season. Even in cases when they were noted in warmer season, they were, for the most part, located in deeper layers. The highest coccolithophorids abundance was up to 10^3 cells/l in December 2009. Drakulović [82] recorded 4 taxa that belong to silicoflagellates (2.08%) and among silicoflagellates dominant species was *Dictyocha fibula* (15.55%). Vuksanović [80] noted higher abundance of the species *Dictyocha speculum*, while Bosak et al. [86] recorded two species – *D. fibula* and *Octonaria octonaris*.

In the north Adriatic, higher abundance of silicoflagellates was recorded in late autumn and early winter [93]. Šupraha et al. [95], also, noted very low silicoflagellates concentrations in the north Adriatic. Compared to the data from the Bay research conducted in 2009–2010 [82], in the Lim Bay – north Adriatic, higher silicoflagellates abundance was recorded [103] (Table 4).

Table 3 Coccolithophorids species recorded in the Boka Kotorska Bay

Coccolithophorids	
Acanthoica quattrospina Lohmann	Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
Calciosolenia brasiliensis (Lohmann) J. R. Young	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
C. granii Schiller	Drakulović [82]
C. murrayi Gran	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
Calyptrosphaera oblonga Lohmann	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
Chrysochromulina sp.	Bosak et al. [86]
*Discosphaera tubifer (*Murray and Blackmann) Ostenfeld	Drakulović [82]
Emiliania huxleyi (Lahmann) Hay and Mohler	Bosak et al. [86]
*Helicosphaera carteri (*Walich) Kamptner	Bosak et al. [86]
H. wallichii (Lohmann) Okada and McIntyre	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]
Ophiaster formosus Gran	Drakulović [82]
O. hydroideus (Lohmann) Lohmann	Drakulović [82]; Drakulović et al. [81];
Ophiaster sp.	Bosak et al. [86]
Pontosphaera nigra Schiller	Drakulović [82]
Pontosphaera sp.	Drakulović [82]
Rhabdosphaera stylifera Lohmann	Vuksanović [80]; Bosak et al. [86]
R. tignifer Schiller	Drakulović [82]; Drakulović et al. [81]
Syracosphaera pulchra Lohmann	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
Syracosphaera sp.	Drakulović [82]

Table 4 Silicoflagellates species recorded in the Boka Kotorska Bay

Silicoflagellates	
Dictyocha fibula Ehrenberg	Vuksanović [80]; Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]
D. polyactis Ehrenberg	Drakulović et al. [81]
D. septenaria Ehrenberg	Drakulović [82]
D. speculum Ehrenberg	Vuksanović [80]; Drakulović [82]
Octactis octonaria (Ehrenberg) Hovasse	Drakulović [82]; Drakulović et al. [81]; Bosak et al. [86]

3.5 Other Groups

Apart from diatoms, dinoflagellates, coccolithophorids and silicoflagellates, two more phytoplankton groups were noted – euglenophytes and chlorophytes. Among euglenophytes in the Boka Kotorska Bay, *Eutreptia lanowii* species was recorded [80, 82] and among chlorophytes, *Pediastrum* spp. and *Pseudoscourfieldia marina* [86].

4 Trophic State in Boka Kotorska Bay

Investigation of Regner et al. [104], using criteria for determination of the trophic state according to Yamada et al. [105], classified the Boka Kotorska Bay (the Kotor Bay) as extremely eutrophic area in relation to high phosphate concentrations, high oxygen saturations and microplankton abundance of more than 10^6 cells/l.

Krivokapić et al. [88] investigated the temporal distribution of biological and environmental parameters and the trophic state of the Bay. Sampling was conducted weekly from March 2008 to February 2009 in the inner part of the Bay (Kotor Bay). The phytoplankton biomass ranged between <1 and >4 μg l^{-1} chlorophyll *a* (Chl *a*), reaching maximum values in the late winter and spring period. Chlorophyll *a* concentrations, as an indicator of phytoplankton biomass, are often higher after rainfall, particularly if the rain has flushed nutrients into the water. Chlorophyll *a* seasonality is characterized by the distinctive maximum appeared in late winter (February) which was in concordance with the results for the middle part of Adriatic Sea [106] and in north-eastern Mediterranean [107, 108] where Chl *a* concentration increased in late winter. The coefficients of determination (r^2) obtained in the current study indicate that 23–28% of the variations of Chl *a* in the Boka Kotorska Bay could be explained by variations in nutrient concentrations. However, the environmental factors (temperature, insolation, microelements, etc.) could be responsible for additional variations which affect the phytoplankton community. Also, Chl *a* had a significant negative correlation with salinity ($p < 0.05$), which suggests the importance of enhanced winter runoff on the annual phytoplankton biomass balance. The mean monthly values of the Chl *a* concentrations were high compared to data published elsewhere in the Mediterranean, such as for the Bay of Trieste [109], the Ionian sea [110] and Morocco [111], and the north-eastern Adriatic coast [42, 112], but they were lower than values from the western port of Aleksandria [113] and the local area of the island of Mallorca [114].

According to the Chl *a* concentration and the criteria of Ignatiades et al. [115] and Håkanson [116] the area in the present study could be described as oligo-mesotrophic. Two indicators of the trophic state, trophic index – TRIX and the pigment ratio – Fp were calculated from the available physico-chemical and biological data. The TRIX value ranged from 3.02 to 5.58 (average 4.11 ± 0.66) while the Fp ratio varied between 0.05 and 0.33 (average 0.17 ± 0.08).

The values of TRIX and Fp were similar to those described in the Gulf of Trieste [117, 118], the northern Adriatic [119], the Gulf of Gabes [120] and the Ionian Sea [110], indicative of slightly eutrophic conditions. It seems that these two indicators are complementary, and we agree with Flander-Purtle and Malev's [121] suggestion that in new studies the TRIX trophic index needs to include Chl *a* degradation products as an indication of the physiological status of the phytoplankton community. In this study, we did not include Chl *a* degradation products but we used the Fp ratio, which indicated a large phytoplankton pigment biomass (diatoms and dinoflagellates) to the total diagnostic pigment biomass. The large phytoplankton species are known to be the main factors responsible for new production [122], so the basic hypothesis used herein is as follows: the higher the Fp, the more eutrophic the ecosystem [123].

Krivokapić and Pestorić [124] (in press) analysed Chl *a* variability in Kotor Bay for the period 2003–2013. Chlorophyll *a* concentration showed a pronounced temporal variability. The highest value was measured in winter 09/10 and reached 10.11 mg m^{-3} (Fig. 2). Medians in annual cycles showed higher values during winter season. Chlorophyll *a* concentration on 10-year scale decreased and showed significant negative correlation related to monitoring from 2003 to 2013 ($r = -0.392$; $p < 0.05$) and according to Håkanson [116] this area can be defined mainly as mesotrophic (median: 1–3 mgm^{-3}) with individual exceptions which showed eutrophic and hypereutrophic characteristics. TRIX index ranged from 2.33 in spring 09/10 to 3.26 in winter 12/13 showing lower values of calculated TRIX mean values as 5.507 ± 0.889 for the Adriatic Sea [18], northern Aegean Sea [125] and southern Black Sea [126]. Calculated TRIX values were slightly lower than expected because NH_4 was not measured in this study and used in the original formula. This study showed state of water quality on 10-year scale, in three annual cycles in Kotor Bay and can be used as a main source in predicting (determining) possible changes in this Bay in future (Fig. 3).

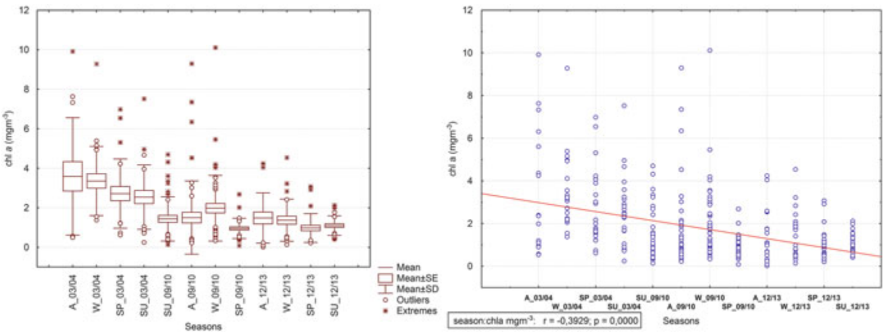


Fig. 2 Box and Whisker representation of seasonal variation of chlorophyll *a* concentration and linear regression in Kotor Bay for period 2003–2013 (362 samples)

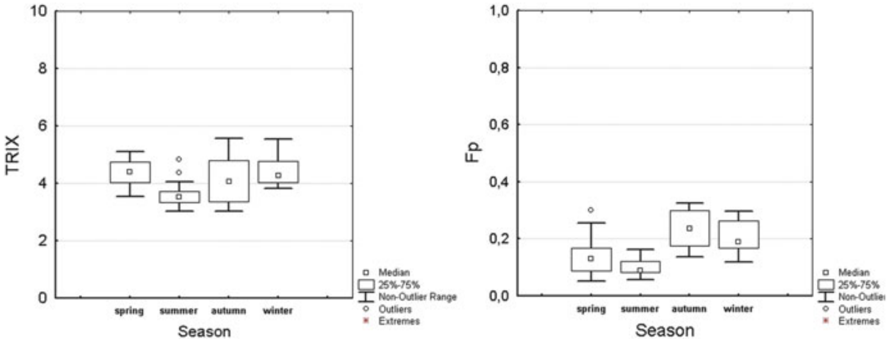


Fig. 3 Box and Whisker representation of seasonal TRIX and Fp index in the Boka Kotorska Bay (60 samples)

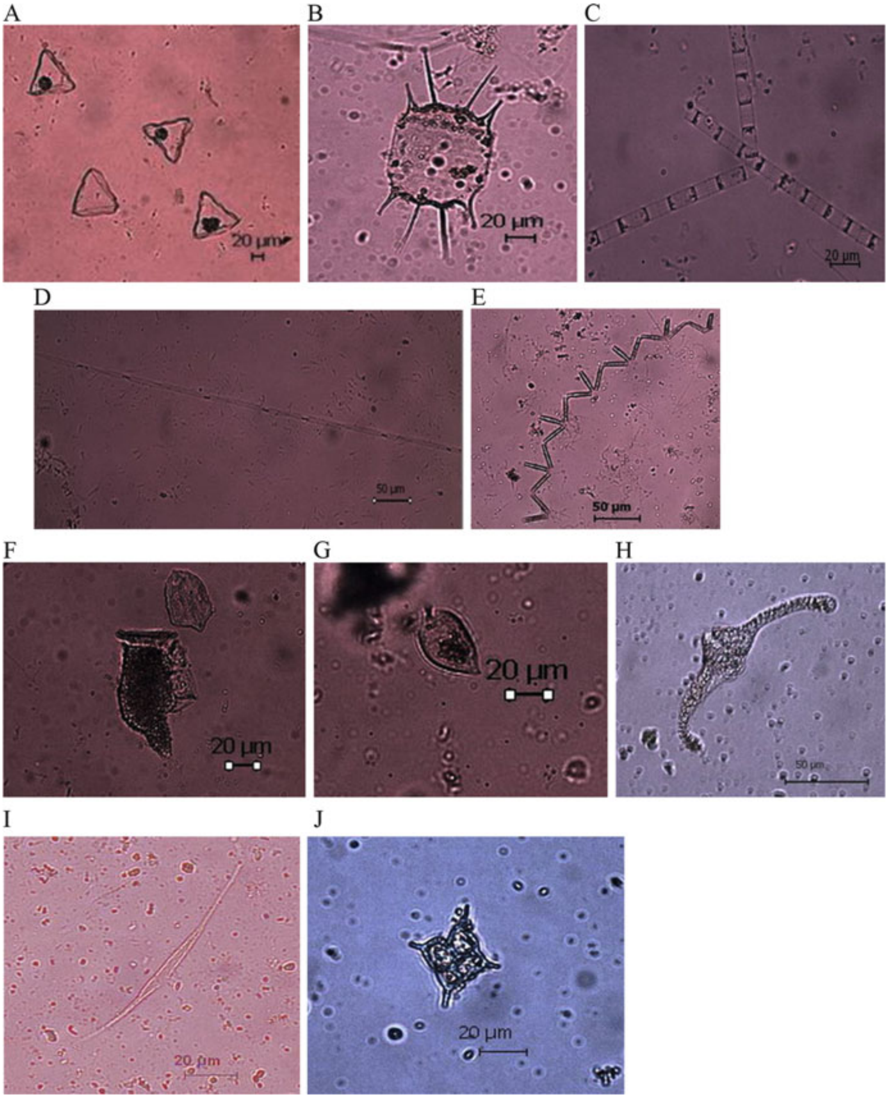
5 Conclusions

The area of Boka Kotorska Bay is a semi-enclosed area, with higher water dynamics in the more open parts, and lower dynamics in its inner part – the Kotor Bay. Due to the variations in factors such as salinity, temperature, light (influenced by turbidity) and nutrients that influence phytoplankton production and water dynamics of this ecosystem, it is very difficult to distinguish whether noticed higher phytoplankton growth is a result of a natural factor or an anthropogenic activity.

Based on the data presented for the Boka Kotorska Bay, phytoplankton abundance reached up to 10^7 cells/l. Diatoms were generally the dominant group, while dinoflagellates were less frequent, but more in summer periods. Available data showed a high frequency of eutrophic species, typical for nutrient rich areas. Such species are a very good indicator of ecosystem conditions. The presence of diatom *Pseudo-nitzschia* spp. is also important, as this species can produce domoic acid. Some toxic dinoflagellate species were also recorded, but in lower abundances. Thus, in the future, this region may become a eutrophic area, where events related to increased toxicity can be expected, and therefore a continuous monitoring is advisable.

Based on the data for TRIX index and Fp ratio as trophic state indicators, it seems that in the Boka Kotorska Bay changes in physical, chemical and biological parameters are mostly related to fresh-sea water interactions, which in turn depend mainly on natural factors, such as rainfall pattern. According to TRIX index and Fp ratio, it can be argued that in the Boka Kotorska Bay, natural eutrophication is still dominant over anthropogenic eutrophication.

Appendix: Images of the Phytoplankton Taxa Noticed During Research from 2009 to 2010 in Boka Kotorska Bay



Images of the phytoplankton taxa noticed during research from 2009 to 2010 in Boka Kotorska Bay (**Diatoms**: A) *Lithodesmium undulatum*, B) *Trieres mobiliensis*, C) *Skeletonema* spp., D) *Pseudo-nitzschia* spp., E) *Thalassionema nitzschioides*, **Dinoflagellates**: F) *Dinophysis caudata*, G) *Prorocentrum micans*, H) *Ceratoperidinium falcatum*, **Coccolithophorids:** I) *Calciosolenia brasiliensis*, **Silicoflagellates:** J) *Dictyocha fibula*)

References

1. Le Pape O, del Amo Y, Menesguen A, Aminot A, Quequiner B, Treguer P (1996) Resistance of costal ecosystem to increasing eutrophic condition: the Bay of Brest (France), a semi-enclosed zone of Western Europe. Cont Shelf Res 16(15):1885–1907
2. Degobbis D, Prescali R, Ivancic I, Smodlaka N, Fuks D, Kveder S (2000) Long-term changes in the Northern Adriatic ecosystem related to antropogenic eutrophication. Int J Environ Pollut 13:495–533
3. de Jonge VN, Elliott M, Orive E (2002) Causes, historical development, effects and future challenges of a common environmental problem: eutrophication. Hydrobiologia 475 (476):1–19
4. Tett P, Gilpin L, Svendsen H, Erlandson CP, Larsson U, Kratzer S, Fouilland E, Janzen C, Lee J-Y, Grenz C, Newton A, Ferreira JG, Fernandes T, Scory S (2003) Eutrophication and some European waters of resticted exchange. Cont Shelf Res 23:1635–1671
5. Bianchi CN, Morri C (2000) Marine biodiversity of the Mediterranean Sea: situation, problems and prospects for future research. Mar Pollut Bull 40:367–376
6. Béthoux JP, Morin P, Ruiz-Pino DP (2002) Temporal trends in nutrient ratios: chemical evidence of Mediterranean ecosystem changes driven by human activity. Deep Sea Res 49 (II):2007–2016
7. Centre d'Economie et de Finances Internationales - CEFI (1992) La Mediterrenee economique. Economica, Paris, France, p 539
8. EEA (2001) Eutrophication in Europe's costal waters. Topic report 7/2001, p 116
9. Lancelot C, Martin J-M, Palin N, Zaitsev Y (2002) The North-west Black Sea: a pilot site to understand the complex interaction between human activities and the costal environment. Estuar Coast Shelf Sci 54:279–283
10. Caddy JF (1993) Recent trends in Mediterraneae fisheries. In: Caddy JF, Griffiths RC (eds) Recent trends in the fisheries and environment in the general Fisheries Council for the Mediterranean (GFCM) area. GFCM Studies and Reviews. No. 63. Food and agriculture Organization of the United Nations (FAO), Rome
11. UNEP (2003) Eutrophication monitoring strategy of MED POL. UNEP (DEC) MED WG. 231/14, Athens
12. Krivokapić S, Stanković Ž, Vuksanović N (2009) Seasonal variation of phytoplankton biomass and environmental conditions in the inner Boka Kotorska Bay (eastern Adriatic Sea). Acta Bot Croat 68(1):45–55
13. Campanelli A, Bulatovic A, Cabrini M, Grilli F, Kljajic Z, Mosetti R, Paschini E, Penna P, Marini M (2009) Spatial distribution of physical, chemical and biological oceanographic properties, phytoplankton, nutrients and coloured dissolved organic matter (CDOM) in the Boka Kotorska Bay (Adriatic Sea). Geofizika 26(2):215–228
14. Macic V, Antolić B, Thibaut T, Svircev Z (2010) Distribution of the most common Cystoseira C. Agardh species (Heterokontophyta, Fucales) on the coast of Montenegro (South-East Adriatic Sea). Fresenius Environ Bull 19(6):1191–1198
15. Zohary T, Robats RD (1998) Experimental study of microbial P limitation in the eastern Mediterranean. Limnol Oceanogr 43(3):387–395
16. Thingstad TF, Krom MD, Mantoura RFC, Flaten GAF, Groom S, Herut B, Kress N, Law C, Pasternak A, Pitta P, Psarra S, Rassoulzadegan F, Tanaka T, Tselepides A, Wassmann P, Woodward EMS, Wexels Riser C, Zodiatis G, Zohary T (2005) Nature of P limitation in the ultraoligotrophic Eastern Mediterranean. Science 309:1068–1071
17. Krom MD, Thingstad TF, Brenner S, Carbo P, Drakopoulos P, Fileman TW, Flaten GAF, Groom S, Herut B, Kitidis V, Kress N, Law CS, Liddicoat MI, Mantoura RFC, Pasternak A, Pitta P, Polychronaki T, Psarra S, Rassoulzadegan F, Skjoldal EF, Spyres G, Tanaka T, Tselepides A, Wassmann P, Wexels Riser C, Woodward EMS, Zodiatis G, Zohary T (2005) Summary and overview of the CYCLOPS P addition Lagrangian experiment in the Eastern Mediterranean. Deep Sea Res Part II 52:3090–3108

18. Vollenweider RA, Giovanardi F, Montanari G (1998) Characterization of the trophic conditions of marine special reference to the NW Adriatic Sea: proposal for trophic scale, turbidity and generalized water quality index. Environmetrics 9:329–357
19. Claustre H (1994) The trophic status of various oceanic provinces as revealed by phytoplankton pigment signature. Limnol Oceanogr 39:1206–1210
20. Nixon SW (1995) Coastal marine eutrophication: a definition, social causes, and future concerns. Ophelia 41:199–219
21. U.S. Environmental Protection Agency (USEPA) (1991) Guidance for water quality-based decisions the TMDL process. Document Number EPA 440/4-91-001. Washington, DC
22. Giordani G, Zaldivar JM, Viaroli P (2009) Simple tools for assessing water quality and trophic status in transitional water ecosystems. Ecol Indic 9:982–991
23. Bricker SB, Longstaff B, Dennison W, Jones A, Boicourt K, Wicks C, Woerner J (2007) Effects of nutrient enrichment in the nation's estuaries: a decade o change, national estuarine eutrophication assessment update. NOAA Coastal Ocean Program Decision Analysis Series No. 26. National Centers for Coastal Ocean Science, Silver Spring, MD. http://ccma.nos.noaa.gov/news/feature/Eutroupdate.html, p 322
24. OSPAR (2008) Second OSPAR integrated report on the Eutrophication status of the OSPAR maritime area, 2008-372. OSPAR publication, p 107
25. Souchu P, Ximenes MC, Lauret M, Vaquer A, Dutrieux E (2000) Mise à jour d'indicateurs du niveau d'eutrophisation des milieux lagunaires méditerranéens, août 2000. Ifremer-Créocean-Université Montpellier II, p 412
26. Ignatiades L (2005) Scaling the trophic status of the Aegean Sea, eastern Mediterranean. J Sea Res 54:51e57
27. Eppley RW, Peterson BJ (1979) Particulate organic matter flux and planktonic new production in the deep ocean. Nature 282:677–680
28. Mozetič P, Solidoro C, Cossarini G, Socal G, Precali R, Francé J, Bianchi F, De Vittor C, Smodlaka N, Fonda Umani S (2010) Recent trends towards oligotrophication of the Northern Adriatic: evidence from chlorophyll a time series. Estuaries Coasts 33:362–375. doi:10.1007/s12237-009-9191-7
29. Degobbis D, Gilmartin M (1990) Nitrogen, phosphorus, and biogenic silicon budgets for the northern Adriatic Sea. Oceanol Acta 13:31–45
30. Pettine M, Patrolecco L, Camusso M, Crescenzio S (1998) Transport of carbon and nitrogen to the northern Adriatic sea by the Po River. Estuar Coast Shelf Sci 46:127–142
31. Hopkins TS (1992) The structure of Ionian and Levantine Seas. Rep Meteorol Oceanogr 41 (II):35–56
32. Sournia A (1973) La production primaire planctonique en Mediterranee. Essai de mise a jour Bull Etude Comm Mediterr 5:1–128
33. Hopkins TS, Artegiani A, Kinder C, Pariante R (1999) A discussion of the northern Adriatic circulation and flushing as determined from the ELNA hydrography. In: Hopkins TS et al (eds) The Adriatic Sea. Ecosystem Research Report 32. European Commission, Brussels, pp 85–106
34. Viličić D, Đakovac T, Burić Z, Bosak S (2009) Composition and annual cycle of phytoplankton assemblages in the northeastern Adriatic Sea. Bot Mar 52:291–305
35. Revelante N, Gilmartin M (1976) The effect of Po River discharge on phytoplankton dynamics in the northern Adriatic Sea. Mar Biol 34:259–271
36. Revelante N, Gilmartin M (1992) The lateral advection of particulate organic matter from the Po Delta region during summer stratification, and its implications for the northern Adriatic. Estuar Coast Shelf Sci 35:191–212
37. Totti C, Cangini M, Ferrari C, Kraus R, Pompei M, Pugnetti A, Romagnoli T, Vannucci S, Socal G (2005) Phytoplankton size-distribution and community structure in relation to mucilage occurrence in the northern Adriatic Sea. Sci Total Environ 353:204–217
38. Supić N, Orlić M, Degobbis D (2000) Istrian coastal countercurrent and its year-to-year variability. Estuar Coast Shelf Sci 51:385e397

39. Kraus R, Supić N (2011) Impact of circulation on high phytoplankton blooms and fish catch in the northern Adriatic (1990e2004). Estuar Coast Shelf Sci 91:198–210
40. Artegiani A, Bregant D, Paschini E, Pinardi N, Raicich F, Ruso A (1997) The Adriatic Sea general circulation. Part 1: air-sea interactions and water mass structure. J Phys Oceanogr 27:1492–1514
41. Gačić M, Poulain PM, Zore-Armanda M, Barale V (2001) Overview to the Adriatic sea. In: Cushman-Roisin B, Gačić M, Poulain MP, Artegiani A (eds) Physical oceanography of the Adriatic Sea. Kluwer Academic Publishers, Dordrecht, pp 1–44
42. Viličić D, Terzić S, Ahel M, Burić Z, Jasprica N, Carić M, Mihalić CK, Olijić G (2008) Phytoplankton abundance and pigment biomarkers in the oligotrophic, eastern Adriatic estuary. Environ Monit Assess 142:199–218
43. Orlić M, Dadić V, Grbec B, Leder N, Marki A, Matić F, Mihanović H, Paklar GB, Pasarić M, Pasarić Z, Vilibić I (2007) Wintertime buoyancy forcing, changing seawater properties, and two different circulation systems produced in the Adriatic. J Geophys Res C 112:C03S07
44. Solidoro C, Bastianini M, Bandelj V, Codermatz R, Cossarini G, Melaku Canu D, Ravagnan E, Salon S, Trevisani S (2009) Current state, scales of variability and decadal trends of biogeochemical properties in the Northern Adriatic Sea. J Geophys Res. doi:10.1029/2008JC004838
45. Zanchettin D, Traverso P, Tomasino M (2008) Po River discharges: a preliminary analysis of a 200-year time series. Clim Change 89:411–433. doi:10.1007/s10584-008-9395-z
46. Totti C, Civitarese G, Acri F, Barletta D, Candelari G, Paschini E, Solazzi A (2000) Seasonal variability of phytoplankton populations in the middle Adriatic sub-basin. J Plankton Res 22 (9):1735–1756
47. Marasović I (1989) Encystment and excystment of Gonyaulax polyedra during red tide. Estuar Coast Shelf Sci 28:35–41
48. Marasović I, Gačić M, Kovačević V, Krstulović N, Kušpilić G, Pucher-Petković T, Odžak N, Šolić M (1991) Development of the red tide in the Kaštela Bay (Adriatic Sea). Mar Chem 32:375–385
49. Vukadin I, Stojanoski L (2001) Phosphorus versus nitrogen limitation in the middle Adriatic Sea. Rapp. Comm. int. Mer Médit, vol 36. 24–28 September, Monte-Carlo, p 174
50. Gačić M, Manca B, Vetrano A (1996) Thermohaline properties and circulation in the Strait of Otranto. In: Briand F (ed) Dynamics of Mediterranean straits and channels. Monaco, CIESM Science Series. Bull Inst Oceanogr 2, pp 117–145
51. Yacobi YZ, Zohary T, Kress N, Hecht A, Robarts RD, Waiser M, Wood AM, Li WKW (1995) Chlorophyll distribution throughout the southeastern Mediterranean in relation to the physical structure of the water mass. J Mar Syst 6:179–190
52. Orlić M, Gačić M, La Violette PE (1992) The current and circulation of the Adriatic Sea. Oceanol Acta 15:109–124
53. Viličić D (1983) Zimski aspekt vegetacije fitoplanktona u Kotorskom zaljevu – The winter aspect of phytoplankton vegetation in the Bay of Kotor. Stud Mar 13–14:37–51
54. Rubino F, Sracino OD, Moscatello S, Belmonte G (2009) An integrated water/sediment approach to study plankton (a case study in the southern Adriatic Sea). J Mar Syst 78:536–546
55. Saracino OD, Rubino F (2006) Phytoplankton composition and distribution along the Albanian coast, South Adriatic Sea. Nova Hedwigia 83:253–266
56. Vuksanović N (2000) Quantitative aspect of phytoplankton as an indicator of eutrophication in the Boka Kotorska Bay throughout summer, 1999. In: The 29th Annual conference of the Yugoslav Water Pollution Control Society "Water Pollution Control 2000", Tara, 7–9 June, pp 155–158, Conference Proceedings
57. Vuksanović N (2001) Phytoplankton groups as indicators of eutrophication in the Boka Kotorska Bay. In: The 30th annual conference of the Serbian Water Pollution Control Society "Water Pollution Control 2001", Aranđelovac, Serbia, 12–15 June, pp 329–332, Conference Proceedings

58. Vuksanović N (2002) Phytoplankton organisms as indicator of eutrophication in the Montenegrin coastal sea throughout summer, 2001. In: The 31th annual conference of the Yugoslav Water Pollution Control Society "Water 2002", Vrnjačka Banja, Serbia, 11–14 June, pp 315–318, Conference Proceedings
59. Vuksanović N (2003) Florističko-ekološka istraživanja fitoplanktona Kotorskog zaliva. Doktorska disertacija. Univerzitet u Beogradu, Prirodno-matematički fakultet, Biološki fakultet Beograd, pp 1–122
60. Vuksanović N (2003) Estimation of the phytoplankton quantity in the area of Montenegrin coastal sea as a consequence of eutrophication. In: The 32th Annual Conference of the Yugoslav Water Pollution Control Society "Water Pollution Control 2003", Zlatibor, Serbia, 3–6 June, pp 383–386, Conference Proceedings
61. Vuksanović N (2004) Changes of phytplankton quantity in the Montenegrin coastal sea through summer, 2003. In: The 33th Annual Conference of the Yugoslav Water Pollution Control Society "Water Pollution Control 2004", Borsko jezero, Serbia, 08–11 June, pp 415–418, Conference Proceedings
62. Vuksanović N, Krivokapić S (2005) Contribution to the knowledge of phytoplankton of Kotor Bay in the winter season 2004. In: The 34th Annual Conference of the Yugoslav Water Pollution Control Society "Water Pollution Control 2005", Kopaonik, Serbia, 07–10 June, pp 351–354, Conference Proceedings
63. Vuksanović V, Krivokapić S (2006) Phytoplankton situation in the outer part of Boka Kotorska Bay. The 35 th Annual Conference of the Yugoslav Water Pollution Control Society "Water Pollution Control 2006", Zlatibor, Serbia, 06–09 June, pp 289–294, Conference Proceedings
64. Drakulović D, Vuksanović N (2010) Phytoplankton assemblages and density in the Montenegrin coastal Sea. Rapp. Comm. int. Mer Médit. (CIESM), vol 39. 10–14 May, Venice, Italy, p 351
65. Drakulović D, Vuksanović N, Joksimović D (2011) Dynamics of phytoplankton in Boka Kotorska Bay. Stud Mar 25(1):1–20
66. Schiller J (1925) Die planktonischen Vegetationen des Adriatischen Meeres. Die Coccolitoforiden-Vegetation in der Jahren 1911–1914. Arch Protistenk 51:1–130
67. Ercegovic A (1938) Ispitivanja hidrografskih prilika i fitoplanktona u vodama Boke u jeseni 1937. Godišnjak Oceanografskog instituta Kraljevine Jugoslavije 1:91–110
68. Dobrosavljević M (1971) Preliminarna opažanja o distribuciji fitoplanktona u Bokokotorskom zalivu. Stud Mar 5:3–16
69. Mandić S, Stjepčević J (1972) Sezonska distribucija i sastav fitoplanktona u priobalnim vodama Bokokotorskog zaliva u jednogodišnjem ciklusu. Poljoprivreda i šumarstvo 18:57–76
70. Dobrosavljević M (1983) Regresivne transformacije u planktonskim fitocenozama južnog Jadrana. Stud Mar (13–14):3–324
71. Vukanić D, Dobrosavljević M, Dutina M (1979) Prilog poznavanju hidrografskih prilika i planktona Kotorskog zaliva. II kongres ekologa Jugoslavije, Zadar, pp 1977–1986
72. Vuksanović N (1983) Sezonski aspekti procentualnog sastava fitoplanktonskih grupa u Kotorskom zalivu – Les aspects saisonniers de la composition des groups phytoplanctoniques en pour-cent dans le Golfe de Kotor. Stud Mar 13–14:61–67
73. Viličić D (1986) A study of phytoplankton population density and cell volume in the Kotor Bay, the Southern Adriatic. Stud Mar 17–18:87–104
74. Viličić D (1989) Phytoplankton population density and volume as indicators of eutrophication in the eastern part of the Adriatic Sea. Hydrobiologia 174:117–132
75. Venediktov PS, Matorin DN, Vuksanović N (1989) Isledovanje fluorescencii i visokotemperaturnoi termoluminescencii hlorofila v Kotorskom zalive Adriaticeskogo morja. Izvestia AN SSSR, Serija biologiceskaja 4:623–628
76. Vukanić D, Dutina M, Vuksanović N (1989) Contribution to the investigations of the ecological characteristics and plankton of the Bay of Kotor. Period Biol 91(1):125–126

77. Vukanić D, Dutina M, Vuksanović N (1990) prilog istraživanju planktonskih zajednica Kotorskog zaliva. Bilten društva ekologa BiH, s. B 5:175–180
78. Vuksanović N, Dutina M, Vukanić D (1990) Dinamika populacija fitoplanktona u Kotorskom zalivu. Bilten Društva ekologa BiH, s. B 6:181–184
79. Vuksanović N, Dutina M, Vukanić D (1990) Prilog poznavanju fitoplanktona Tivatskog zaliva. Bilten Društva ekologa BiH, s. B 5:185–188
80. Vuksanović N (1993) Florističko-ekološka istraživanja fitoplanktona Kotorskog zaliva. Doktorska disertacija. Univerzitet u Beogradu, Biološki fakultet. Beograd, pp 1–122
81. Drakulović D, Pestorić B, Cvijan M, Krivokapić S, Vuksanović N (2012) Distribution of phytoplankton community in Kotor Bay (south-eastern Adriatic Sea). Cent Eur J Biol 7 (3):470–486. doi:10.2478/s11535-012-0023-6
82. Drakulović D (2012) Značaj fitoplanktona kao indikatora eutrofikacije u akvatorijumu Bokokotorskog zaliva. Doktorska disertacija. Univerzitet u Beogradu, Biološki fakultet. Beograd, pp 1–224
83. Drakulović D, Mandić M, Joksimović D, Petovic S (2013) Distribution of phytoplankton on mussel farms in Boka Kotorska Bay. Stud Mar 26(1):65–82
84. Drakulović D, Pestorić B, Joksimović D, Redžić A, Petović S (2014) Dinoflagellates assemblages in the Boka Kotorska Bay. Stud Mar 27(1):65–84
85. Drakulović D, Pestorić B, Joksimović D, Marković S, Mandić M (2015) Composition and distribution of diatoms on mussel farms in Boka Kotorska Bay. Stud Mar 28(1):51–60
86. Bosak S, Šilović T, Ljubešić Z, Kušpilić G, Pestorić B, Krivokapić S, Viličić D (2012) Phytoplankton size structure and species composition as an indicator of trophic status in transitional ecosystems: the case study of a Mediterranean fjord-like karstic bay. Oceanologia 54(2):255–286. doi:10.5697/oc.54-2.255
87. Krivokapić S, Pestorić B, Bosak S, Kušpilić G (2010) Trophic condition in the Boka Kotorska Bay. Rapp Comm Int Mer Médit 39:767
88. Krivokapić S, Pestorić B, Bosak S, Kušpilić G, Wexels Riser C (2011) Trophic state of Boka Kotorska Bay (South-Eastern Adriatic Sea). Fresenius Environ Bull 20(8):1960–1969
89. Krivokapić S (2005) Dinamika biomase fitoplanktona i nutrijenata kao indikatora stepena trofičnosti u unutrašnjem dijelu Bokokotorskog zaliva. Doktorska disertacija. Univerzitet u Novom sadu, Prirodno-matematički fakultet, Departman za biologiju i ekologiju. Novi Sad, pp 1–144
90. Burić Z, Cetinić I, Viličić D, Caput–Mihalić K, Carić M, Olujić G (2007) Spatial and temporal distribution in a highly stratified estuary (Zrmanja, Adriatic Sea). Mar Ecol 28:169–177
91. Fanuko N, Valčić M (2009) Phytoplankton composition and biomass of the northern Adriatic lagoon of Stella Maris, Croatia. Acta Bot Croat 68(1):29–44
92. Caroppo C, Stabili L, Cavallo RA (2003) Diatoms and bacteria diversity: study of their relationships in the Southern Adriatic Sea. Mediterr Mar Sci 4(2):73–82
93. Bernardi-Aubry F, Acri F, Bastianini M, Bianchi F, Cassin D, Pugnetti A, Socal G (2006) Seasonal and interannual variations of phytoplankton in the Gulf of Venice (Northern Adriatic Sea). Chem Ecol 22(Suppl 1):71–91
94. Caroppo C, Congestri R, Bracchini L, Albertano P (2005) On the presence of Pseudo-nitzschia calliantha Lundholm, Moestrup et Hasle and Pseudo-nitzschia delicatissima (Cleve) Heiden in the Southern Adriatic Sea (Mediterranean Sea, Italy). J Plankton Res 27:763–774
95. Šupraha L, Bosak S, Ljubešić Z, Olujić G, Horvat L, Viličić D (2011) The phytoplankton composition and spatial distribution in the north-eastern Adriatic channel in autumn 2008. Acta Adriat 52(1):29–44
96. Pucher-Petković T, Marasović I (1987) Contribution á la connaissance d'une pousse é extraordinaire d'algues unicellulaires (Adriatique Septentrionale). Centro 1(3):33–44

97. Burić Z, Viličić D, Caput-Mihalić K, Carić M, Kralj K, Ljubešić N (2008) Pseudo-nitzschia blooms in the Zrmanja River estuary (Eastern Adriatic Sea). Diatom Res 23(1):51–63. doi:10.1080/0269249X.2008.9705736
98. Cetinić I, Viličić D, Burić Z, Olujić G (2006) Phytoplankton seasonality in a highly stratified karstic estuary (Krka, Adriatic Sea). Hydrobiologia 555:31–40
99. Bernardi-Aubry F, Berton A, Bastianini M, Socal G, Acri F (2004) Phytoplankton succession in a coastal area of the NW Adriatic, over a 10-year sampling period (1990–1999). Cont Shelf Res 24:97–115
100. Svensen C, Viličić D, Wassmann P, Arashkevich E, Ratkovac T (2007) Plankton distribution and vertical flux of biogenic matter during high summer stratification in the Krka estuary (Eastern Adriatic). Estuar Coast Shelf Sci 71:381–390
101. Možetić P, Fonda Umani S, Kamburska L (2002) Plankton variability in the gulf of Trieste (Northern Adriatic). Archo Oceanogr Limnol 23:7–19
102. Fonda Umani S (1996) Pelagic production and biomass in the Adriatic Sea. Sci Mar 60(Suppl 2):65–77
103. Viličić D, Ivančić I, Bosak S (2007) Toksični dinoflagelati u Limskom zalivu. Hrvatska konferencija o vodama. Opatija, Hrvatska, pp 46–60
104. Regner D, Vuksanović N, Stjepčević B, Dutina M (2001) Ecological investigations of the Montenegrin coastal sea throughout summer, 2000. In: The 30th annual conference of the Yugslav Water Pollution Control Society "Water Pollution Control 2001", Aranđelovac, Serbia, 12–15 June, pp 314–319, Conference Proceedings
105. Yamada M, Tsuruta A, Yoshida Y (1980) Classification of eutrophic level in several marine regions. Bull Jpn Soc Sci Fish 46:1439–1444
106. Ninčević Ž, Marasović I (1998) Chlorophyll a and primary production of size fractionated phytoplankton in the middle Adriatic Sea. Rapp Comm Int Mer Médit 35:472–473
107. Ediger D, Yilmaz A (1996) Characteristics of deep chlorophyll maximum in the northeastern Mediterranean with respect to environmental conditions. J Mar Syst 9:291–303
108. Polat S (2002) Nutrients, chlorophyll a and phytoplankton in the Iskenderun bay (Northeastern Mediterranean). P.S.Z.N.I: Mar Ecol 23(2):115–126
109. Tedesco L, Socal G, Bianchi F, Acri F, Veneri D, Vichi M (2007) NW Adriatic Sea variability in relation to chlorophyll-a dynamics in the last 20 years (1986–2005). Biogeosciences 4:651–685
110. Nikolaidis G, Moschandreou K, Patoucheas DP (2008) Application of a trophic index (TRIX) for water quality assessment at Kalamitsi coasts (Ionian sea) after the operation of the wastewater treatment plant. Fresenius Environ Bull 17(11b):1938–1944
111. Claustre H, Hooker SB, Van Heukelem L, Berthon JF, Barlow R, Ras J (2004) An intercomparison of HPLC phytoplankton pigment methods using in situ samples: application to remote sensing and database activities. Mar Chem 85:41–61
112. Precali R, Daković T, Smodlaka N, Ivančić I (2001) Long-term changes of nutrient concentration and phytoplankton biomass in the Northern Adriatic Sea. Rapp Comm Int Mer Médit 36:156
113. Dorgham M, Abdel-Aziz NE, El-Deeb KZ, Okbah MA (2004) Eutrophication problems in the Western Harbour of Alexandria, Egypt. Oceanologia 46:25–44
114. Puigserver M, Ramon G, Moýa G, Martinez-Taberner A (2002) Planktonic chlorophyll a and eutrophication in two Mediterranean littoral system (Mallorca Island, Spain). Hydrobiologia 475(476):493–503
115. Ignatiades L, Karydis M, Vounatsou P (1992) A possible method for evaluating oligotrophy and eutrophication based on nutrient concentration scales. Mar Pollut Bull 24:238–243
116. Håkanson L (1994) A review of effect-dose-sensitivity models for aquatic ecosystems. Int Rev Hydrobiol 79:621–667
117. Turk V, Mozetič P, Malej A (2007) Overview of eutrophication-related events and other irregular episodes in Slovenian sea (Gulf of Trieste, Adriatic Sea). Ann Ser Hist Nat 17 (2):197–216

118. Malej A, Mozetič P, Malačič V, Terzić S, Ahel M (1995) Phytoplankton responses to freshwater inputs in a small semi-enclosed gulf (Gulf of Trieste, Adriatic Sea). Mar Ecol Prog Ser 120:111–121
119. Pečar O, Precali R (2004) Long-term changes of the Northern Adriatic trophic conditions. Rapp Comm Int Mer Médit 37:234
120. Hassen MB, Drira Z, Hamza A, Ayadi H, Akrout F, Issaoui H (2008) Summer phytoplankton pigments and community composition related to water mass properties in the Gulf of Gabes. Estuar Coast Shelf Sci 77:645–656
121. Flander-Purtle V, Malev A (2003) The trophic state of coastal waters under the influence of anthropogenic sources of nutrients (fish farm, seawage outfalls). Period Biol 105(4):359–365
122. Dugdale RC, Goering JJ (1967) Uptake of new and regenerated forms of nitrogen in primary productivity. Limnol Oceanogr 12(2):196–206
123. Avril B (2002) DOC dynamics in the northwestern Mediterranean Sea (DYFAMED site). Deep Sea Res II 49:2163–2182
124. Krivokapic S, Pestoric B (unpublish data) Chlorophyll a variability in the inner part of Boka Kotorska Bay last 10 years
125. Moncheva S, Gotsis-Skretas O, Pagou K, Krastev A (2001) Phytoplankton blooms in Black Sea and Mediterranean costal ecosystems subjected to anthropogenic eutrophication: similarities and differences. Costal Shelf Sci 53:281–295
126. Baytut O, Gonulol A, Koray T (2010) Temporal variations of phytoplankton in relation to eutrophication in Samsun Bay, Southern Black Sea. Turk J Fish Aquat Sci 10:363–372

Phytobenthos in the Boka Kotorska Bay: State of Knowledge and Threats

Vesna Mačić and Slađana Krivokapić

Abstract Research of phytobenthos in Boka Kotorska Bay did not start until the second half of the twentieth century and 219 species have been described so far in this area. The highest number of identified taxa in the Bay belongs to the Atlantic phytogeographic element (35.1%), followed by the Mediterranean (18.9%), cosmopolitan (12.2%), and others. Endemic species of the Adriatic Sea are represented with only one species, *Fucus virsoides*, with the Bay as its southernmost distribution limit. Four species of seagrass are found, and meadows of *Posidonia oceanica* and *Cymodocea nodosa* are numerous, especially in the outer part of the Bay. *Zostera noltei* builds meadows together with the *C. nodosa* at several locations, while *Zostera marina* was found at one location only.

Human influences on marine plant communities are grouped into direct impacts including mechanical damage, pollution, and biological damage and indirect effects such as global/regional warming and changes in sea level. Regression of seagrass meadows is high.

Further research of phytobenthos, better use of these still insufficiently known resources, and effective protection measures are needed.

Keywords Biodiversity, Phytobenthos, Regression, Seagrass, Threats

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Contents

1 Introduction

Sea, as the living environment, in comparison with the land is characterized by continuity and relative uniformity of living conditions, thus causing major biogeographic units and marine organisms of wide distribution. Various abiotic and biotic factors affected the formation of small biogeographic units and the development of species of narrow distribution and even endemic species, with very limited distribution areas, so today's flora and fauna of the Boka Kotorska Bay are a result of actions of many historical geomorphological, climatic, biological, and anthropogenic impacts, which often provoked very intense changes in different stages of development, of the Bay itself, the Adriatic Sea, and the entire Mediterranean Basin.

Phytobenthos was mostly hidden from the eye of researchers in the past and, in relation to fisheries and edible resources from the sea, was of far less economic and scientific interest. This is illustrated by Nardo [1] stating that Aristotle, Ovid, Juvenal, Pliny, and Martial all speak not so much of environments, as in price of the products of the Adriatic, especially edible ones. However, the development of well-known scientific and cultural centers, such as Venice, Padua, Vienna, Rome, Trieste, and others, contributed to the intensification of research of the Adriatic Sea (especially its northern part) since the end of the eighteenth and early nineteenth centuries, which already at the end of nineteenth century was among the best floristically explored seas [2].

One of the first, unavoidable, works referring to the study of the Adriatic Sea is "The natural history of the Adriatic Sea," by Vitaliano Donati (1750) [3]. In fact, due to the plague in Messina, planned research was moved to the area then called Illyria, between Dalmatia and Albania, in the eastern Adriatic and his survey may be considered the very first natural history oceanographic campaign. Report from this research was prepared in the form of essays and was very popular in Europe. In addition to being the first to show physico-geological picture of the bottom of the Adriatic Sea, which had hills and valleys such as visible on land and showed that sponges and corals were animals and not plants or minerals, or "zoophytes" as once thought to be, Donati discovered and described in great detail new natural marine objects such as the rockweed (*Fucus virsoides*) and mermaid's wineglass (*Acetabularia* sp.), algae that were abundant in several places in the Adriatic [1].

In 1910, the meeting was held in Venice with the aim of forming an international institution for the study of the sea (*Commissione Intenazionale per lo studio dell' Adriatico*) with Austria and Italy as the first members, while Turkey and Montenegro joining them immediately after. This organization until 1914, i.e. the First World War, organized five major research missions. Some of these missions were carried out in Boka Kotorska Bay, but only in its outer part (from Cape Ošro to Tivat) and dealt only with hydrographic factors (salinity and temperature), but did not further examine relations of hydrological and biological factors [4]. From this period, we should mention the work of Schiller (1914), an algologist of the expedition of the research ship "Najade," who gave a kind of general biological overview of the Adriatic flora, unlike Lorenzo (1863), Techeto (1906), Vouk (1914), and others before him, who focused their research on smaller areas, mainly the northern Adriatic [5]. Thanks to "Najade" expedition, it was found that in the depths of the central Adriatic, flora was considerably richer than the one in the northern part, because the number of species increased rapidly from the line Kvarner-Mali Lošinj to the south. These studies of Schiller during 1914 were later confirmed by the Vienna algologist Schiffner in 1933, who explored the coastal flora of some parts of the southern Adriatic in the period between two world wars and described significant number of new forms unnoticed before [2].

2 Macroalgae

Referring to the distribution of brown alga *Fucus virsoides* Agardh (Fig. 1), species endemic to the Adriatic Sea, Linardić was among the first to stress particularities of the Boka Kotorska Bay and its phytobenthos [6]. During the exploration of the eastern Adriatic coast (in 1939), Linardić defined Boka Kotorska Bay, more precisely, Herceg Novi and Tivat, as the southernmost location of distribution of this species. At that time, on the Italian coast of the Adriatic, southernmost finding of this brown alga was in Ancona, which is significantly to the north of the Boka Kotorska Bay. Comparing the eastern and western coast of the Adriatic Sea and the distribution of the *F. virsoides*, it is clear that the climate factor is not the only determining factor in the distribution of this, as well as other species. Linardić used this example to highlight the importance of not only the climate but also significantly more geomorphological and hydrographic factors. Jagged eastern coast offers great number of bays that provide shelter from the strongest impact of waves, and these are locations that *F. virsoides* prefers in the northern Adriatic as well. In addition, this brown alga grows most abundantly in positions where there is freshwater springing along the coast or under the sea ("vrulje"), which significantly reduces the salinity of seawater [6, 7]. Simultaneously with the decline in salinity, the decrease in temperature of seawater happens, because freshwater originating from the mainland has a much lower temperature than the seawater [6]. Research of the distribution of this species in Boka Kotorska Bay, done by Mačić much later (on 2006) [8], indicates 14 locations for *Fucus virsoides*, with the largest number in

Fig. 1 *Fucus virsoides* Agardh

the Bay of Risan. Favorable conditions for *F. virsoides* in Risan Bay are due to the great input of freshwater, lower temperature and salinity values (considerably different from those of the Montenegrin open part of the Adriatic Sea), rocky surface in the intertidal zone, and relatively undisturbed environment [8]. Both of these two factors (reduced salinity and reduced temperature) are in accordance with the conditions which were most likely existing at the place of origin of *F. virsoides*, when it was belonging to the boreal-Atlantic species, whose geographical distribution was much larger and further to the north than today. Also, the lower average annual temperature in the Adriatic Sea is probably the reason why *F. virsoides* did not enter the remaining parts of the Mediterranean and remained one of the typical examples of the Adriatic endemism [6, 9].

Inevitable name in the review of the study of phytobenthos in the Adriatic Sea is Ante Ercegović, who in the second half of the twentieth century published a series of important papers, notably the "Adriatic *Cystoseira*" ("Sur les Cystoseira adriatiques") [2], which today serves as one of the fundamental works on these dominant algae in the Mediterranean Sea. Unfortunately, out of 150 locations on the eastern Adriatic where Ercegović performed research of the genus *Cystoseira*, neither one was located in the Boka Kotorska Bay. The reason for this is most likely the earlier findings of Ercegović [4] in relation to hydrographic conditions in Boka Kotorska Bay and findings that the vegetation of algae of the genus *Cystoseira* in areas that are under significant influence of freshwater is very poor or completely absent [2].

For Boka Kotorska Bay, first references of phytobenthos and biocenosis of seagrass were given by Karaman and Gamulin-Brida [10]. By studying benthic biocenoses during 1963–1964, they noted the presence of ten species of algae and three types of seagrass. Few years later, Solazzi [11] reported the presence of 48 species of algae for the inner part of the bay (the Bay of Kotor and Risan). This was actually done in the context of the research of Stjepčević and Parenzan [12] "Il golfo delle Bocche di Cattaro – condizioni generali e biocenosi bentoniche

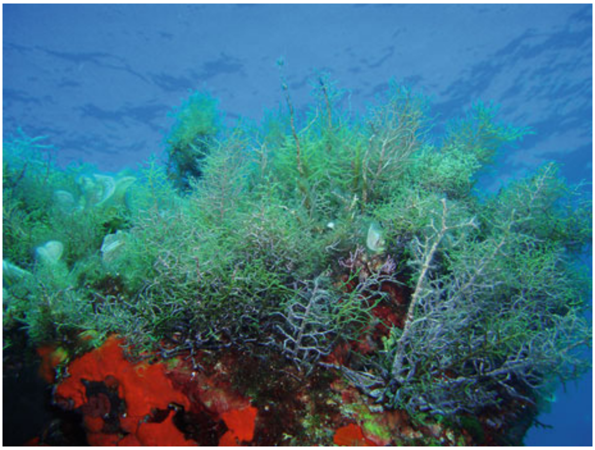

Fig. 2 *Cystoseira*-dominated assemblage

con carta ecologica delle sue due baie interne: di Kotor (Cattaro) e di Risan (Risano)." Although their goal was not to study algae, phytobenthos samples collected on that occasion were sent for determination to Prof. Attilio Solazzi (University of Padua) and later included in the aforementioned work of Stjepčević and Parenzan [12]. By comparing these preliminary results with the findings from the opposite side of the Adriatic, i.e., the island of Pianosa, Tremiti [13], located on the high seas, it was found that only nine species were of the common nature, while the remaining 47 found on Pianosa were not present in the Boka Kotorska Bay. In this way the specificity of phytobenthos in the Boka Kotorska Bay was noted and documented.

Stjepčević and Parenzan [12] provided a valuable presentation and analysis of benthic biocenoses for the inner part of the Bay, which are still used today as an inevitable reference in describing the Boka Kotorska Bay. Among others, communities with algae of the genus *Cystoseira* (Fig. 2), assemblages of *Osmundaria volubilis* (Linnaeus) R.E. Norris, as well as biocenosis of seagrass *Posidonia oceanica* (L.) Del. and *Cymodocea* sp. or *Zostera* sp. have been shown.

The first studies that were specifically related to the flora of benthic algae and marine flowering plants in Boka Kotorska Bay and which have produced the most detailed view of the taxonomic structure of phytobenthos in this area so far were conducted by Antolić and Špan [14]. Their research lasted for 5 years (1985–1989) and was conducted by autonomous diving at 12 transects from surface up to 30 m depth. Given the taxonomic nomenclature of that time, 236 taxa (204 species, one subspecies, 22 varieties, six forms, and three stages) of benthic algae and two species of seagrass *P. oceanica* and *Cymodocea nodosa* (Ucria) Ascherson were determined. With the number and percentage, representatives of *Rhodophyta* dominated with 146 taxa or 61.9%, followed by representatives of *Ochrophyta* with 46 taxa or 19.5% and *Chlorophyta* with 44 taxa or 18.6%.

In relation to the information on the open part of the Montenegrin coast [15], the same number of higher taxonomic categories was found, while the number of lower taxonomic categories (families, genera, species, varieties) was significantly different. In addition, the biggest differences were found in the class of Chlorophyceae. Compared to the studies of benthic flora of the eastern part of the southern Adriatic, 57.3% of the total number of taxa (412) was found in Boka Kotorska Bay [16]. In the phylum Rhodophyta, 60.1% of the total number of determined taxa was found, 48.9% in Charophyta, and 58.7% in *Chlorophyta*.

The coefficient R/P (numerical relation between taxa in phylum Rhodophyta and Pheophyta (now Ochrophyta)) now amounts to 3.2 and was slightly lower than the one for the open waters of the Montenegrin coast (3.4) and surroundings of Dubrovnik (3.3) and relatively a lot higher than that for the entire eastern part of the southern (2.6) and the central part of the Adriatic (2.2) [13, 16].

Analysis of representation of certain floral elements from different phytogeographical regions of benthic flora of southern and central Adriatic showed that elements of the same phytogeographical regions were represented in both floras which are normally present in the Adriatic, but with a different numerical representation. This applies particularly to the representatives of the Atlantic-Mediterranean and endemic-Mediterranean region, which are the most numerous and which together comprise 409 taxa in the central Adriatic and make 77% of determined taxa and in the southern Adriatic are present with 334 taxa, but make 81.1% of all determined taxa [16].

According to current findings, 219 species were found in Boka Kotorska Bay (Annex), whose taxonomy is compliant with www.algaebase.org [17], and phytogeographical regions were established by slightly simplified groups of floral elements outlined by Giaccone et al. [18] and Špan and Antolić [19]. In this way, the following categories were defined: A – Atlantic (which includes Ab, Atlantic-boreal; At, Atlantic tropical; and Abt, Atlantic-boreal-tropical), AP – Atlanto-Pacific (which includes Apo, Atlanto-Pacific holo; Apt, Atlanto-Pacific tropical; and Aptc, Atlanto-Pacific tropical cold), IA – Indo-Atlantic (which includes IAo, Indo-Atlantic holo; IAt, Indo-Atlantic tropical; and IATC, Indo-Atlantic tropical cold), C – cosmopolitan, SC – subcosmopolitan, IP – Indo-Pacific, CB – circumboreal, CT – circumtropical, and EAD – Adriatic endemic.

The highest number of identified taxa in the Bay belongs to the Atlantic phytogeographic element (35.1%), followed by the Mediterranean (18.9%) and cosmopolitan (12.2%) (Fig. 3). Endemic species of the Adriatic Sea are presented with only 0.5%, i.e., with only one species (*Fucus virsoides* Agardh). Such a situation with a small number of Adriatic endemic elements and a high number of the Atlantic-Mediterranean elements has already been ascertained for the South Adriatic and differs from the central Adriatic, which has more endemic-Adriatic and less Atlantic-Mediterranean elements and shows the specific character of the Adriatic [16].

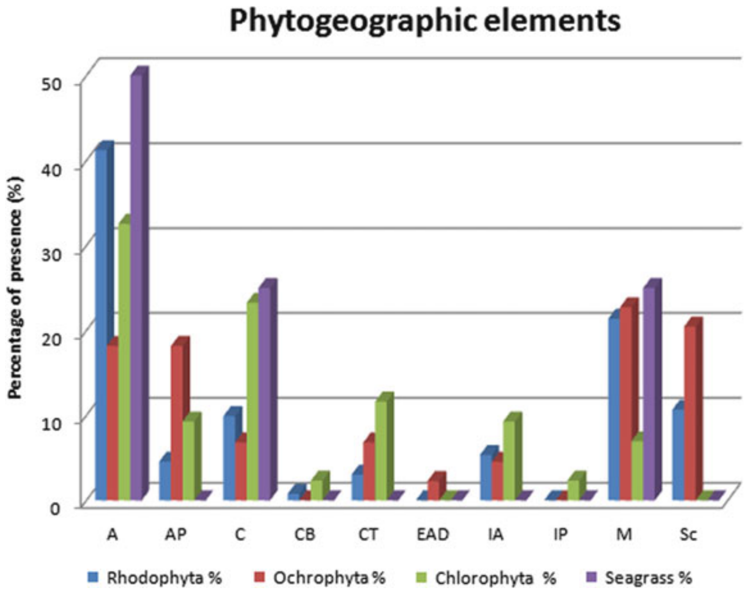

Fig. 3 Percentile representation of different floral elements according to groups of phytobenthos (A, Atlantic; AP, Atlanto-Pacific; IA, Indo-Atlantic; C, cosmopolitan; SC, subcosmopolitan; IP, Indo-Pacific; CB, circumboreal; CT, circumtropical; and EAD, Adriatic endemic)

3 Seagrass

Seagrass is a flowering plant secondarily adapted to life in the aquatic environment, and the term "seagrass" was defined by Arber in 1920 as plants that meet the following characteristics: (a) to grow in seawater (obligate halophytes), (b) to be fully immersed in water (submerged), (c) must be rooted strong enough to resist the impact of the tide, and (d) must complete life cycle in submersed conditions (hydrophilic pollination) [20]. Biocenoses of seagrass, even though they have a relatively low biomass production compared to terrestrial ecosystems, are much richer in comparison to plankton biocenoses [21]. Moreover, they play an indispensable role in enriching the bottom layers of water with the oxygen, strengthening of the sediment, and creation of biocenoses suitable for housing, feeding, and reproduction of many plant and animal species [22, 23].

The most typical biocenosis of seagrass in the Mediterranean is a meadow of the seagrass *Posidonia oceanica* (L.) Del. (commonly known as Neptune grass) (Fig. 4). About the importance and respect that has been given to this plant speaks the fact that a genus is named by Poseidon, the god of sea by the ancient Greeks. This species may inhabit the seabed at depths of up to 40 m, while its companion in shallow waters, at depths ranging from 1 to 10 m, is *Cymodocea nodosa* (Ucria) Asch (Fig. 5). The name of this genus comes from the name of Nereids Cymodocea, which according to Greek mythology was the companion of the god Poseidon

Fig. 4 *Posidonia oceanica* meadow

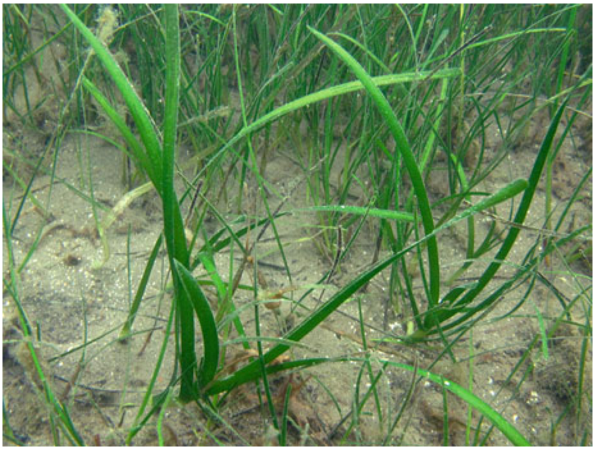

Fig. 5 *Cymodocea nodosa* around few shoots of *Zostera marina*

[20]. Similar in structure, in shallow waters, are species *Zostera noltei* Hornemann and *Zostera marina* Linnaeus (Fig. 5) that are significantly less present on the Montenegrin coast [24, 25].

According to research of Mačić and Pal [24], meadows of marine flowering plants *P. oceanica* and *C. nodosa* in Boka Kotorska Bay are very numerous, and schematic overviews of these biocenoses are shown in Figs. 6 and 7.

As it could be observed, biocenoses of both species are considerably more numerous in the outer part of the Bay, and they extend up to the highest depths at the very entrance to the Bay. For the species *P. oceanica*, the largest known depth in the Bay is 27 m (at the location of the island Mamula), and meadows of its companion in shallow waters, the species *C. nodosa*, were reported up to 4–5 (7) m. In the meadows of *Posidonia* at shallow depths (1–10 m), as is the case in the Bay of Herceg Novi, very strong waves could lead to erosion of the bottom and partial degradation of meadows. If the directions of the intermatte channels coincide

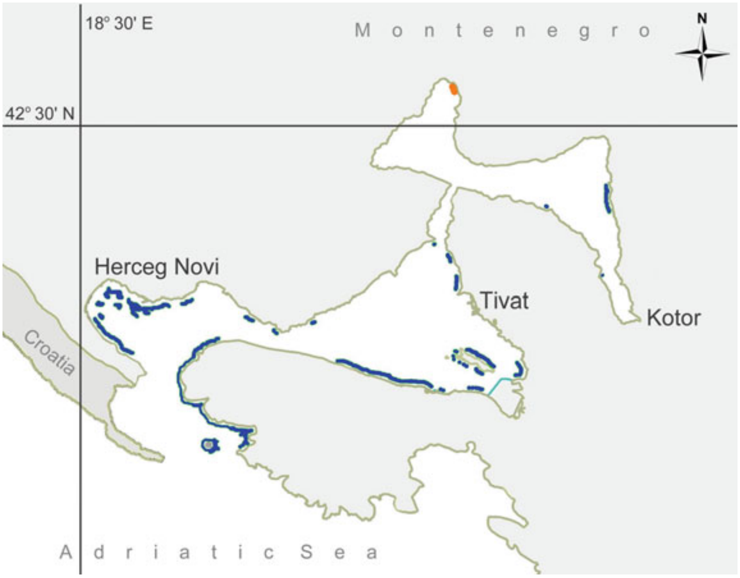

Fig. 6 Meadows of seagrasses (*blue color*) *Posidonia oceanica* and (*orange color*) *Zostera marina*

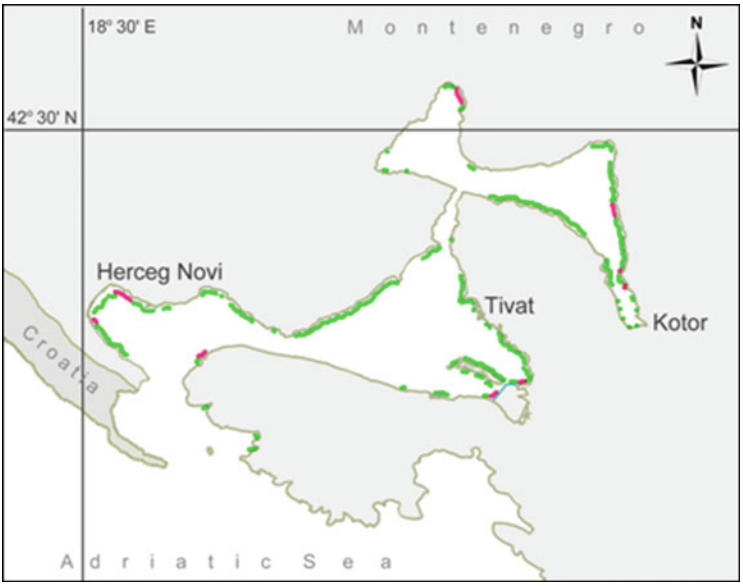

Fig. 7 Meadows of seagrass (*green color*) *Cymodocea nodosa* and (*red color*) *Cymodocea nodosa* and *Zostera noltei*

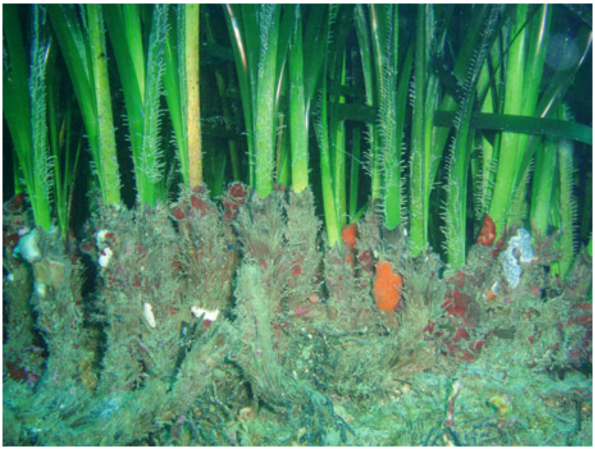

Fig. 8 Vertical (orthotropic) shoots of *Posidonia oceanica*

with the direction of water flow, they eventually expand and cause heavy damage of the meadow. Large amounts of fallen leaves, other detritus, and marine litter accumulate in intermatte channels especially in late autumn and early winter, and with a stronger movement of the sea during the winter months, they are washed out toward and on the coast. By eliminating fallen leaves, part of rhizomes of *Posidonia*, and other detritus on the coast, "banquettes" are created. In some Mediterranean countries, "banquettes" may be higher than 1 m, building specific coastal habitat, which is getting smaller, primarily due to the cleaning of beaches and their use for tourism purposes. In the Bay, "banquettes" are very small in size and mostly removed from the beaches.

In the Bay of Kotor, seagrass meadow of *P. oceanica* is mainly built of orthotropic (vertical) shoots (Fig. 8), while in the horizontal (plagiotropic) shoots, it is less frequent. This is because in this part of the Bay, movements of water are very weak, which leads to the deposition of the finest particles of sediment. The plant is facing a burial of leaves, and in order to avoid such a fate, it reacts by rising from the ground, i.e., by vertical growth [24].

Density of underwater meadows of this seagrass in the Bay of Kotor is quite small (286 shoots/m^2) compared to data from other parts of the Mediterranean [26]. However, it should be kept in mind that these data refer to three different locations within the Bay (Kotor, Tivat, and Herceg Novi), to a depth of 7 m, and in the part of Tivat and Kotor Bay on that depth, the seagrass meadows of *P. oceanica* are not typically developed. In the inner part of the Bay in particular, there is a large inflow of freshwater causing a decrease in salinity, which does not favor the growth of *P. oceanica* [26, 27]. In addition, due to the erosion of the surrounding terrain, but also because of the organic load originating from municipal wastewaters and plankton production, water transparency is significantly reduced, which together with reduced salinity is probably the main reason of atypically developed meadows of *P. oceanica* in the inner part of the Bay.

The presence of the species *Z. marina* in the past was reported to the Bay of Tivat and Herceg Novi [28], while for the Bay of Kotor and Risan, Stjepčević and Parenzan [12] reported the presence of the species *Cymodocea* sp. or *Zostera* sp. Mačić and Pal [24] reported the presence of the species *Z. noltei* on several locations (Fig. 7), while *Z. marina* was found in only one location in the Bay of Risan (Fig. 6) [25]. This finding of the species *Z. marina* at the location of Risan is the first accurate finding for this species in the Boka Kotorska Bay. The reason is probably the fact that only few shoots of the seagrass *Z. marina* were found, which are much more difficult to spot during the summer period, when other species are in the maximum of vegetation and when most of the earlier studies were performed. Considering that in previous research of Stjepčević and Parenzan [12] the type of species was not specified, from this time/distance, it is impossible to claim whether the meadows of *Z. marina* were much more extensive in the past or this type of seagrass was present in the Bay of Risan in only small numbers from earlier. Still, due to many meadows of the seagrass *C. nodosa* present over the whole Boka Kotorska Bay (Fig. 7), it seems likely that *Z. marina* was present with a very small number of shoots and that earlier reference to the meadows of this species could be a misidentification.

At marked locations for the species *Z. noltei* (Fig. 4), no monospecies underwater meadows were found, but *Z. noltei* builds meadows together with the seagrass *C. nodosa*. Meadows of these two species are registered at depths of 1–3 (4) m on muddy surfaces. Since reduced salinity is often the case in the Boka Kotorska Bay [7, 12], it is likely to have a positive effect on the development of these populations, because studies under laboratory conditions show that reduced salinity of 1–10 ppt stimulates germination of the species *Z. noltei* [29]. However, *Z. noltei*, unlike *P. oceanica* and *C. nodosa*, has no ability of vertical growth and can only survive in environments where erosion and sedimentation are in a dynamic equilibrium [22]. In the Bay, the flow of water masses, compared to the high seas, is of significantly smaller intensity, but the sedimentation is higher, due to erosion from the surrounding hills and the urban wastewater discharge, so this is probably the main reason why these meadows are scarce and endangered.

Furthermore, some authors consider the genus *Ruppia* to belong to the group of seagrasses, but according to Den Hartog [22], the species within this genus are not true seagrasses, because they do not occur in oceanic water with consistently high salinity. So, despite its Latin name, *Ruppia maritima* L. is not a seagrass, and maybe the best description for this species is a salt-tolerant freshwater plant. Still, here we will mention the finding of the species *R. maritima* in the inner part of the Bay, on the site of Morinj, because it provides a suitable habitat and food for wildlife. This species is distributed worldwide, occurring in both temperate and subtropical estuaries, bays, and lagoons and prefers brackish water less than 25 ppt salinity [30], but never before was mentioned for Boka Kotorska Bay.

4 Threats

Covering over two-thirds of Earth, the oceans and coastal waters have been viewed as unlimited sources of food, transportation, energy, and waste removal. The free use of the seas has been the prevailing philosophy of governments up to the middle of the twentieth century when environmentalists, the fishing industry, and managers of bays and estuaries began to identify serious losses and increasing levels of pollution. Human influences on marine plant communities can be grouped into direct impacts including mechanical damage, pollution, and biological damage and indirect effects such as global/regional warming and changes in sea level. On the other hand, the positive side in human affairs is the use of marine plants that with proper management can be renewable resources for farming, food, and industry [31].

Mechanical damages of phytobenthos in the Boka Kotorska Bay are mainly the result of new construction on the coast. In the Bay, which in some parts was urban area for centuries, such influence was practically inevitable, due to the construction of ports and small piers. However, with increasing intensity of urbanization, there has been excessive construction on the coast (in many cases even illegal building), so a great part of the coast of Boka Kotorska Bay is no longer natural.

Apart from the construction of small piers, at the large part of the coast, in order to build beaches for purposes of tourism, the coastal area was being leveled and filled with pebbles. In this way, some coastal phytobenthic communities were covered and physically completely destroyed. Furthermore, recovery in these areas was hampered due to the renourishment of beaches almost every year. These kind of changes are very easy to spot comparing old and new aerial photographs. Unfortunately, data for the Bay of Risan are for concern, because regressions of *C. nodosa* meadows were indicated even for more than 60 % in the last 35 years [25]. High regression is also occurring in other parts of the Bay, but unfortunately there is no published data which could provide more detailed information.

Another type of physical destruction of phytobenthos refers to the extraction of protected mollusk – date shell (*Lithophaga lithophaga* L.). Although this species of mollusks is protected and its collection prohibited, as well as its sales and consumption [32], public awareness about the negative impact on the environment has not been developed, and unfortunately inspection services and the ministries are not dedicated enough and determined to prevent this illegal activity.

Due to the intensive development of nautical tourism and still poorly defined zones for anchoring, it is expected that the negative physical impact of anchors will be increasing. In this regard appropriate measures should be taken for ensuring moorings that would replace anchoring in meadows of seagrass, especially in locations that are popular for nautical tourism, such as Žanjice, Dobreč, Igalo, and Kukuljina.

Collection of certain species of phytobenthos for research and potential use as raw materials in various branches of industry can also cause physical damage and depletion of whole populations. In circumstances where the marine algae are increasingly becoming a raw material for various substrates applicable in the food, pharmaceutical, and cosmetic industries, as well as other activities, it is clear that detailed studies are necessary not only in biotechnology but also about the ecological potential of the individual species [33, 34]. Still, up to date in Montenegrin coast, only initial researches were made of quantities of biomass of some algae, as well as their eventual application in pharmacy [33, 35, 36].

Pollution is another aspect of the direct impact that is reflected mostly through the intake of various types of nutrients and toxic substances. The large inflow of mineral and organic materials, primarily not only due to discharge of untreated wastewater but also due to terrain configuration, is causing increased level of eutrophication, especially in the inner part of the Bay. The effects of eutrophication are many and include (1) decreases in dissolved oxygen that can reach anaerobic levels, (2) shifts in species composition and diversity decline, and (3) degradation of the habitat from decreased light transmittance due to increases in phytoplankton growth and increases in turbidity [31, 37].

Density of underwater seagrass meadows of *P. oceanica* in Boka Kotorska Bay is quite small compared to the data from other parts of the Mediterranean [26]. When only the Boka Kotorska Bay is in question, there are significant differences observed between the sites of Kotor, i.e., the inner part of the Bay, in relation to the outer part of the Bay, i.e., sites of Tivat and Herceg Novi [24]. In addition, it is important to note that the length of adult leaves shows great variability (from 15.7 to 76.2 cm). Between the length of undamaged adult leaves and the length of sheaths, positive correlation in many underwater meadows of this plant was determined [38], and the research of Mačić and Pal [24] confirms that for the Boka Kotorska Bay. That is why, in relation to the smallest length of sheaths in the Bay of Kotor, we can conclude that at the site of Kotor, the adult leaves are significantly shorter than those on locations of Tivat and Herceg Novi. In addition, at the site of Kotor, significantly lower values were found for the lengths of intermediate and juvenile leaves, which is also reflected in reduced total leaf area on the site of Kotor. As a result, organic production of these meadows is being significantly lower in relation to the meadows in the outer part of the Bay. The main reason for this situation, in addition to reduced salinity, is too high quantity of nutrients causing phytoplankton bloom [37]. In fact, these circumstances, as well as the bloom of other leaf epiphytes, cause the reduction of the amount of light that reaches the leaves of the seagrass. In the most drastic conditions, intensity of photosynthesis is reduced to minimum or completely interrupted, and the underwater meadows of these species are dying out. With the regression of *Posidonia* meadows, numerous fauna species are disappearing and these areas are partly occupied by seagrass *C. nodosa*. This species is less demanding in terms of quality of substrates and seawater, but cannot provide more stable conditions within its meadows, and that is why these biocenoses are significantly poorer than the previous ones. Also, this seagrass contributes little to stability of sediment, and siltation of benthos is thus increased. As these conditions correspond to a small number of organisms, such sites are becoming poorer and completely altered.

When analyzing historical data for the inner part of the Bay, Stjepčević and Parenzan [12] report meadows of seagrass near the town of Risan along the coastline of about 2,200 m, while recently surveyed meadows cover only 951 m of the coastline [25]. In the Bay of Morinj, degradation is even more intensive because *C. nodosa* meadows that earlier were referred to having a coast length of 1,284 m now are confirmed for just 290 m off the coastline. If we consider the total length of the coastline, where colonies of seagrass were previously referred, in the Bay of Risan, that is, 3,484 m, now this length is only 1,377 m of the coastline [25]. If we have in mind that these meadows suffered significant regression in terms of vertical distribution as well (most likely due to reduced transparency of seawater), it can be concluded that in the Bay of Risan for the past 35 years, more than two-thirds of the seagrass meadows disappeared. This level of regression should be alarming, particularly bearing in mind that with the withdrawal of these meadows, many other organisms disappear, changing the overall composition of marine biocenosis. Numerous activities on the collection and disposal of wastewater from the Bay of Kotor and Risan will certainly result in improvement in the quality of seawater. But the question remains whether these actions will be completed soon, while we still have seagrass meadows present and, then, how much time will be needed for their recovery.

When we talk about pollution with toxic substances, we often referred to heavy metals, although it should be kept in mind that different heavy metals are normally found in seawater, in low concentrations, and as such are not toxic. Metals such as mercury (Hg), cadmium (Cd), lead (Pb), arsenic (As), copper (Cu), and chromium (Cr) occur in industrial and domestic wastes and they can contaminate seawater and coastal area [31]. Due to their low solubility, usually they are not found in high concentrations in seawater, but they can reach higher levels in organisms via biomagnification. Due to many years of life seagrass have, they are often considered as one of the indicator species for the monitoring of heavy metal concentrations in the marine environment.

Distribution of the relative concentration of some investigated metals in various plant tissues shows that for most of the elements in the seagrass *P. oceanica*, little higher concentration was measured in the leaves than in the part of the root and rhizomes, which is explained by the large metabolic activity of leaves [39, 40]. On the other hand, a much higher amount of Cr was recorded in the root and rhizomes. As the bottom of Boka Kotorska Bay on different locations is made up of clay elements (which can contain higher amounts of this element) and how large amounts of municipal wastewaters flow into the Bay (which also contain large amounts of Cr) [41], it is likely that this affected the higher concentration of Cr in the lower parts of the seagrass (which are normally in the most direct connection with the bottom and sewage sludge). This is particularly prevalent with the species of *C. nodosa*, which is specific for substrates containing large amounts of organic matter. According to Brix and Lyngby [42], the acceptance of large amounts of Cr in the lower part of the plant is likely contributed by much greater surface area as compared to the volume.

Compared with data from the literature, the values reported by Mačić and Sekulić [40] were significantly greater for Pb and Cr. Lead is an element that is very reactive, and in all water basins, its concentrations are highest near the source of pollution [41]. Large amounts of this element are present in sewage sludge as well [41], and because of the inflow of urban wastewater into the Bay, it is possible to have large amounts of this element in the sediment. The input of this element from the atmosphere should not also be ignored, because it is the main mode of introduction of this element in the Mediterranean Sea [42]. So far, the analysis of marine sediment in Boka Kotorska Bay shows increased concentrations of elements such as Pb, Cd, Cu, Hg, As, Cu, and Zn [43, 44]. As *P. oceanica* was suggested for the species bioindicator of concentrations for Cd, Cu, and Pb [45] and species *C. nodosa* as a bioindicator for the elements Cr, Mn, and Cu [46], seagrass tests should be repeated and extended with a large number of samples and simultaneous analysis of seawater and sediment, in order to be able to assess the level of bioaccumulation.

It is known that the level of toxicity of heavy metals is highly dependent on the physicochemical form in which they are found, although the direct effects of these elements have not been fully understood. There is even less information on the impact of radioactive isotopes, which are also found in the medical waste and some military weapon. At the entrance of Boka Kotorska Bay, at the Cape of Arza, after the bombing with radioactive uranium missiles (by NATO in 1999), the Center for Ecotoxicological Research (CETI) carried out repair of the parts of the coastal zone [47]. However, no testing was performed of the seawater and organisms of that part of the Bay in order to determine potential radioactivity and bioaccumulation of radioactive isotopes in the food chain of marine organisms.

Synthetic hydrocarbons such as pesticides, herbicides, PCBs, and antifouling compounds are toxic substances, but they usually occur in such low concentration in seawater that they do not pose a serious problem. Even so, biomagnification of these compounds can cause their accumulation in food chains. Antibiofouling organotins such as triphenyltin (TPT) and tributyltin (TBT) are extensively used as biocides on pilings and boat hulls. As biocides, these compounds are very toxic to macroalgae, apparently affecting mitochondria development and function [31]. Unfortunately, because of their long life span, biocides can remain in the sediment of harbors and bays for many years causing a variety of impacts on marine plants and their associated fauna [31]. This is particularly important bearing in mind the shipyard Bijela and the marina Porto Montenegro, which also used to be the shipyard “Arsenal.” In this sense, it would be good to take measures of remediation of marine sediment at these locations, as soon as possible, which had previously been marked as black spots, especially for heavy metals Cu, As, Hg, and Pb [48].

With the increase in intensity of nautical tourism and trade in general, the risk of oil spill is increasing. In various cases of oil spill, the worst negative impacts on phytobenthos were related to mangroves and intertidal communities, but also a much worse effect was in bays compared to open sea and rocky surface exposed to strong currents [31]. For these reasons, all precautionary measures must be taken to ensure that spills of oil and its derivatives are prevented and to act promptly and adequately in potential accident situations.

Marine litter is usually not a direct problem for marine plant communities and may even offer new, more or less solid substrates for macroalgae and other epiphytes. However, marine litter can cause physical damage to an intertidal

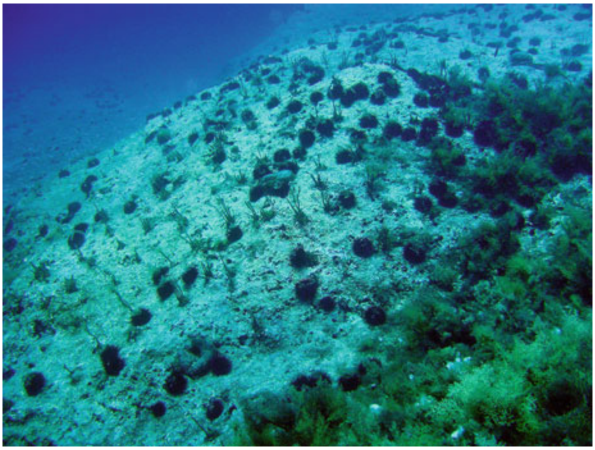

Fig. 9 Overgrazing of seaweed communities by urchins

community by covering substrata and if of sufficient size will remove plants during storms. Unfortunately, there are many locations in Boka Kotorska Bay where there is a large amount of solid waste that is not biodegradable and which does not belong there. Various cleaning actions of the Boka Kotorska seabed have been realized so far, with the aim of rising public awareness about the marine debris and importance of the marine ecosystem protection.

Another threat is coming from overfishing and disruption of the food chain. Overgrazing of seaweed communities by urchins (Fig. 9) is linked to the lack of their natural fish predators because of overexploitation [49]. In addition, the previously mentioned illegal collection of date shells that physically destroys the habitat and all sessile organisms on it further exacerbates the situation and slows down the renewal of macroalgal communities [50, 51]. Furthermore, as coastal biocenoses of macroalgae serve as a breeding site for many economically important species of fish, regressions described above or caused by pollution and other impacts are causing a decrease in the average adult size and volume of fish catches, as well as many consequential cascading effects [31, 49].

More recently a growing problem is introduced, especially invasive species [52]. In most examples, the exotic species will suppress resident plants through niche replacement and eventually alter the community structure and function [53, 54]. At the entrance of Boka Kotorska Bay, two species of invasive algae were noted, and these are *Caulerpa cylindracea* Sonder [53] and *Womersleyella setacea* (Hollenberg) R.E. Norris [55], but there is no monitoring of these algae and their impact on autochthonous biocenoses.

Indirect influences such as climate change are increasingly becoming evident not only for phytobenthos, but for all living organisms. Even a small increase in temperature causes changes in distribution of many marine organisms, which can cause major shifts in the biogeography of marine plant communities. Furthermore, fluctuation in sea level has been rapid on a historical basis, suggesting that tidal communities can survive. However, the current melting of ice at the poles and the sea level rise are faster than what happened in the past, so wetlands, of the plant communities, for now seem the most vulnerable because of that kind of changes [31]. In addition to changes in sea level, global warming would reflect an increase in atmospheric CO_2 levels and thus increased availability to submerged plants. There are many assumptions on how would macroalgae react in that case, and Beer and Koch [56] suggest that should global CO_2 levels rise, nearshore seagrasses may proliferate and outcompete macroalgae. On the other hand, increased UV radiation, which is related to holes in the ozone layer, may cause enhanced cellular and photosynthetic damage for diverse organisms and, in particular, seaweeds, phytoplankton, and seagrasses [57].

However, assemblages of macroalgae and seagrass are found mostly in shallow, coastal regions, where they were most exposed to the negative impacts of man, which caused the regression of these settlements around the world [25, 58]. The loss of a large percentage of these communities has resulted in significant decreases in water quality and marine animal wildlife [59]. It is a paradox that many of the actions of protection were initiated not because of those who live directly of the sea (fishermen and sailors), but because of the requirements of the modern consumer society, which often perceives the sea only as a leisure and recreation [60]. This is why many of the actions deal with resolving locally limited problems, primarily bearing in mind the demands of the tourism industry and economic viability. However, a great number of scientists warn that pollution of the sea does not only reflect the deterioration of parameters that travel agencies considered as priority, but that "invisible" effects of pollution are much greater and more dangerous, such as improper sanitary quality of seafood, overfishing of resources, bioaccumulation of various toxic substances, degradation and disappearance of indigenous communities, a growing number of allochthonous and invasive species, etc. [25, 58, 60].

The importance of seagrasses and some macroalgae, as structural and functional components of phytobenthos, is underlined in many cases by a great number of researchers, so more attention is paid to these plants, and even according to the EU Habitats Directive [61], colonies of seagrasses are categorized as priority habitats. In addition, since these are perennial plants, relatively easily available, they are very suitable for monitoring of average values of the marine environment, as well as the possible effects caused by various human activities. According to the EU Water Framework Directive [62], the main goal is to prevent degradation and to maintain the good status of ecosystems. Good condition of the ecosystem is not always easy to define, but it was agreed, on the basis of biological, physical, chemical, and hydrographic parameters, to determine whether the tested part of the aquatic ecosystem is significantly different from the reference condition for this type of water as a whole. In addition, the reference condition is an indicator of the state of this type of ecosystems with very weak anthropogenic influence, and in the ideal cases, it should be defined according to historical data.

For all these reasons, we need further research of phytobenthos, better use of these still insufficiently known resources, and effective protection measures.

5 Conclusions

Phytobenthos was mostly hidden from the eye of researchers in the past and in relation to fisheries and edible resources from the sea and was of far less economic and even scientific interest. The development of well-known scientific and cultural centers, such as Venice, Padua, Vienna, Rome, Trieste, and others, contributed to the intensification of research of the Adriatic Sea (especially its northern part), and at the end of the nineteenth century, the Adriatic Sea was one of the best floristically explored seas. Unfortunately, research of phytobenthos in Boka Kotorska Bay did not start until the second half of the twentieth century. Linardić was among the first to stress the particularities of the Boka Kotorska Bay and its phytobenthos. During the exploration of the eastern Adriatic coast (in 1939), he defined Boka Kotorska Bay as the southernmost location of distribution for *F. virsoides*, endemic species of the Adriatic. Furthermore, comparing the distribution of this alga on the eastern and western coast of the Adriatic Sea, Linardić highlighted the importance of not only the climate but also significantly more geomorphological and hydrographic factors.

For Boka Kotorska Bay, the first references of phytobenthos and biocenosis of seagrass were given by Karaman and Gamulin-Brida, Solazzi, and Stjepčević and Parenzan. But the first studies that were specifically related to the flora of benthic algae in Boka Kotorska Bay and which have produced the most detailed view of the taxonomic structure of phytobenthos in this area so far were conducted by Antolić and Špan. Their research lasted for five years (1985–1989), and given the taxonomic nomenclature of that time, 236 taxa (204 species, one subspecies, 22 varieties, six forms, and three stages) of benthic algae and two species of seagrass (*P. oceanica* and *C. nodosa*) were determined. According to current findings, 219 species were found in Boka Kotorska Bay (Annex 1), and Rhodophyta dominated with 146 taxa or 61.9 %, followed by representatives of Ochrophyta with 46 taxa or 19.5 %, and Chlorophyta with 44 taxa or 18.6 %. The highest number of identified taxa in the Bay belongs to the Atlantic phytogeographic element (35.1%), followed by the Mediterranean (18.9%) and cosmopolitan (12.2%). Endemic species of the Adriatic Sea are represented with only one species, *F. virsoides*.

Four species of seagrass are found, and meadows of *P. oceanica* and *C. nodosa* are very numerous, especially in the outer part of the Bay. *Z. noltei* builds meadows together with the *C. nodosa* at several locations, while *Z. marina* was found at one location only. Despite its Latin name, *R. maritima* is not a seagrass, and maybe the best description for this species is a salt-tolerant freshwater plant. Still, it is mentioned for the inner part of the Bay, on the site of Morinj, because this species never before was mentioned for Boka Kotorska Bay.

Human influences on marine plant communities are grouped into direct impacts including mechanical damage, pollution, and biological damage and indirect effects such as global/regional warming and changes in sea level. Physical damage caused by the construction of new buildings on the coast and by the leveling and filling of beaches, as well as with the illegal extraction of date shell, along with eutrophication has the most negative effects on phytobenthos in Boka Kotorska Bay. Regression of seagrass meadows is high, especially in the inner part of the Bay. The loss of a large percentage of these communities has resulted in significant decreases in water quality and marine animal wildlife, but more data are needed. Scientists warn that pollution of the sea does not only reflect the deterioration of parameters that travel agencies considered as priority, but that "invisible" effects of pollution are much greater and more dangerous, such as, for example, improper sanitary quality of seafood, overfishing of resources, bioaccumulation of various toxic substances, degradation and disappearance of indigenous communities, a growing number of allochthonous and invasive species, etc.

For all these reasons, we need further research of phytobenthos, better use of these still insufficiently known resources, and effective protection measures.

Annex

List of phytobenthos species in the Boka Kotorska bay (Phytogeographical regions (PhGR) are: A-Atlantic (which includes Ab-Atlantic boreal, At-Atlantic tropical and Abt-Atlantic boreal-tropical), AP-Atlanto-Pacific (which includes Apo – Atlanto-Pacific-holo, Apt – Atlanto-Pacific tropical and Aptc – Atlanto-Pacific tropical-cold), IA – Indo-Atlantic (which includes IAo – Indo-Atlantic holo, IAt – Indo Atlantic tropical and IATC – Indo-Atlantic tropical-cold) C – cosmopolitan, SC – subcosmopolitan, IP – Indo-Pacific, CB – circumboreal, CT – circumtropical, EAD – Adriatic endemic and Int-Introduced.

	Chlorophyta	PhGR
1	*Acetabularia acetabulum* (Linneaus) Silva 1952	IAt
2	*Anadyomene stellata* (Wulfen) C. Agardh 1822	CT
3	*Bryopsis corymbosa* J. Agardh 1842	M
4	*Bryopsis duplex* De Notaris 1844	Ab
5	*Bryopsis hypnoides* Lamouroux 1809	C
6	*Bolbocoleon piliferum* Pringsheim 1862	Aptc
7	*Caulerpa cylindracea* Sonder 1845	Int
8	*Chaetomorha linum* (Muller) Kutzing 1845	C
9	*Chaetomorpha aerea* (Dillwyn) Kutzing 1849	C
10	*Cladophora albida* Kutzing 1843	CB
11	*Cladophora coelothrix* Kutzing 1843	Iao
12	*Cladophora dalmatica* Kutzing 1843	Abt
13	*Cladophora echinus* (Biasoletto) Kutzing 1849	IP
14	*Cladophora glomerata* (Linnaeus) Kutzing 1843	Aptc
15	*Cladophora lehmanniana* (Lindenberg) Kutzing 1843	Ab
16	*Cladophora pellucida* (Hudson) Kutzing 1843	Ab
17	*Cladophora prolifera* (Roth) Kutzing 1843	Abt
18	*Cladophora socialis* Kutzing 1849	P
19	*Cladophora vagabunda* (Linnaeus) Van den Hoek 1963	Abt
20	*Codium bursa* (Olivi) C. Agardh 1822	Abt

(continued)

	Chlorophyta	PhGR
21	*Codium effusum* (Rafinesque) Delle Chiaje 1829	Iao
22	*Codium tomentosum* Stackhouse 1797	APo
23	*Codium vermilara* (Olivi) Delle Chiaje 1829	Iatc
24	*Dasycladus vermicularis* (Scopoli) Krassar 1898	At
25	*Derbesia tenuissima* (Moris & De Notaris) P.Crouan & H.Crouan 1867	Ab
26	*Derbesia tenuissima* (Morris et De Notaris) Crouan et Crouan 1867	Ab
27	*Enteromorpha intestinalis* (Linnaeus) Nees 1820	C
28	*Enteromorpha multiramosa* Bliding 1960	M
29	*Flabellia petiolata* (Turra) Nizamuddin 1987	C
30	*Halimeda tuna* (Ellis et Solander) Lamouroux 1816	At
31	*Phaeophila dendroides* (Crouan et Crouan) Batters 1902	CT
32	*Pseudochlorodesmis furcellata* (Zanardini) Borgesen 1925	Abt
33	*Rhizoclonium implexum* (Dillwyn) Kutzing 1845	Apo
34	*Siphonocladus pusillus* (Agardh ex Kutzing) Hauck 1884	Abt
35	*Ulva compressa* Linnaeus 1753	M
36	*Ulva lactuca* Linnaeus 1753	C
37	*Ulva linza* Linnaeus 1753	C
38	*Ulva rigida* C. Agardh 1823	C
39	*Ulvella lens* Crouan et Crouan 1859	C
40	*Ulvella leptochaete* (Huber) R.Nielsen, C.J.O'Kelly & B.Wysor 2013	Abt
41	*Ulvella viridis* (Reinke) R.Nielsen, C.J.O'Kelly & B.Wysor 2013	Abt
42	*Valonia macrophysa* Kutzing 1843	C
43	*Valonia utricularis* (Roth) C. Agardh 1823	CT

	Ochrophyta	PhGR
44	*Arthrocladia villosa* (Hudson) Duby 1830	Ab
45	*Asperococcus bullosus* Lamour 1813	SC
46	*Cladosiphon mediterraneus* Kutzing 1843	M
47	*Cutleria canariensis* (Sauvageau) I.A.Abbott & J.M.Huisman 2003	M
48	*Cutleria multifida* (Smith) Greville 1830	SC
49	*Cystoseira amentacea var. stricta* Montagne 1846	M
50	*Cystoseira barbata* (Stackhouse) C. Agardh 1842	M
51	*Cystoseira compressa* (Esper) Gerloff & Nizamuddin 1975	M
52	*Cystoseira corniculata* ssp. *laxior* Ercegović 1952	M
53	*Cystoseira crinita* Duby 1830	M
54	*Cystoseira crinitophylla* Ercegović 1952	M
55	*Cystoseira foeniculacea* (Linnaeus) Greville 1830	M
56	*Cystoseira spinosa* Sauvageau 1912	M
57	*Dictyopteris membranacea* (Stackhouse) Batters 1902	C
58	*Dictyota dichotoma* (Hudson) Lamouroux 1809	C
59	*Dictyota fasciola* (Roth) J.V.Lamouroux 1809	IAo
60	*Dilophus spiralis* (Mont.) Hamel 1939	Abt
61	*Ectocarpus siliculosus* (Dillwyn) Lyngbye 1819	SC

(continued)

	Ochrophyta	PhGR
62	*Elachista fucicola* (Velley) Areschoug 1842	APtf
63	*Elashista intermedia* Crouan et Crouan 1867	Ab
64	*Feldmannia irregularis* (Kutzing) Hamel 1939	C
65	*Fucus virsoides* (Donati) J. Agardh 1868	EAD
66	*Giraudia sphacelarioides* Derbes et Solier 1851	IAtc
67	*Halopteris filicina* (Grateloup) Kutzing 1843	APtc
68	*Halopteris scoparia* (L.) Sauvageau 1904	SC
69	*Myriactula rigida* (Sauvageau) Hamel 1931-'39	M
70	*Myriactula rivulariae* (Suhr in Areschoug) J. Feldmann 1937	Ab
71	*Myriactula stellulata* (Griffiths) Levring 1937	Ab
72	*Myrionema orbiculare* J. Agardh 1848	Apo
73	*Nereia filiformis* (J. Agardh) Zanardini 1846	At
74	*Padina pavonica* (Linnaeus) Thivy 1960	CT
75	*Ralfsia verrucosa* Areschoug 1847	Aptc
76	*Sargassum vulgare* C. Agardh 1820	CT
77	*Spermatochnus paradoxus* (Roth) Kutzing 1845	SC
78	*Sphacelaria cirrosa* (Roth) C. Agardh 1824	SC
79	*Sphacelaria fusca* (Hudson) S.F. Gray 1821	SC
80	*Sphacelaria plumula* Zanardini 1865	Ab
81	*Sporochnus pedunculatus* (Hudson) C. Agardh 1817	APo
82	*Stilophora tenella* (Esper) P.C.Silva 1996	SC
83	*Striaria attenuata* (C. Agardh) Greville 1828	Aptc
84	*Taonia atomaria* (Woodward) J. Agardh 1848	Abt
85	*Zanardinia prototypus* Nardo 1841	APo

	Rhodophyta	PhGR
86	*Acrochaetium daviesii* (Dillwyn) Nägeli 1862	APo
87	*Acrochaetium hauckii* Schiffner 1916	Ab
88	*Acrochaetium secundatum* (Lyngbye) Nägeli 1858	M
89	*Acrodiscus vidovichii* (Meneghini) Zanardini 1868	M
90	*Acrosymphyton purpuriferum* (J. Agardh) Sjostedt 1926	M
91	*Aglaothamnion tenuissimum* (Bonnemaison) Feldmann-Mazoyer 1941	SC
92	*Amphiroa rigida* Lamouroux 1816	Abt
93	*Anotrichium barbatum* (C.Agardh) Nägeli 1862	Abt
94	*Antithamnion cruciatum* (C. Arardh) Nageli 1847	M
95	*Apoglossum ruscifolium* (Turner) J. Agardh 1898	Abt
96	*Arachnophyllum confervaceum* (Meneghini) Zanardini 1843	Abt
97	Asparagopsis *armata* Harvey 1855	M
98	*Botryocladia botryoides* (Wulfen) Feldmann 1941	Ab
99	*Botryocladia chiajeana* (Meneghini) Kylin 1931	Abt
100	*Botryocladia microphysa* (Hauch) Kylin 1931	Ab
101	*Brongniartella byssoides* (Good. Et Woodwaed) Schmitz 1893	M
102	*Callithamnion corymbosum* (Smith) Lyngbye 1819	Sc

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	Rhodophyta	PhGR
103	*Callithamnion granulatum* (Duclouzeau) C. Aragdh 1828	SC
104	*Calosiphonia dalmatica* (Kutzing) Bornet Flahault 1883	M
105	*Catenella caespitose* (Withering) L.M.Irvine 1976	Ab
106	*Caulacanthus ustulatus* (Martens ex Turner) Kutzing 1843	Abt
107	*Ceramium bertholdii* Funk 1922	IAo
108	*Ceramium ciliatum* (Ellis) Duclouzeau 1806	SC
109	*Ceramium circinatum* (Kutzing) J. Agardh 1851	Ab
110	*Ceramium codii* (Richards) Feldmann-Mazoyer 1938	C
111	*Ceramium diaphanum* (Lightfoot) Roth 1806	Ab
112	*Ceramium echionotum* J. Agardh 1844	C
113	*Ceramium flaccidum* (Harvey ex Kützing) Ardissone 1871	C
114	*Ceramium rubrum* (Hudson) Agardh 1811	SC
115	*Champia parvula* (C. Agardh) Harvey 1853	At
116	*Chondracanthus acicularis* (Roth) Fredericq 1993	IAtc
117	*Chondria dasyphylla* (Woodward) Agardh 1817	Abt
118	*Chrysymenia ventricosa* (Lamouroux) J. Agardh 1876	APo
119	*Chylocladia verticillata* (Lightfood) Bliding 1928	M
120	*Compsothamnion thuyoids* (Smith) Nageli 1862	SC
121	*Corallina officinalis* Linnaeus 1758	M
122	*Corallophila cinnabarina* (Grateloup ex Bory) R.E.Norris 1993	IAo
123	*Crouania attenuata* (C. Agardh) J. Agardh 1842	Abt
124	*Cryptopleura ramosa* (Hudson) L.Newton 1931	Ab
125	*Dasya baillouviana* (S.G.Gmelin) Montagne 1841	Abt
126	*Dasya corymbifera* J. Agardh 1841	Ab
127	*Dasya hutchinsiae* Harvey 1833	Ab
128	*Dasya ocellata* (Grateloup) Harvey 1833	C
129	*Dasya punicea* (Zanardini) Meneghini Ex Zanardini 1841	Ab
130	*Dudresnaya verticillata* (Withering) Le Jolis 1863	Ab
131	*Erythrotrichia carnea* (Dillwyn) J. Agardh 1883	C
132	*Erythrotrichia investiens* (Zanardini) Bornet 1892	Ab
133	*Erythrotrichia reflexa* (Crouan & Crouan) Thuret ex De Toni 1897	Ab
134	*Eupogodon planus* (C.Agardh) Kützing 1845	Ab
135	*Gastroclonium clavatum* (Roth) Ardissone 1883	Ab
136	*Gelidiella lubrica* (Kutzing) Feldmann et Hamel 1934	Abt
137	*Gelidiella pannosa* (Bornet ex J. Feldm.) Feldmann et Hamel 1934	M
138	*Gelidium crinale* (Turner) Gaillon 1828	M
139	*Gelidium pussillum* (Stachouse) Le Jolis 1863	SC
140	*Gelidium serra* (S.G.Gmelin) E.Taskin & M.J.Wynne 2013	Apo
141	*Gelidium spathulatum* (Kutzing) Bornet 1892	C
142	*Gelidium spinosum* (S.G.Gmelin) P.C.Silva 1996	Ab
143	*Gracilaria armata* (Agarth) Greville 1830	Ab
144	*Gracilaria bursa-pastoris* (Gmelin) Silva 1952	SC
145	*Gracilaria dura* (C. Arardh) J. Agardh 1842	At

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	Rhodophyta	PhGR
146	*Gracilariopsis longissima* (S.G.Gmelin) M.Steentoft, L.M.Irvine & W.F. Farnham 1995	SC
147	*Griffithsia opuntioides* J. Agardh 1842	IAo
148	*Griffithsia phyllamphora* J. Agardh 1842	C
149	*Griffithsia schousboei* Montagne 1853	Abt
150	*Gulsonia nodulosa* (Ercegovic) J. Feldmann et G. Feldmann 1967	Ab
151	*Halymenia elongata* C.Agardh 1822	M
152	*Halymenia floresii* (Clemente) C. Agardh 1807	Abt
153	*Halymenia pluriloba* Ercegović 1949	M
154	*Herposiphonia secunda* (C. Agardh) Falkenberg 1901	SC
155	*Heterosiphonia crispella* (C.Agardh) M.J.Wynne 1985	SC
156	*Hildenbrandia rubra* (Somerfeld) Meneghini 1841	M
157	*Hydrolithon farinosum* (J.V.Lamouroux) Penrose & Y.M.Chamberlain 1993	CT
158	*Hypnea musciformis* (Wulfen) Lamouroux 1813	SC
159	*Jania rubens* (Linnaeus) Lamouroux 1812	APo
160	*Jania virgata* (Zanardini) Montagne 1846	C
161	*Kallymenia microphylla* J. Agardh 1851	CT
162	*Kallymenia reniformis* (Turner) J. Agardh 1842	C
163	*Laurencia obtusa* (Hudson) J.V.Lamouroux 1813	IAtf
164	*Lejolisia mediterranea* Bornet 1859	Ab
165	*Liagora viscida* (Forsskaal) C. Agardh 1822	CB
166	*Lithophyllum cystosirae* (Hauck) Heydrich 1897	C
167	*Lithophyllum incrustans* Philippi 1837	CT
168	*Lithophyllum racemus* (Lamarck) Foslie 1901	IAo
169	*Lithothamnion corallioides* P.L. Crouan & H. M. Crouan 1867	Ab
170	*Lomentaria articulata var. linearis* Zanardini 1841	M
171	*Lomentaria chylocladiella* Funk 1955	Ab
172	*Melobesia membranacea* (Esper) Lamouroux 1812	M
173	*Mesophyllum expansum* (Philippi) Cabioch & M.L.Mendoza 2003	M
174	*Monosporus pedicellatus* (Smith) Solier 1845	IAo
175	*Nemastoma dichotoma* J. Agardh 1842	AT
176	*Neogoniolithon brassica-florida* (Harvey) Setchell & L.R.Mason 1943	APo
177	*Neogoniolithon mamillosum* (Hauck) Setchell & Mason 1943	M
178	*Osmundaria volubilis* (Linnaeus) R.E.Norris 1991	Ab
179	*Peyssonelia squamaria* (Gmelin) Decaisne 1839	At
180	*Peyssonnelia polymorpha* (Zanardini) Schmitz 1879	At
181	*Peyssonnelia rosa marina* Boudourescque et Denizot 1973	M
182	*Peyssonnelia rubra* (Greville) J. Aragdh 1851	SC
183	*Phyllophora crispa* (Hudson) P.S.Dixon 1964	M
184	*Phymatolithon calcareum* (Pallas) W.H.Adey & D.L.McKibbin 1970	Ab
185	*Platoma cyclocolpum* (Montagne) Schmitz 1894	Ab
186	*Pleonosporium borreri* (Smith) Nageli 1862	Ab
187	*Plocamium cartilagineum* (Linnaeus) Dixon 1967	Ab
188	*Pneophyllum fragile* Kutzing 1843	Abt

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	Rhodophyta	PhGR
189	*Pterocladia capillacea* (Gmelin) Bornet et Thuret 1876	SC
190	*Pterocladiella melanoidea* (S. ex Bornet) Santelices & Hommersand 1997	C
191	*Ptilothamnion pluma* (Dilwyn) Thuret 1863	SC
192	*Rhodophyllis divaricata* (Stackhouse) Papenfuss 1950	M
193	*Rhodymenia ardissonei* J. Feldmann 1937	Ab
194	*Rhodymenia pseudopalmata* (J.V.Lamouroux) P.C.Silva 1952	M
195	*Rodymenia ligulata* Zanardini 1843	Ab
196	*Rytiphlaea tinctoria* (Clemente) C. Agardh 1824	Ab
197	*Sebdenia dichotoma* Berthold 1884	Abt
198	*Sebdenia riodrigueziana* (J. Feldmann) Codomier ex Parkinson 1980	M
199	*Seirospora apiculata* (Meneghini) G. Feldmann-Mazoyer 1942	At
200	*Seirospora interrupta* (Smith) F. Schmitz 1893	M
201	*Seirospora sphaerospora* Feldmann 1942	M
202	*Spermothamnion johannis* Feldmann-Mazoyer 1941	M
203	*Spermothamnion repens* (Dillwyn) Rosenvinge 1924	Ab
204	*Sphaerococcus coronopifolius* Stackhouse 1797	M
205	*Sphondylothamnion multifidum* (Hudson) Nageli 1862	M
206	*Spyridia filamentosa* (Wulfen) Harvey 1833	M
207	*Stylonema alsidii* (Zanardini) K.M.Drew 1956	Ab
208	Titanoderma pustulatum (J.V.Lamouroux) Nägeli 1858	Ab
209	*Womersleyella setacea* (Hollenberg) R.E. Norris 1992	C
210	*Wrangelia penicillata* C. Agardh 1828	C
211	*Wurdemannia miniata* (Sprengel) Feldmann et Hamel 1934	Int

	Tracheophyta	PhGR
212	*Cymodocea nodosa* (Ucria) Ascherson 1870	Ab
213	*Posidonia oceanica* (Linnaeus) Delile 1813	M
214	*Ruppia maritima* Linnaeus 1753	C
215	*Zostera marina* Linnaeus 1753	C
216	*Zostera noltei* Hornemann 1832	Ab

References

1. Caselatto S (2008) Marine biology in the Adriatic Sea: an historical review. Proc Calif Acad Sci 59(12):191–2013
2. Ercegović A (1952) Prilog poznavanju nekih rodova crvenih alga u Jadranu 2:1–212
3. Dulčić J (2012) Povijest prirodoznanstvenih istraživanja Jadranskoga mora. Hrvatska akademija znanosti i umjetnosti & Institut za okeanografiju i ribarstvo, Split
4. Ercegović A (1937) Ispitivanja hidrografskih prilika i fitoplanktona u vodama Boke u jesen 1937. Godišnjak oceanografskog institute Kraljevine Jugoslavije 1:91–110
5. Ercegović A (1966) Pogled na floru i ekologiju plitkovodne vegetacije alga u srednjem Jadranu. Ekologija 1(1–2):55–75

6. Linardić J (1940) Prilog poznavanju geografskog rasprostranjenja jadranskog fukusa (*Fucus virsoides* (Don.) J. Ag.). Godišnjak oceanografskog institute Kraljevine Jugoslavije 2:115–122
7. Vouk V (1938) Bilješke o Jadranskom Fukusu (*Fucus virsoides* (Don.) J. Ag.). Godišnjak Oceanografskog instituta 1:153–159
8. Mačić V (2006) Seaweed *Fucus virsoides* J. Agardh in the Boka Kotorska Bay (south Adriatic sea). Annales Ser hist nat 16(1):1–4
9. Munda I (2008) Benthic marine algae as reflection of environmental changes in the Northern Adriatic Sea. In: Briand F (ed) CIESM workshop monographs - climate warming and related changes in Mediterranean marine biota, Helgoland, 27–31 May 2008
10. Karaman G, Gamulin-Brida H (1970) Contribution aux recerches des biocenoses benthiques du golfe de Boka Kotorska. Studia Marina 4:3–42
11. Solazzi A (1971) Reperti algologici delle Bocche di Cattaro. Thalasia Salientiana 5:3–18
12. Stjepčević J, Parenzan P (1980) Il Golfo delle Bocche di Cattaro-condizioni generali e biocenosi bentoniche con carta ecologica. Studija Marina 9–10:3–149
13. Rizzi L, Pignatti S, Froglia C (1967) Fora delle acque circostanti l'isola di Pianosa (Tremiti). Giorn Bot Ital 101(4):237–239
14. Antolić B, Špan A (1990) Istraživanja bentoske flore Bokokotorskog zaliva (Južni Jadran). Biosistematics 16(1):1–7
15. Špan A, Antolić B (1983) Prilog poznavanju fitobentosa Crnogorskog primorja (Južni Jadran). Studija Marina 13–14:87–110
16. Špan A, Antolić B (1989) Bentoska flora Južnog Jadrana. Biosistematics 15(2):93–104
17. Guiry MD, Guiri GM (2016) AlgaeBase. World-wide electronic publication, National University of Ireland, Galway. http://www.algaebase.org. Accessed 24 Apr 2016
18. Giaccone G, Colonna C, Graziano C et al (1985) Revisione della flora marina di Sicilia e isole minori. Boll Accad Gioenia Sci Nat Catania 18:537–582
19. Špan A, Antolić B (1999) The benthic marine flora of the Brač Island area (Middle Adriatic, Croatia). Acta Adriat 40(1):87–104
20. Sullivan M (1994) The taxonomy of seagrasses surveyed from the higher taxa down through to the family level. Department of Biology, Florida International University, Florida
21. Short F, Carruthers T, Dennison W et al (2007) Global seagrass distribution and diversity: a bioregional model. J Exp Mar Biol Ecol 350:3–20
22. Den Hartog C (1971) The dynamic aspect in the ecology of seagrass communities. Thalassia Yugoslavica 7(1):101–112
23. Garrido M, Lafabrie C, Torre F et al (2013) Resilience and stability of *Cymodocea nodosa* seagrass meadows over the last four decades in the Mediterranean lagoon. Estuar Coast Shelf Sci 130:1–10
24. Mačić V, Pal B (2001) Seagrass meadows in the bay of Boka Kotorska. Paper presented at the Zasavica 2001, Sremska Mitrovica, 2–5 May 2001
25. Mačić V (2014) Regresija morskih trava u Risanskom zalivu (Crna Gora). Paper presented at the 43. konferenciji o aktuelnim problemima korišćenja i zaštite voda, Voda 2014, Tara, 3–5 June 2014
26. Mačić V (2000) Morska cvjetnica *Posidonia oceanica* (L.) Del u Bokokotorskom zalivu. Paper presented at the 39. konferenciji o aktuelnim problemima korišćenja i zaštite voda, Zaštita voda 2000, Mataruška banja, 6–9 June 2000
27. Boudouresque CF, Bernard G, Bonhomme P et al (2012) Protection and conservation of *Posidonia oceanica* meadows. Ramoge and RAC/SPA, Tunis
28. Stjepčević J (1967) Makro-Mollusca Bokokotorskog zaliva. Studia Marina 2:3–64
29. Van lent F, Nienhuis PH, Verschuute JM (1991) Production and biomass of the seagrass *Zostera noltii* Hornem. and *Cymodocea nodosa* (Ucria) Aschers. at the Banc d Agruin (Mauritania, NW Africa): a preliminary approach. Aquat Bot 41(4):353–367
30. Thursby GB (1984) Nutritional requirements of the submerged angiosperm *Ruppia maritima* in algae-free culture. Mar Ecol Prog Ser 16(1–2):45–50
31. Dawes C (1998) Marine botany. Wiley, New York

32. Službeni list Republike Crne Gore (2009) Zakon o morskom ribarstvu i marikulturi. Sl. list 56
33. Lj T, Gašić MJ, Kljajić Z (1995) Polisaharidi algi jadranskog mora. Arhiv za farmaciju 45 (5):290–291
34. Špan A (1969) Quantities of the most frequent Cystoseira species and their distribution in the central and northern Adriatic. Paper presented at the VI International Seaweed Symposium, 6:383–387
35. Stanojković T, Konić-Ristić A, Kljajić Z et al (2011) Antioxidant, antiplatelet and cytotoxic activity of Cystoseira amentacea from the coast of Montenegro (South-East Adriatic Sea). Dig J Nanomater Biostruct 9(2):1842–3582
36. Mačić V (2013) Some characteristics of the *Cystoseira* (Phaeophyceae) assemblages in the intertidal fringe on the coast of Montenegro. Natura Montenegrina 12(2):325–333
37. Krivokapić S, Pestorić B, Kušpilić G et al (2011) Trophic state of Boka Kotorska Bay (Eastern Adriatic Sea). Fresenius Environ Bull 20(8):1960–1969
38. Guidetti P, Buia MC, Mazzela L (2000) The use of lepidochronology as a tool of analysis of dynamic features in the seagrass Posidonia oceanica of the Adriatic Sea. Bot Mar 43:1–9
39. Catsiki VA, Panayotidis P (1993) Copper, chromium and nickel in tissues of the Mediterranean seagrasses *Posidonia oceanica & Cymodocea nodosa* (Potamogetonaceae) from Greek coastal areas. Chemosfere 26(5):963–978
40. Mačić V, Sekulić P (2001) Investigation of mineral contents of seagrasses Posidonia oceanica (L.) Del. and Cymodocea nodosa (Ucria) Asch. Paper presented at the 30. konferenciji o aktuelnim problemima zaštite voda, Zaštita voda 2001, Aranđelovac, 12–15 June 2001
41. Kastori R (ed) (1997) Teški metali u životnoj sredini. Poljoprivredni fakultet Novi Sad
42. Brix H, Lingby JE (1983) The distribution of some metallic elements in eelgrass (Zostera marina) and sediment in the Limfjord, Dentark. Estuar Coast Shelf Sci 16:455–467
43. Joksimović D, Mihajlović R (2002) Heavy metals in sediments from Boka Kotorska. Studia Marina 23:49–56
44. Spahić E (ed) (2015) Informacija o stanju životne sredine u Crnoj Gori u 2014. godini. Agencija za zaštitu životne sredine Crne Gore Podgorica
45. Romeo M, Gnassia-Barelli M, Juhel T et al (1995) Memorization of heavy metals by scales of the seagrass Posidonia oceanica collected in the NW Mediterranean. Mar Ecol Prog Ser 120:211–218
46. Malea P, Charitonidis S (1999) *Cymodocea nodosa* (Ucria) Aschers. as a bioindicator of metals in Thermaikos gulf, Greece, during monthly samplings. Bot Mar 42:419–430
47. Mišurović A (ed) (2002) Dekontaminacija rta Arza od osiromašenog urana (DU). Centar za ekotoksikologiju (CETI), Vlada Crne Gore. http://mne.ceti.co.me/?portfolio=dekontaminacija-rta-arza-od-osiromasenog-urana-du#tab-id-2, 2002. Accessed 24 Apr 2016
48. Spahić E (ed) (2015) Informacija o stanju životne sredine u Crnoj Gori u 2014. godini. Agencija za zaštitut životne sredine http://www.epa.org.me/images/izvjestaji/Informacija-o-stanju-%C5%BEivotne%20sredine-u-Crnoj-G. Accessed 24 Apr 2016
49. Giudetti P, Fraschetti S, Terlizzi A et al (2003) Distribution patterns of sea urchins and barrens in shallow Mediterranean rocky reefs impacted by the illegal fishery of the rock-boring mollusc *Lithophaga lithophaga*. Mar Biol 143(1):1135–1142
50. Macic V, Thibaut T, Antolic B et al (2010) Distribution of the most common *Cystoseira* species on the coast of Montenegro (South-East Adriatic Sea). Fresenius Environ Bull 19 (6):1191–1198
51. Mačić V, Antolić B (2015) Distribution of rare Cystoseira species along the Montenegro coast (South-Eastern Adriatic Sea). Period Biol 117(3):57–63
52. Mačić LD, Gangai-Zovko B et al (2014) Monografija: alohtone vrste istočne obale južnog Jadrana, kratki pregled vrsta i ekologije. Institut za biologiju mora Univerziteta Crne Gore i institut za more i priobalje Sveučilište u Dubrovniku, Kotor
53. Mačiic V, Kašćelan S (2006) *Caulerpa racemosa* on the Montenegrian coast. Rapp. Comm.int. Mer. Paper presented at the 38th CIESM Congress, Istanbul, 9–14 April 2007
54. Zenetos A, Gofas S, Verlaque M et al (2010) Alien species in the Mediterranean Sea by 2010. A contribution to the application of European Union's Marine Strategy Framework Directive (MSFD) part I. Spatial distribution. Mediterr Mar Sci 11(2):381–493

55. Battelli C, Rindi F (2008) The extensive development of the turf-forming red alga Womersleyella setacea (Hollenberg) R. E. Norris (Rhodophyta, Ceramiales) in the Bay of Boka Kotorska, Montenegro (southern Adriatic Sea). Plant Biosyst 142(1):120–125
56. Beer S, Koch E (1996) Photosynthesis of marine macroalgae and seagrasses in globally changing CO2 environments. Mar Ecol Prog Ser 141:199–204
57. Larkum AWD, Wood WF (1993) The effect of UV-B radiation on photosynthesis and respiration of phytoplankton, benthic macroalgae and seagrass. Photosynth Res 36:17–23
58. Orth RJ, Carruthers TJB, Dennison WC et al (2006) A global crisis for seagrass ecosystems. Bioscience 56(12):987–996
59. Diliberto S (1989) Le fanerogame marine in Mediterraneo (sistematica-distribuzione-ecologia). Universita' degli studi di Palermo, Facolta di Scienze, Palermo
60. Zavodnik D, Zavodnik N (1985) Uticaj zagađivanja na životne zajednice u moru. Zbornik radova-Problematika procjene opasnosti od štetnih tvari u Jadranu JAZU, pp 135–160
61. EC Directive (1992) EC Directive on the conservation of natural habitats and of wild fauna and flora. Official Journal L 206, 22/07/1992 P. 0007 - 0050. http://data.europa.eu/eli/dir/1992/43/oj. Accessed 24 Apr 2016
62. EC Directive (2000) Directive of the framework for Community action in the field of water policy. Official Journal L 327, 22/12/2000 P. 0001 - 0073. Accessed 24 Apr 2016

Zooplankton Community in the Boka Kotorska Bay

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Abstract This study includes a review of recently published results regarding zooplankton in the Boka Kotorska Bay (since 2009), and comparison of these results with earlier investigations. Non-loricate ciliates were the most numerous microzooplankton in spring 2013 (37%). Loricate ciliates (tintinnids) values were low and similar to those recorded in the open Adriatic Sea. However, their diversity was quite high: 20 estuarine–neritic and 26 species typical of the open sea were identified. Copepod nauplii were dominant metazoan microzooplankton component (32%). Seven phylums and 81 mesozooplankton taxa were determined. Copepods were the most dominant group. Among them, *Oncaea*–cyclopoids and *Oithona nana* were the dominant copepod taxa at all stations. Heterotrophic dinoflagellate *Noctiluca scintillans* and cladocera *Penilia avirostris* were often extremely numerous during warm seasons. Changes in the zooplankton community noted during recent investigations can be linked with the observed climate changes identified in the Adriatic and Mediterranean Sea since the 1990s, which are reflected in: (1) zooplankton high densities in the winter period with a lack of spring peak; (2) domination of small-size cyclopoid copepods and decreasing of contribution of neritic calanoid species; (3) prolongation of high *Penilia avirostris* abundance in the

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autumn period; (4) spreading of invasive siphonophorae *Muggiaea atlantica* in the inner part of the Bay; (5) frequent outbreaks of gelatinous zooplankton; and (6) The first registered bloom of the ctenophore *Bolinopsis vitrea* in the Mediterranean in spring 2014, having a major impact on the regular planktonic food web system.

Keywords Boka Kotorska Bay, Mesozooplankton, Microzooplankton, South Adriatic, Spatial and temporal variability

Contents

1 Introduction

Planktonic communities play a vital role in the functioning of ecosystems and biogeochemical cycles [1]. Zooplankton is characterized by a high diversity of different taxonomic categories that occupy different ecological position and importance in the trophic network [2, 3]. Zooplankton is the main source of food for fish larvae; therefore, it has a significant impact on their survival, possibly more than temperature [4]. Information about the space-time variations of zooplankton community structure and succession of species, or group, is of fundamental importance for understanding the functioning of ecosystems in different environments. Many studies have shown that zooplankton can be used as an indicator for monitoring the status of marine ecosystems, as well as climatic changes [5, 6].

The first data on zooplankton pointed to poor fauna of the Boka Kotorska Bay [7, 8]. Among zooplankton species, only copepod *Oithona nana* was found in large numbers. Systematic research started after 1964 with the founding of the Institute of Marine Biology in Kotor. Planktonic copepods remain the main subject of research, and Vukanić [9–11] investigated their annual cycle in the Bay. The author found 70 copepod species and concluded that biodiversity increased from the inner area toward the open sea stations. The subsequent studies used an ecological approach linking hydrographic parameters and abundance of phytoplankton with zooplankton population densities [12–14]. More frequent studies in the Boka Kotorska Bay resulted in a detailed analysis of other mesozooplankton groups: appendicularians [15]; chaetognaths [16]; hydromedusa [17]; cladocerans [18]; and pteropods [19]. Mesozooplankton were collected by vertical tows of plankton nets (250–125 m), and most of the results were shown as percentage contribution or as number of individuals per m^{-2}.

During recent research activities, a more complex approach was used in order to include parameters that explain the processes that are important for understanding the secondary production in the Bay. Comprehensive results, based on more frequent sampling, and which include all animal phyla represented in mesozooplankton community, were presented by Pestorić [20]. Detailed descriptions of planktonic cladocerans, cnidarians, and chaetognaths included their annual abundance variability and influence of abiotic/biotic parameters on it [21–23]. Disturbances within the food web due to the strong grazing influence of ctenophore *Bolinopsis vitrea* were described by Lučić [24].

In difference to the mesozooplankton, microzooplankton (protozoans and metazoans developmental stages) was less investigated. The first data were presented by [8] based on the just one investigation along the Boka Kotorska Bay in November 1937. The author used a Nansen net supplied with a fine silk. Data indicated a qualitative composition and quantitative domination of small copepods. The plankton protozoans, tintinnids, and the radiozoan *Sticholonche zanclea* were numerically important in the inner part of the Bay. More comprehensive investigation was carried by Kršinić and Viličić [25] from December 1981 to December 1982 using a 53 μm mesh-netting net and 5 L Van Dorn sampler. On the basis of monthly interval sampling, they described qualitative and quantitative microzooplankton composition only in the Kotor Bay, and compared their numbers with variations of phytoplankton. Using Niskin 5 L bottle, Lučić [26] studied the microzooplankton horizontal and vertical distributions of the entire area during spring 2013.

The objective of this chapter is to review the main results of all previous studies of zooplankton in the Boka Kotorska Bay with particular emphasis on results of more recent research activities providing a more detailed overview of relations with hydrographic parameters, primary production, and food web in general. In addition, we intend to present some unpublished results related to changes in the zooplankton composition and abundance that have been recorded in the past few years in the Bay, and which could correlate with global warming phenomena.

2 Material and Methods

Microzooplankton samples were collected at three stations (A1, B1, and C1) from March to May 2013 (Fig. 1 and Table 1). Plankton was sampled at 0, 5, 10, 20, and 30 m depth and above the sea-bottom, using 5-L Niskin bottles. The samples were preserved in 2.5% formaldehyde–seawater solution, previously buffered with $CaCO_3$. The methodology of samples sedimentation and decanting used was described in detail by Kršinić [27]. Counting and identification of the species were performed with "Olympus" inverted microscopes IMT_2 and CK40 at 100× and 400× magnification. The abundance was expressed as number of cells per liter (cells L^{-1}).

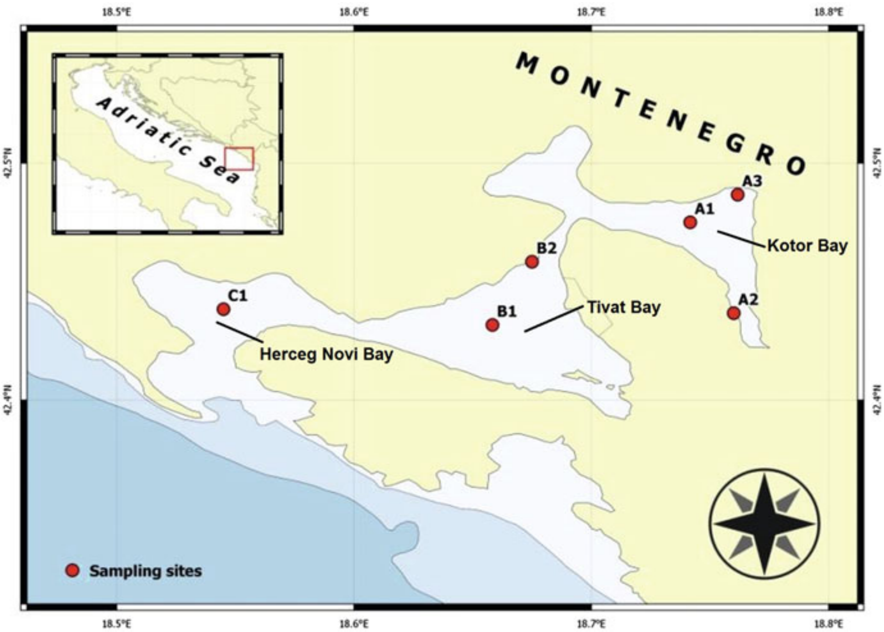

Fig. 1 Map of sampling sites in the Boka Kotorska Bay. Microzooplankton (A1, B1, and C1) and mesozooplankton (A1, A2, A3, B1, B2, and C1)

Table 1 Longitude and latitude of sampling stations

Station	Latitude	Longitude	Working depth (m)
A1	42°28.5′N	18°44.5′E	A 30
A2	42°26.2′N	18°45.6′E	A 15
A3	42°29.2′N	18°45.7′E	A 15
B1	42°25.9′N	18°39.5′E	B 30
B2	42°27.5′N	18°40.5′E	B 15
C1	42°26.3′N	18°32.7′E	C 40

Mesozooplankton samples were collected at three stations in the Kotor Bay (A1, A2, A3), two stations in the Tivat Bay (B1, B2) and one station in the Herceg Novi Bay (C1) from March 2009 to June 2010 (Fig. 1 and Table 1). One station in the Kotor Bay (A2) was sampled weekly. The remaining stations in the Kotor Bay and the Tivat Bay were sampled twice a month while one station in the Herceg Novi Bay was sampled monthly.

Zooplankton samples were taken by vertical hauls from bottom to surface with a Nansen plankton net, 0.55 m diameter and 125 μm mesh size. The collected zooplankton material was preserved in 2.5% formaldehyde seawater solution and analyzed using a Nikon SMZ800 stereomicroscope.

Detailed methodology of sampling and counting of mesozooplankton samples are described by [28–32].

3 Microzooplankton

Microzooplankton are a group of heterotrophic and mixotrophic organisms 20–200 mm in size, which include many protists, as well as small metazoans, such as copepod nauplii and some copepodites, and some meroplanktonic larvae. Traditionally, microzooplankton has been relegated to the ranks of secondary contributors when describing the dynamics of marine ecosystems, especially those of productive waters [3]. They occupy a key position in marine food webs as major consumers of primary production [33], as intermediaries between primary producers and copepods [34], and as key components of the microbial loop [35]. On average, their consumption is 60–75% of particulate primary production and about half of the phytoplankton biomass per day in a temperate, tropical waters, as soon as in very productive areas, such as estuaries and upwelling [33].

4 Investigation Carried Out from 1981 to 1982 (Kršinić and Viličić [25])

It was the first microzooplankton complexity investigation in this region, but conducted only in the inner part of the Boka Kotorska Bay. High population densities were noted.

The non-loricate ciliates were numerous at the surface layer at low salinity. The maximum of 673 ind. L^{-1} was in April. Similar values were recorded in the eutrophicated Mediterranean areas [36–41].

Authors found a small number (17) of estuarine and neritic species. Despite high near-bottom salinity values (>38), only one open sea species with a single specimen was observed. Maximum of 432 ind. L^{-1} in September at 20 m depth was caused exclusively by abundance of *Codonellopsis schabi*.

Most of the year, nauplii were the dominant component of the total microzooplankton abundance with a maximum of 300 ind. L^{-1} in May at the surface. Among small copepods, typical coastal forms occurred. Unexpectedly, *Oithona nana* was not the dominant species among adult copepods, and was replaced by harpacticoid *Microsetella norvegica* with the highest values known for the Adriatic Sea, and a maximum of 50 ind. L^{-1} in July at the surface.

No significant correlations were observed to exist between nano-microphytoplankton and the microzooplankton groups. The reason could be in high phytoplankton population densities throughout the year, and their uniform distribution through water columns, opposite of microzooplankton seasonal variations and their patched vertical distribution.

5 Investigation Carried Out in Spring 2013 (Lučić [26])

The horizontal and vertical distributions of microzooplankton were studied at three stations along the Boka Kotorska Bay (Fig. 1). Unexpectedly, very low values for all microzooplankton groups were noted, similar to the open sea waters [42–44], and considerably lower than in the productive areas of the Mediterranean [45, 46] and the Adriatic Sea [39–41, 47–49].

Non-loricate ciliates were the most numerous microzooplankton group, with the highest values (178 ind. L^{-1}) at the surface layer that was strongly influenced by fresh water. For many temperate seas, the maximum number of non-loricate ciliates was found in spring–summer period, where these protists reach values over 1,000 ind. L^{-1} [36, 37, 50]. Average and maximal abundances (Table 2) were lower than the previously noted values in the Boka Kotorska Bay: Kršinić and Viličić [25] found 254 ind. L^{-1} in May and a maximum of 673 ind. m^{-3} in September.

Table 2 Average (Avg), standard deviation (SD), and maximal (Max) abundance of the microzooplankton taxa in the Boka Kotorska Bay during spring 2013

	The Kotor Bay		The Tivat Bay		The Herceg Novi Bay	
Taxa	Max	Avg ± SD	Max	Avg ± SD	Max	Avg ± SD
Non-loricate ciliates	178	39.14 ± 44.20	100	40.12 ± 27.83	71	33.67 ± 17.63
Tintinnids	94	20.44 ± 24.41	32	10.91 ± 7.92	33	10.97 ± 8.40
Copepods nauplii	67	26.96 ± 19.29	70	39.08 ± 21.61	69	28.63 ± 19.23
Calanoids copepodites	9	3.86 ± 2.77	34	9.51 ± 9.56	24	7.28 ± 6.37
Oithona like cyclopoids	29	7.54 ± 8.78	21	7.39 ± 6.51	12	3.73 ± 3.96
Oncaea like cyclopoids	25	6.74 ± 7.19	8	3.04 ± 2.57	5	1.03 ± 1.26
Harpacticoids	5	1.41 ± 1.54	9	9.00 ± 3.00	7	1.61 ± 2.11
Appendicularians juvenile	4	1.46 ± 1.23	5	1.85 ± 1.70	3	1.12 ± 0.89
Bivalvia larvae	2	0.93 ± 0.85	4	1.15 ± 1.04	6	1.77 ± 1.64

Table 3 Tintinnids diversity in the Boka Kotorska Bay during spring 2013

Stations	*S*	*N*	*d*	*'H*
Kotor	29	95	6.14	2.11
Tivat	34	55	8.25	2.55
Herceg-Novi	33	55	8.00	2.49

S a total number of founded species, *N* a total abundance of all species, ind. L^{-1}, *d* Margalef's diversity index, *'H* Shannon's diversity index

As for non-loricate ciliates, tintinnid (loricate ciliates) values were low (Table 2). However, tintinnid species diversity was considerably high, especially at the station in the Tivat arm of the Boka Kotorska Bay system (Table 3). In total, 46 tintinnids were identified, among which 20 were estuarine–neritic and 26 were characteristic of the open sea. Twenty-three species were recorded for the first time in Boka Kotorska Bay. These were estuarine or coastal species: *Tintinnopsis campanula* f. *bütschlii*, *Tintinnopsis cylindrica*, *Tintinnopsis fennica*, *Tintinnopsis karajacensis*, *Tintinnopsis mortensenii*, *Tintinnopsis parvula*, *Metacylis joergenseni*, and *Favella taraikaensis,* and characteristic open sea species: *Codonella aspera*, *Undella subcaudata acuta*, *Undella subcaudata subcaudata*, *Dyctocysta lepida*, *Amphorides amphora*, *Amphorides quadrilineata*, *Amphorides quadrilineata* f. *minor*, *Canthariella pyramidata*, *Dadayiella ganymedes*, *Eutintinnus apertus*, *Eutintinnus latus*, *Eutintinnus tubulosus*, *Salpingella acuminata*, *Salpingella glockentoegeri*, and *Salpingella rotundata*. In particular, a large number of oceanic species registered in the deeper layer correlated to high salinity values (>38) below 15 m during this investigations. Higher availability of the potential food sources compared to the area of the open sea station [26] could be the reason for their prolonged stay in the bay.

According to the "Simper" analysis 11 species were representing tintinnids fauna in spring 2013 (Table 4). Among them, *Stenosemella nivalis* was the most numerous species (Fig. 2b). This tintinnid is a typical estuary/coastal species, frequent and numerous in the coastal communities of Mediterranean Sea [42, 51, 52].

Among metazoan fraction of microzooplankton, copepod nauplii were the most numerous metazoans (Table 2). Commonly, nauplii aggregations could be found in the layers of maximum primary production [3]. In the Boka Kotorska Bay, the highest values were noted between 5 and 20 m depth. It seems that the nauplii avoided the influence of fresh water in the surface layer, as well as higher salinity and lower values of the primary production in the near-bottom layer.

The majority of microzooplankton groups had a negative correlation with hydrographic factors (Table 5). The significantly positive correlations were observed between microzooplankton and phytoplankton fraction, especially for nanophytoplankton, in accordance with their well-known relationship within the food web [3]. These results confirm that the food relations have considerably greater influence on microzooplankton abundance variations than hydrographic factors, which is particularly notable in oligotrophic areas [3]. During recent investigations of microzooplankton in the Boka Kotorska Bay, low chlorophyll concentrations and phytoplankton densities were recorded. Similar absences of

Table 4 The "Simper" analysis of tintinnid species in the Boka Kotorska Bay during spring 2013

Species	Average abundance	Average similarity	Similarity/standard deviation	Contribution %	Cumulative contribution %
The Kotor Bay–average similarity 21.27					
Stenosemella nivalis	9.34	11.52	0.70	54.15	54.15
Tintinnopsis levigata	1.43	2.41	0.54	11.35	65.50
Tintinnopsis cylindrica	1.59	2.31	0.43	10.85	76.35
Codonellopsis schabi	0.20	0.87	0.34	4.09	80.44
Tintinnopsis radix	1.79	0.84	0.24	3.93	84.37
Tintinnopsis campanula	0.51	0.50	0.42	2.35	86.72
Eutintinnus latus	1.16	0.48	0.17	2.26	88.98
Tintinnopsis fennica	0.14	0.43	0.26	2.01	90.99
The Tivat Bay–average similarity 30.49					
Stenosemella nivalis	3.05	11.94	1.03	39.17	39.17
Tintinnopsis levigata	1.27	7.00	1.33	22.95	62.12
Tintinnopsis campanula	0.55	2.40	0.60	7.86	69.98
Codonellopsis schabi	0.31	1.73	0.53	5.66	75.65
Tintinnopsis radix	1.01	1.50	0.41	4.91	80.55
Eutintinnus latus	0.31	1.37	0.40	4.48	85.03
Stenosemella sp.	1.03	1.13	0.30	3.70	88.73
Tintinnopsis cylindrica	0.21	0.92	0.44	3.02	91.75
The Herceg Novi Bay–average similarity 23.37					
Stenosemella nivalis	1.85	7.21	0.75	30.84	30.84
Tintinnopsis levigata	2.28	4.03	0.52	17.23	48.08
Tintinnopsis campanula	1.69	3.97	0.51	16.96	65.04
Codonellopsis schabi	0.71	2.57	0.43	10.98	76.02
Dadayiella ganymedes	0.43	1.05	0.36	4.50	80.52

(continued)

Table 4 (continued)

Eutintinnus latus	0.19	0.79	0.27	3.38	83.90
Eutintinnus fraknoi	0.55	0.73	0.30	3.14	87.04
Streenstrupiella steenstrupii	0.23	0.67	0.37	2.85	89.89
Tintinnopsis radix	0.21	0.61	0.38	2.60	92.49

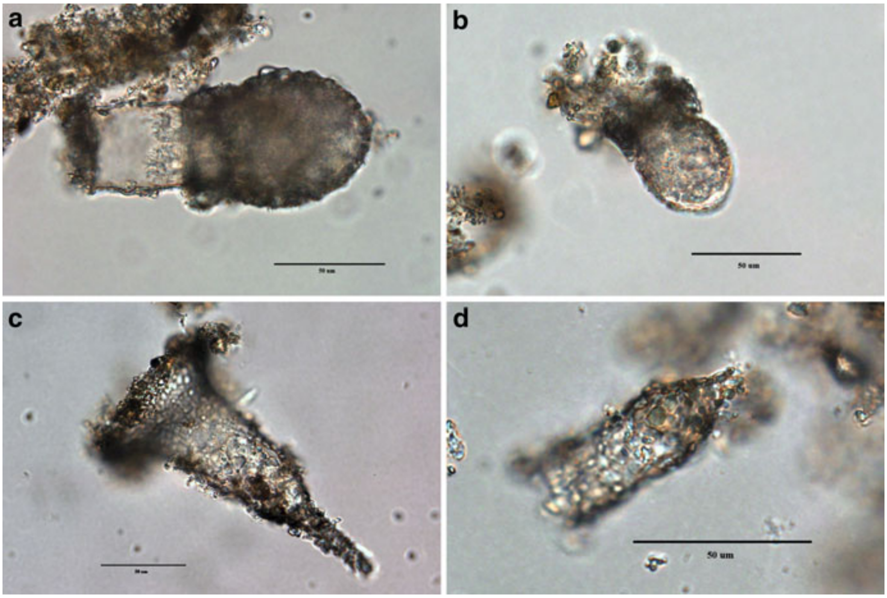

Fig. 2 Dominant tintinnids in Boka Kotorska Bay in Spring 2013: (**a**) *Codonellopsis schabi*; (**b**) *Stenosemella nivalis*; (**c**) *Tintinnopsis campanula*; and (**d**) *Tintinnopsis levigata*

typical phytoplankton spring bloom were observed in other productive areas during the last decade, such as Northern Adriatic [52]. Cabrini et al. [53] in their research in 1994 found higher values of phytoplankton in the Northern Adriatic in January, in contrast to previous years, when the maximum was usually in March or April. Moreover, in the last decade, considerably lower production of previously high-productive areas was frequently recorded [54, 55], pointing to oligotrophic processes of the Adriatic Sea [56]. The authors linked these changes with evident climate change since the mid-1990s that affected the precipitation regime.

Thus, the results obtained by Lučić [26] are considerably different from results given by Kršinić and Viličić [25], from researches conducted 30 years earlier. Such differences can also confirm the general change in the plankton position and abundance recorded during the last two decades. However, these hypotheses should

Table 5 "Spearman rank" correlation coefficient between microzooplankton taxa, hydrographic parameters, chlorophyll a concentration, and phytoplankton size-fractions

	Temperature	Salinity	Chl a	Nanophytoplankton	Microphytoplankton
Non-loricate ciliates	−0.253*	−0.057	0.247*	0.443***	0.411***
Tintinnids	−0.451***	−0.018	0.220	0.498***	0.270*
Nauplii	−0.229	−0.024	0.042	0.338**	0.306*
Calanoida copepodites	−0.189	0.062	0.051	0.376**	0.173
Oithona like cyclopoids	−0.382**	−0.002	−0.015	0.419***	0.163
Oncaea like cyclopoids	−0.235	0.098	−0.104	0.087	−0.099
Harpacticoids	−0.573***	−0.081	0.207	0.472***	0.120

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

be taken with caution due to the complexity of the production relations within the water column and also because the recent investigation was carried out over a shorter period.

6 Mesozooplankton

In this investigation, in Boka Kotorska Bay seven phylums of net zooplankton were recorded: Myzozoa, Ctenophora, Cnidaria, Arthropoda, Mollusca, Chordata, and Chaetognatha. Within these phyla 81 taxa were identified, of which 69 in Kotor Bay, 70 in Tivat Bay, and 72 in Herceg Novi Bay.

7 Heterotrophic Dinoflagellates

The link between the occurrences of blooms of dinoflagellates, especially *Noctiluca* sp., with nutrients enrichment of coastal ecosystems has been the subject of frequent discussion among researchers [57]. Blooming *N. scintillans* in the Northern Adriatic in the 1970s was related to the increase of eutrophication [58]. In summer 2009, during our investigation, blooming of *N. scintillans* was observed after large blooms of diatoms in March. High abundance of *N. scintillans* usually occurs after blooming diatoms [59]. A maximum of 64,375 ind. m^{-3} (Figs. 3 and 4)

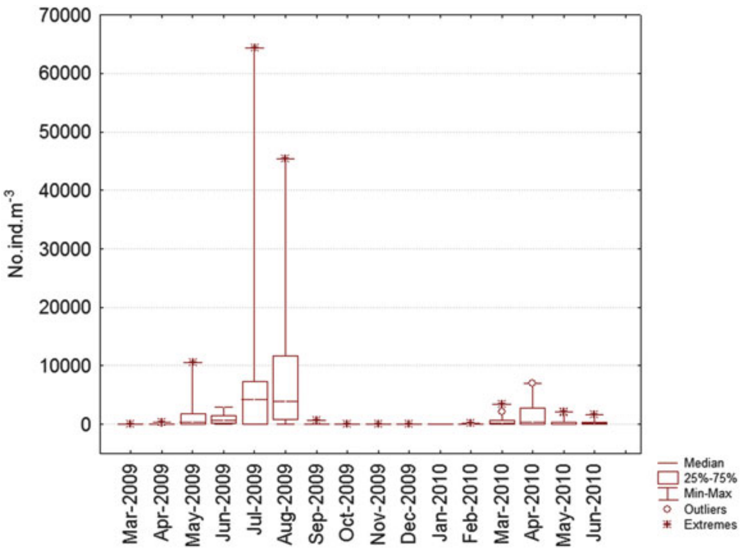

Fig. 3 Temporal variability of *Noctiluca* sp. abundance in Boka Kotorska Bay from March 2009–June 2010

Fig. 4 *Noctiluca scintillans* (photo: S. Ljubimir)

was recorded in the Kotor Bay, where the abundance was 10 times higher than in the Tivat Bay. Abundance in the Herceg Novi Bay did not exceed 180 ind. m^{-3}. In the period from September to February *Noctiluca scintillans* occurred in individual specimens.

These findings are consistent with the values found on the west coast of the Adriatic Sea and in the Gulf of Trieste [60]. So far, the largest number of these dinoflagellates was determined in 1977 and 1980 in the Gulf of Trieste, when the number of *N. scintillans* reached $> 10^6$ ind. m^{-3} [60]. Although *N. scintillans* is recognized as eurythermal and euryhaline species [61], it occurs in large numbers in the Kotor Bay in summer months, while during winter it is either absent or present in very small numbers. This is confirmed by significant positive correlation with temperature [20].

During blooming, *N. scintillans* exceeds biomass of zooplankton feeding on their eggs and is actively competing for the same nutritional resources [60, 62].

8 Cnidarians

Planktonic cnidarians are conspicuous components of pelagic food webs and their distribution and abundance have a large influence on marine communities. Species that have alternating pelagic (medusa) and bottom dwelling (polyp) phases not only play an important role in the transfer of energy from pelagic to benthic systems, but are also likely to be sensitive to environmental changes which can result in extremely high temporal and spatial variability in abundance, resulting in the form of “blooms” [63, 64]. Species belonging to Hydrozoa and Scyphozoa and Siphonophora are carnivores, preying mainly on other planktonic organisms (notably copepods) and even fish [65]. They usually serve as a link between zooplankton and higher trophic levels in the marine food webs [66].

9 Hydrozoans

While earlier studies on hydromedusae in the Central and South Adriatic reported 26 hydrozoan species [67], significantly smaller numbers were determined in the Boka Kotorska Bay: 7 species (6 holoplanktonic, 1 meroplanktonic) during 2002 [17] and 12 taxa (8 holoplanktonic, 4 meroplanktonic) during monthly samplings in 2009 and 2010 [22]. The most recent investigation showed that meroplanktonic species of hydromedusae prevail in the inner parts of the Bay, while holoplanktonic species were more abundant in the outer of the Bay. High variations of hydromedusae abundance among stations are in concordance with their metagenetic biology which is reflected in significant monthly and annual oscillations [63]. Although their median values rarely exceeded 1 ind. m^{-3}, monthly maximum values more than 20 ind. m^{-3} were often noted (Fig. 5). An extraordinarily high number of *Obelia* spp. of 341 ind. m^{-3} (Table 6) recorded in the Tivat Bay during December 2009 coincided with high concentrations of chlorophyll *a*. Such high abundance of this species was not recorded before in the Adriatic coastal ecosystems.

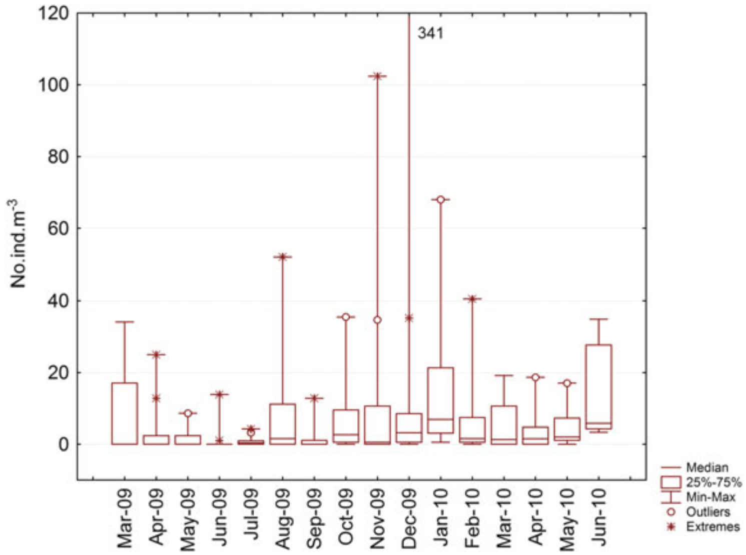

Fig. 5 Temporal variability of hydromedusa abundance in Boka Kotorska Bay from March 2009–June 2010

Table 6 Composition of hydromedusa species in the Boka Kotorska Bay, with their maximum abundance values (max; ind. m^{-3}), average abundances (av ± SD; ind. m^{-3}), and mean percentage of the total hydromedusa abundance (mean %)

	Kotor Bay			Tivat Bay			Herceg Novi Bay		
Species	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %
Anthomedusae									
Stauridiosarsia gemmifera	–	–	–	1	0.05 ± 0.18	0.27	–	–	–
Podocorynoides minima	51	1.07 ± 6.11	20.96	4	0.32 ± 0.10	1.88	<1	0.06 ± 0.122	2.20
Hydractinia carica	5	0.17 ± 0.65	3.26	17	1.21 ± 3.26	7.11	2	0.13 ± 0.43	4.95
Leptomedusae									
Obelia spp.	68	2.97 ± 9.17	58.06	341	8.32 ± 50.45	72.06	2	0.30 ± 0.66	11.37
Clytia spp.	1	0.04 ± 0.18	0.69	17	1.09 ± 3.59	6.46	1	0.09 ± 0.23	3.30
Eirene viridula	2	0.06 ± 0.30	1.23	4	0.19 ± 0.67	1.12	–	–	–
Eutima gracilis	1	0.02 ± 0.12	0.31	17	0.66 ± 2.79	3.92	<1	0.01 ± 0.05	0.55
Helgicirrha schulzei	8	0.10 ± 0.85	2.02	2	0.09 ± 0.34	0.52	<1	0.01 ± 0.05	0.55
Trachymedusae									
Liriope tetraphylla	1	0.03 ± 0.18	0.66	2	0.17 ± 0.43	0.99	<1	0.01 ± 0.05	0.55
Aglaura hemistoma	2	0.06 ± 0.32	1.12	4	0.13 ± 0.65	0.78	6	0.81 ± 1.73	31.38
Rhopalonema velatum	–	–	–	1	0.05 ± 0.19	0.30	2	0.31 ± 0.49	12.11
Narcomedusae									
Solmaris spp.	34	0.76 ± 4.08	14.90	17	0.84 ± 3.11	4.85	6	0.80 ± 1.83	30.83

10 Siphonophores

Siphonophores, as a group of complex colonial organisms, have often been poorly surveyed because their fragile body is often broken by traditional sampling nets. Pestorić et al. [22] provided the first detailed report of the composition and abundance of the siphonophoran community for this region. Among six recorded species *Muggiaea kochi*, *Muggiaea atlantica,* and *Sphaeronectes gracilis* were most frequent and abundant, with highest densities in spring–summer period (Fig. 6). This is in accordance with the established general pattern of siphonophoran seasonal distribution in the sea [68, 69].

M. atlantica, a typical boreal species, dominant in the inner Bay of Kotor during spring and summer, while autochthonous Adriatic and Mediterranean species *M. kochi* was more numerous in the outer area of the Bay (Table 7). These results confirm previous shift within the coastal calycophores, with *M. kochi* being replaced by *M. atlantica*, that was observed in the Adriatic Sea in 1996 [70]. In addition, the linear regression of the abundance of *M. kochi* with water temperature revealed a strong positive relationship ($r = 0.388$; $p = 0.0015$), while for *M. atlantica* the correlation was not statistically significant ($r = 0.059$; $p > 0.05$) [22]. The analyses of relationships of the common siphonophores and their potential prey showed significant positive correlations for *M. atlantica* and representative

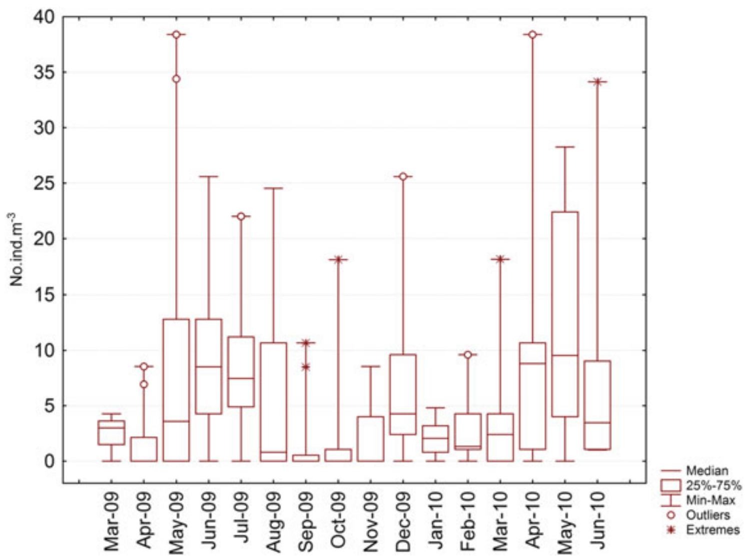

Fig. 6 Temporal variability of siphonophores abundance in Boka Kotorska Bay from March 2009–June 2010

Table 7 Composition of siphonophore species in the Boka Kotorska Bay, with their maximum abundance values (max: ind. m^{-3}), average abundances (av ± SD; ind. m^{-3}), and mean percentage of the total siphonophore abundance (mean %)

Species	Kotor Bay			Tivat Bay			Herceg Novi Bay		
	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %
Lensia subtilis	4	0.06 ± 0.42	0.99	–	–	–	<1	0.06 ± 0.15	1.76
Muggiaea kochi	17	1.53 ± 3.51	25.38	17	1.98 ± 3.89	38.19	13	1.17 ± 3.37	33.68
Muggiaea atlantica	34	3.26 ± 6.77	54.02	21	2.40 ± 4.70	46.27	4	0.84 ± 1.39	24.23
Eudoxoides spiralis	2	0.04 ± 0.30	0.69	–	–	–	<1	0.04 ± 0.12	1.23
Sphaeronectes köllikeri	13	1.09 ± 2.37	18.05	5	0.81 ± 1.51	15.55	13	1.36 ± 3.41	39.07
Sphaeronectes irregularis	4	0.05 ± 0.43	0.86	–	–	–	–	–	–

Table 8 Spearman's rank order correlation coefficients between frequently occurring and abundant siphonophore species and small copepods–copepodites in the Boka Kotorska Bay

	Paracalanus parvus	Calanoida copepodites	*Oithona nana*	Cyclopoida copepodites
Muggiaea kochi	0.118	0.219*	0.061	0.171
Muggiaea atlantica	0.231*	0.247*	0.298**	0.327*
Sphaeronectes köllikeri	−0.014	−0.026	−0.091	−0.112

*p <0.05; ** $p < 0.01$

small copepods and copepods numerically dominated at all stations (Table 8). *M. kochi* was positively correlated to abundance of calanoid copepodites (Table 8). *Sphaeronectes köllikeri* didn't show significant correlation with analyzed potential pray.

11 Cladocerans

Cladocerans play a major role in freshwater ecosystems, but they are not successful in colonizing the marine environment [71]. There are only eight cosmopolitan species in the world ocean [72] distributed in three genera: Penilia (comprising only *Penilia avirostris*), Evadne, and Podon [73]. Due to cladocerans parthenogenetics reproduction in coastal and estuarine environments they may occur with extent monospecific cladoceran populations that are usually predominant by copepods [74].

Information on the cladoceran population in the Montenegrin coast is scarce [18, 21]. Seven species were found in the Boka Kotorska Bay: *Penilia avirostris, Evadne spinifera, Evadne nordmanni, Pseudevadne tergestina, Pleopis poliphemoides, Podon intermedius, and Podon leuckarti*. Species *Podon leuckarti* was noted only by Vukanić [18] as very rarely recorded single specimens during the warmer period of the year.

The most dominant species in all areas was *Penilia avirostris* (Fig. 8). The highest percentage contribution was observed in Tivat Bay 91.75% while the maximum abundance was noted in the Kotor Bay, where in September reached value of 24,303 ind. m^{-3} (Fig. 7 and Table 9).

This species, whose average abundance for the water column exceeds 20,000 ind. m^{-3}, are characteristic for high eutrophic areas [75–77]. During the summer months, it was the dominant species of zooplankton which confirms its thermophilic nature [72, 73]. A large number (>1,000 ind. m^{-3}) of *P. avirostris* was recorded in the Bay of Kotor in December 2009 (Fig. 7). These findings coincide with the time of the highest concentration of chlorophyll *a* in the study area, which indicates that available food is also an important factor of its abundance [20].

Species *Penilia avirostris, Evadne spinifera*, and *Pseudevadne tergestina* showed significantly positive correlation with hydrological parameters

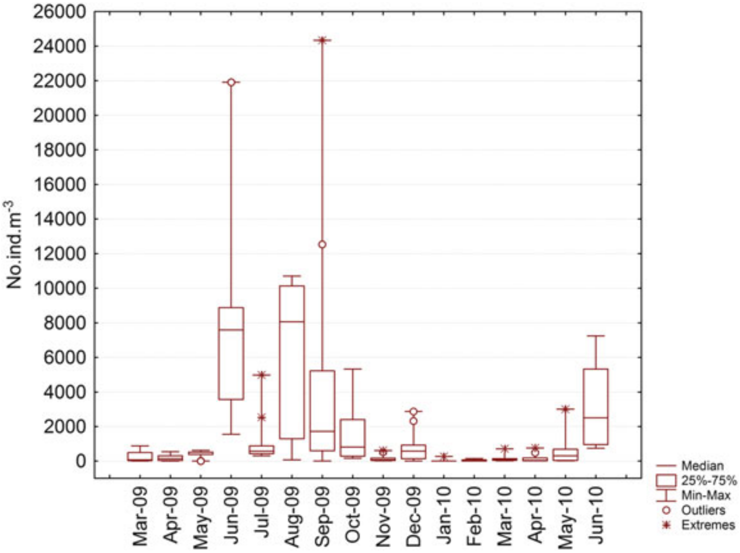

Fig. 7 Temporal variability of cladoceran abundance in Boka Kotorska Bay from March 2009–June 2010

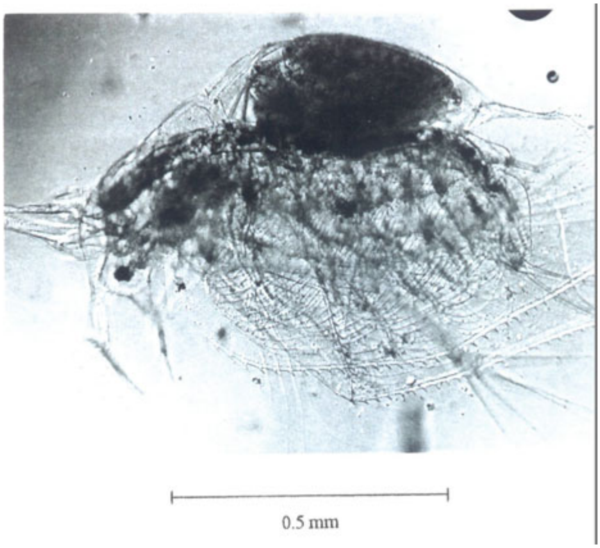

Fig. 8 *Penilia avirostris* (photo: I. Brautović)

Table 9 Composition of cladoceran species in the Boka Kotorska Bay, with their maximum abundance values (max: ind. m^{-3}), average abundances (av ± SD; ind. m^{-3}), and mean percentage of the total cladoceran abundance (mean %)

	Kotor Bay			Tivat Bay			Herceg Novi Bay		
Species	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %
Penilia avirostris	24,303	1,444 ± 3,825	76.21	13,956	1,881 ± 3,247	91.75	7,578	935 ± 2,105	91.74
Evadne. nordmanni	768	30.35 ± 93.8	8.16	68	3.25 ± 11.5	0.97	3	0.23 ± 0.9	0
Evadne spinifera	478	38.48 ± 92.1	1.97	205	21.38 ± 44.4	1.44	51	7.12 ± 16.3	0.77
Pseudevadne tergestina	68	2.80 ± 10.7	0.07	34	2.53 ± 7.0	0.05	6	0.46 ± 1.7	0
Podon intermedius	269	13.03 ± 36.5	2.83	68	6.06 ± 13.7	4.91	26	3.83 ± 7.2	7.49
Pleopis polyphaemoides	1,638	97.31 ± 247.7	10.76	68	4.20 ± 14.4	0.88	–	–	–

(temperature and salinity) while *Evadne nordmanni* had a significant negative correlation with temperature and salinity [20].

12 Copepods

The mesozooplankton community is dominated mainly by copepods, especially in the estuaries and coastal regions [78, 79]. In Boka Kotorska Bay their share ranged from 67% to 81% in the total mesozooplankton densities [20]. Copepods are notable consumers of microplankton, and play a key role in the diet of juvenile stages of many fish species. These keystone trophic links in aquatic ecosystems transfer energy and carbon to higher trophic levels more efficiently than any other zooplankton taxa [80]. Thus, copepods can be considered a particularly successful group in the pelagic environment.

Historical data, collected with 250–360 μm mesh size nets, reported 70 copepod species inhabiting the Boka Kotorska Bay and outer station [9]. Recent investigation performed with 125 μm mesh size showed that copepod community of the Boka Kotorska Bay comprised 38 taxa (Table 10), which is 14% of the total of 262 copepod species recorded in the Adriatic Sea [20]. Among them, 10 coastal and estuarine taxa exhibited high dominance and accounted for 99.11% of the total copepod numbers: *Oncaea* spp.*, Oithona nana, Acartia (Acartiura) clausi, Paracalanus parvus, Euterpina accutifrons, Centropages kroyeri, Oithona similis, Clausocalanus jobei, Temora stylifera, and Corycaeus* spp. *Cyclopoids Oncaeidae* and *Oithonidae* dominated mesozooplankton community of the Boka Kotorska Bay and accounted for, on average, 68% of the total abundances [20]. This is in accordance with the previous investigations carried out with fine mesh nets which highlighted the importance of small copepod species in structuring coastal ecosystem dynamics [81–84]. Among calanoids, *Acartia* (*Acartiura*) *clausi* was the most numerous in the Kotor Bay, where this species contributed up to 73% (April 2009) of the total mesozooplankton numbers with average abundance of $710 \pm 1{,}357$ ind. m^{-3} [20]. High numbers of this species over the spring period were found in other productive enclosed areas, like Kaštela Bay [85], Gruž Bay [86], and Mali Ston Bay [87]. In the Tivat and the Herceg Novi Bays, *Paracalanus parvus* was the most abundant calanoid (average abundance of 422 ± 532 ind. m^{-3} and 399 ± 408 ind. m^{-3}, respectively) with higher values recorded in spring. The only numerically important member of the harpacticoids, *Euterpina accutifrons*, was present throughout the area of the Boka Kotorska Bay, reaching maximum of even 2,526 ind. m^{-3} in the Kotor Bay in March 2010.

The Boka Kotorska Bay, as enclosed coastal area under the great fluctuations caused by influences from the land, is a highly variable system and this variability may reflect in temporal dynamics of the copepod populations. Beside rapid response of individual species to ecosystem perturbations, large fluctuations in overall copepod densities were also recorded. Therefore, total copepod abundances varied from minimum of 800 ind. m^{-3} in the Kotor Bay in January 2010 to the

Table 10 Composition of copepod species in the Boka Kotorska Bay, with their average abundances (av ± SD; ind. m^{-3}) and mean percentage of the total copepod abundance (mean %)

Copepod taxa	Kotor Bay		Tivat Bay		Herceg Novi Bay	
	Av. Abund.	Contr. %	Av. Abund.	Contr. %	Av. Abund.	Contr. %
Calanus helgolandicus	25	<1	10	<1	19	<1
Mesocalanus tenuicornis	5	<1	4	<1	3	<1
Nannocalanus minor	<1	<1	<1	<1	1	<1
Calocalanus pavo					<1	<1
Calocalanus contractus					<1	<1
Calocalanus styliremis					<1	<1
Ischnocalanus plumulosus			<1	<1		
Paracalanus parvus	324	8	422	12	399	19
Paracalanus nanus	1	<1	<1	<1	13	<1
Paracalanus denudatus			<1	<1		
Meynocera clausi	<1	<1	9	<1	6	<1
Clausocalanus jobei	21	<1	42	<1	24	<1
Clausocalanus arcuicornis	9	<1	13	<1	7	<1
Clausocalanus furcatus	1	<1	11	<1	9	<1
Clausocalanus pergens					<1	<1
Ctenocalanus vanus	20	<1	8	<1	38	<1
Pseudocalanus elongatus	<1	<1				
Paraeuchaeta hebes	<1	<1	2	<1	2	<1
Diaixis pygmoea	1	<1	2	<1		
Centropages kroyeri	138	3	44	<1	64	1.7
Centropages typicus	1	<1	4	<1	10	<1
Isias clavipes	2	<1	1	<1	4	<1
Temora stylifera	47	<1	54	<1	52	1.2
Candacia giesbrechti	1	<1	1	<1	4	<1
Labidocera wollastoni	<1	<1	3	<1	3	<1
Acartia clausi	710	12	303	6	358	16
Acartia longiremis			<1	<1	4	<1
Oithona similis	91	2	96	1	106	5
Oithona plumifera	7	<1	17	<1	27	1.6
Oithona nana	1,071	32	1,012	33	399	23
Oithona setigera					<1	<1

(continued)

Table 10 (continued)

Copepod taxa	Kotor Bay Av. Abund.	Kotor Bay Contr. %	Tivat Bay Av. Abund.	Tivat Bay Contr. %	Herceg Novi Bay Av. Abund.	Herceg Novi Bay Contr. %
Microsetella spp.	31	<1	5	<1	1	<1
Macrosetella sp.	3	<1	1	<1	9	<1
Euterpina acutifrons	291	7	236	7	74	3
Goniopsilus rostratus	<1	<1				
Oncaea–cyclopoid	1,196	36	1,109	38	534	25
Saphirina spp.	1	<1	1	<1	1	<1
Corycaeus spp.	8	<1	18	<1	40	1.3

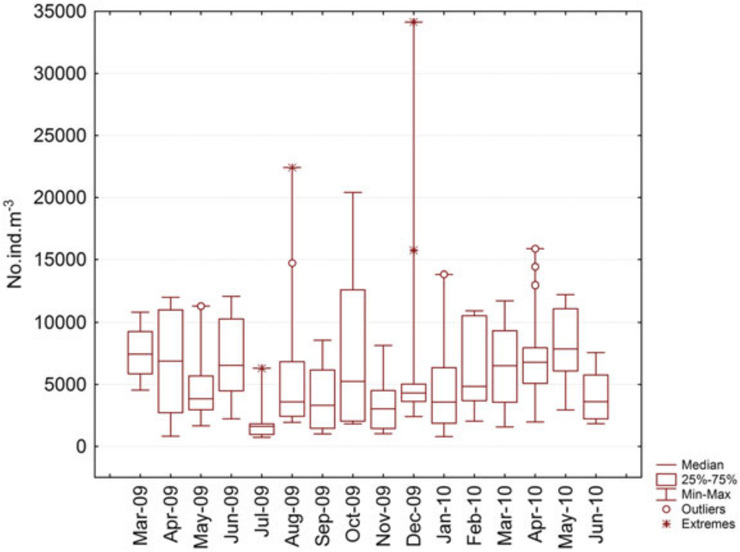

Fig. 9 Temporal variability of copepods abundance in the Boka Kotorska Bay from March 2009–June 2010

maximum of 34,137 ind. m^{-3} recorded in the Tivat Bay in December 2009 [20]. Annual dynamics of the total densities of this group in the Boka Kotorska Bay showed slightly increased values over the spring period (Fig. 9).

Considering influence of the hydrographic properties on the most abundant species (Table 11), negative correlation of the temperature on the abundances of the *Oncaeidae* ($p < 0.05$) and *Euterpina accutifrons* ($p < 0.01$) was recorded, while salinity has been limiting factor on the occurrence of *Oithona nana* ($p < 0.05$).

Table 11 Spearman correlation of copepod species included in 90 % of total numbers and independent parameters (temperature, salinity, TNP-total nanophytoplankton, TMP-total microphytoplankton; $*p < 0.05$; $**p < 0.01$; $***p < 0.001$)

	Temperature	Salinity	TNP	TMP
Paracalanus parvus	−0.065	0.043	−0.109	−0.198*
Acartia (Acartiura) clausi	−0.001	−0.038	0.185*	0.031
Oithona nana	−0.091	−0.180*	0.052	0.015
Oithona similis	−0.060	−0.051	0.174	0.062
Oncaeidae	−0.204*	−0.112	−0.062	−0.039
Euterpina acutifrons	−0.283**	−0.176	−0.065	0.063

Furthermore, our findings suggested that *Acartia* (*Acartiura*) *clausi* benefited most from nano- and microphytoplankton blooms ($p < 0.05$).

13 Pteropods

During the study period, four species of plankton pteropods were found: *Limacina trochiformis*, *Heliconoides inflata*, *Creseis virgula,* and *Creseis clava*. In previous investigation of the Boka Kotorska Bay a total of seven species were found [19]. Species *Pneumodermopsis canephora* and *Atlanta helicinoidea* in previous research were cited as very rare, while species *Cymbulia peronii* and *Limacina bulimoides* that were frequent, during our study, were not observed. In the Boka Kotorska Bay, during our research, species *Limacina trochiformis* was noticed for the first time.

Pteropods are characterized by the possibility of high and sudden variations of the population: they can occasionally occur in large numbers, and then disappear completely from plankton [88]. The maximum total abundance of 137 ind. m^{-3} was found in November 2009 and in May 2010 (Fig. 10).

Succession of species is noticeable. Species of the genus *Limacina* prevail in the period from May 2009 to September 2009. Species of the genus *Creseis* occur only in August 2009, and from November 2009 to January 2010, representing 100% pteropod. In the period from February to June 2010, the dominating species was again *Limacina*.

Limacina trochiformis was the dominant species in the area of the Kotor and the Tivat Bays with a percentage contribution of 44% and 59%, while it was absent from the area of the Herceg Novi Bay. A maximum of 128 ind. m^{-3} was recorded in the Kotor Bay. Another quantitatively significant species in the Kotor Bay was *Creseis virgula*, and the maximum number was 136 ind. m^{-3}. *Creseis virgula* dominated in the Herceg Novi Bay with a contribution of 82% (Table 12).

All species of pteropods showed a significant positive correlation with temperature (p <0.001) while in May 2010, when the water temperature of the column was ~ 16°C, a high number of pteropods were accompanied by a higher abundance

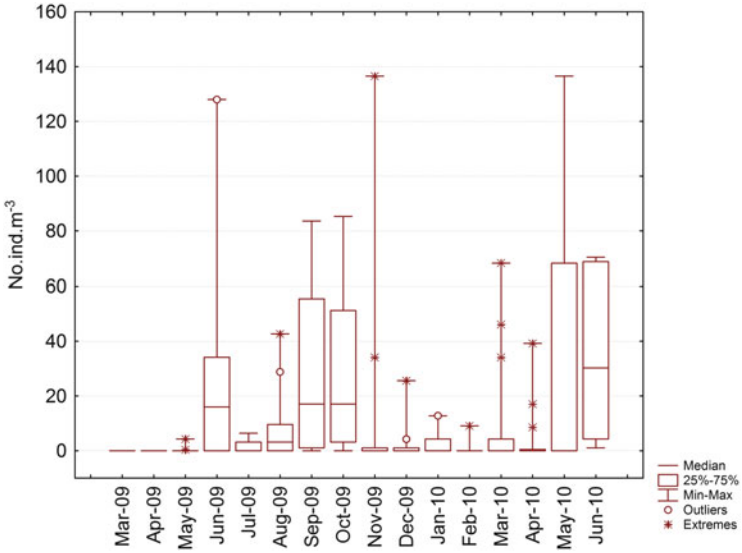

Fig. 10 Temporal variability of pteropod abundance in Boka Kotorska Bay from March 2009–June 2010

of phytoplankton, particularly nanophytoplankton (<20 μm) [20]. Similar situation was observed in the open sea of the Southern Adriatic, in the area of the Jabuka Pit [89].

14 Chaetognaths

Chaetognaths play an important functional role in marine food webs, and within carnivorous zooplankton often dominated in their biomass [90]. As one of the main predators of copepods [91, 92], chaetognaths play an important role of energy transfer through marine food webs. Apart from food availability hydrological conditions also seem to influence chaetognaths distribution.

In the world's seas and oceans 47 species of planktonic chaetognaths have been found, 17 of which are present in the Mediterranean and 10 in the Adriatic Sea [93]. The first data for the Adriatic (Gulf of Trieste) chaetognaths fauna was published by Graeffe [94]. There are scarce data about this zooplankton group in the Boka Kotorska Bay. Benović and Onofri [13] presented the first data for the area. They found four species of chaetognaths in the Boka Kotorska Bay (*Flaccisagitta enflata, Parasagitta setosa, Serratosagitta serratodentata,* and *Mesosagitta minima*). Surprisingly, Vukanic and Vukanic [16] registered four new species for the Boka Kotorska Bay (*Parasagitta friderici, Pseudosagitta lyra, Flaccisagitta hexaptera,* and *Sagitta bipunctata*). Pestorić et al. [23] found

Table 12 Composition of pteropod species in the Boka Kotorska Bay, with their maximum abundance values (max: ind. m^{-3}), average abundances (av ± SD; ind. m^{-3}), and mean percentage of the total pteropod abundance (mean %)

	Kotor Bay			Tivat Bay			Herceg Novi Bay		
Species	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %
L. trochiformis	128	4.50 ± 17.45	44.14	68	8.71 ± 18.46	58.88	–	–	–
H. inflata	41	1.47 ± 6.01	22.75	68	4.30 ± 14.32	16.63	51	4.66 ± 13.53	17.67
C. virgula	136	3.69 ± 16.09	33.05	51	3.59 ± 10.33	15.76	77	11.46 ± 22.14	82.33
C. clava	102	1.02 ± 10.13	0.06	17	1.02 ± 3.24	8.73	–	–	–

three coastal species of chaetognaths (*Flaccisagitta enflata*, *Mesosagitta minima,* and *Parasagitta setosa*) thus confirming previous findings [13]. The most dominant species in all areas was *Parasagitta setosa*. The highest percentage contribution was observed in the Tivat Bay, while the maximum abundance was noticed in the Kotor Bay (Table 13). *Flaccisagitta enflata* and *Mesosagitta minima* are more present and abundant in the Boka Kotorska Bay than in other neritic coastal areas. Total densities of chaetognaths showed an upward trend over the spring and summer months (Fig. 11).

Statistical analysis (Spearman correlation) showed significant correlations between different species of chaetognaths and hydrological parameters: a positive correlation with the temperature recorded for juvenile specimens ($r = 0.251$; $p < 0.01$), and salinity for the *Parasagitta setosa* ($r = 0.163$; $p < 0.05$) and *Flaccisagitta enflata* ($r = 0.261$; $p < 0.01$), *Mesosagitta minima* did not significantly correlate with these parameters [23]. Potential pray (small copepods and copepodites) showed strong positive correlation with juvenile stages of chaetognaths and *P. setosa* (Table 14).

The general composition of chaetognaths of the Boka Kotorska Bay did not vary significantly among the three investigated stations. Differences were the highest between the Herceg Novi and the Kotor Bay [23].

15 Pelagic Tunicates

Pelagic tunicates (salps, appendicularians, pyrosomas, and doliolids) are ubiquitous members of all marine pelagic systems, from coastal areas to the deep sea. They are also referred to as gelatinous zooplankton because of their extremely watery body tissue. When abundant, their relatively large size and high water content make them significant contributors to total wet biomass.

All pelagic tunicates are filter feeders filtering the entire size range from very small colloids to large phytoplankton chains in the case of salps and doliolids. The reproduction cycle is complex and includes sexual and asexual generations with high birth rates. Under good food conditions tunicates exhibit population growth rates that rank at the top among the metazoans [95].

16 Appendicularians

Appendicularians are among the most common zooplankton and occur in all oceans. They may therefore act as key top-down regulators in the marine planktonic food web. Appendicularians have a peculiar feeding strategy; they live inside an elaborate multichambered extracellular house, complete with inlet and food-concentrating filters that they secrete from a specialized oikoplastic epithelium [96, 97]. The filter in the house is able to retain particles as small as 0.2 mm.

Table 13 Composition of chaetognath species in the Boka Kotorska Bay, with their maximum abundance values (max: ind. m^{-3}), average abundances (av ± SD; ind. m^{-3}), and mean percentage of the total chaetognath abundance (mean %)

	Kotor Bay			Tivat Bay			Herceg Novi Bay		
Species	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %
P. setosa	204	7.22 + 25.33	75.91	68	9.03 + 17.20	83.22	13	1.69 + 3.38	63.59
F. enflata	68	2.34 + 8.01	22.21	34	3.50 + 8.91	16.34	25	2.40 + 6.73	31.92
M. minima	51	2.48 + 18.57	1.87	10	0.35 + 1.56	0.44	0.8	0.19 + 0.34	4.49

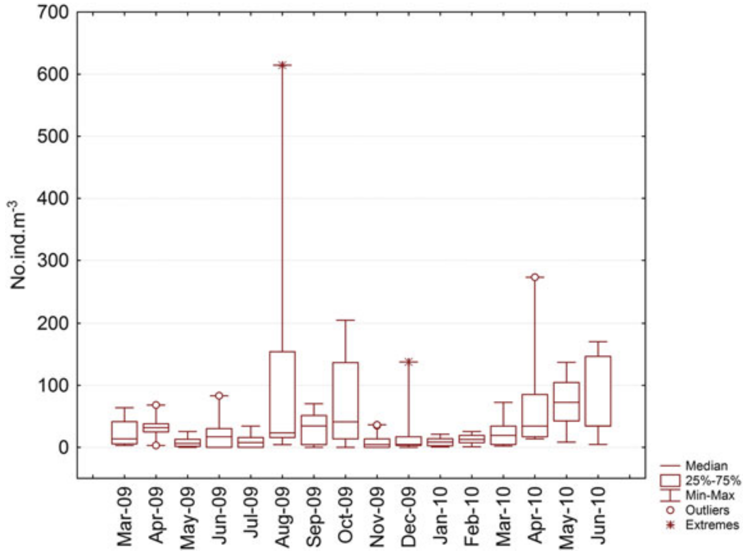

Fig. 11 Temporal variability of chaetognath abundance in the Boka Kotorska Bay from March 2009–June 2010

Table 14 Spearman rank order correlation of chaetognaths and potential pray

	M. minima	*P. setosa*	*F. enflata*	*Sagitta* juv.
Calanoida copepodites	−0.040	0.287***	0.047	0.213**
Cyclopoida copepodites	0.033	0.313***	−0.029	0.158*
Oithona nana	−0.048	0.226**	−0.120	0.154
Appendicularia	0.157	0.310***	−0.023	0.167*

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

Earlier studies of the Boka Kotorska Bay revealed the presence of four species [10], while only *Oikopleura dioica* was found in the Kotor Bay [15]. Recently, nine appendicularian species were recorded in the Boka Kotorska Bay: *Oikopleura dioica*, *Oikopleura longicauda*, *Oikopleura fusiformis*, *Oikopleura gracilis*, *Oikopleura intermedia*, *Kowalevskia tenuis*, *Fritillaria pellucida*, *Fritillaria borealis,* and *Fritillaria haplostoma* [20]. The number of species found gradually decreased from the open sea toward the inner waters of the Bay.

Among appendicularians, *Oikopleura dioica* numerically dominated in Kotor Bay, with the maximum of 1,570 ind. m^{-3} recorded in March 2010 (Table 15). In Tivat Bay and Herceg Novi Bay, *Oikopleura longicauda* was the most abundant representative of this group, whose population showed the highest values in October.

Table 15 Composition of appendicularian species in the Boka Kotorska Bay, with their maximum abundance values (max: ind. m^{-3}), average abundances (av ± SD; ind. m^{-3}), and mean percentage of the total appendicularian abundance (mean %)

	Kotor Bay			Tivat Bay			Herceg Novi Bay		
Species	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %
O. dioica	1,570	78.08 ± 219.07	46.35	819	44.19 ± 139.13	19.55	141	19.48 ± 44.26	5.29
O.longicauda	410	30.25 ± 72.45	43.83	205	26.81 ± 47.34	55.71	51	24.65 ± 16.56	73.09
O. fusiformis	205	11.59 ± 36.10	8.31	358	24.71 ± 64.39	15.47	256	36.04 ± 69.96	17.13
O gracilis	34	0.59 ± 3.54	0.15	9	0.39 ± 1.47	0.27	51	5.68 ± 13.72	1.49
O. intermedia	–	–	–	–	–	–	13	0.68 ± 3.42	0.25
Kowalevskia tenuis	–	–	–	–	–	–	6	0.49 ± 1.71	0.67
F. pellucida	68	2.38 ± 9.23	1.15	273	10.06 ± 41.51	9.00	51	7.94 ± 18.57	2.89
F. borealis	26	0.39 ± 2.57	0.21	17	0.53 ± 2.79	0.37	4	0.28 ± 0.98	0.23
F. haplostoma	17	0.17 ± 1.69	0.31	–	–	–	13	1.06 ± 3.41	0.10

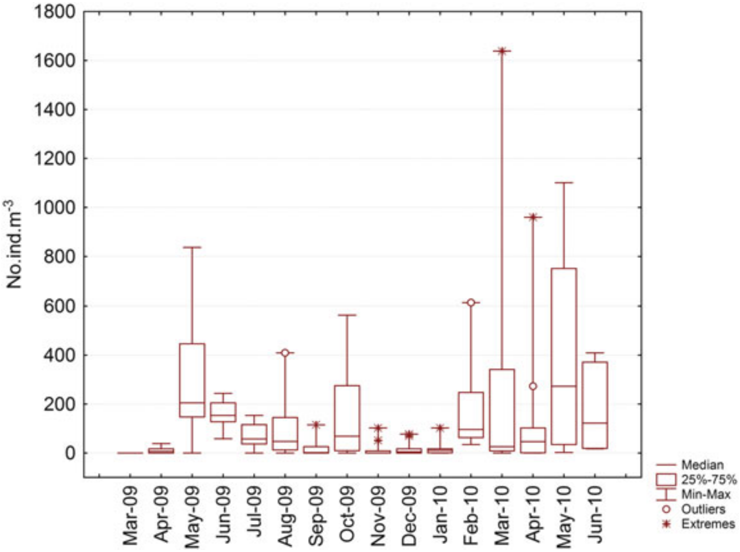

Fig. 12 Temporal variability of appendicularian abundance in the Boka Kotorska Bay from March 2009–June 2010

Significant fluctuations in overall densities of appendicularians were noted in the Boka Kotorska Bay.

Maximum of 1,638 ind. m^{-3} was recorded in March 2010 with generally lower values found over late autumn – early winter period (Fig. 12).

17 Thaliaceans

Thaliaceans were presented by salps and doliolids in Boka Kotorska Bay. High values were noted during summer months and reached maximum value of 461 ind. m^{-3} in August 2009 [20]. Statistical analysis showed significant negative correlations between doliolids and nanophytoplankton [20] which is in agreement with their filter feeding behavior [95].

18 Gelatinous Blooms

Gelatinous carnivorous zooplankton is a conspicuous component of marine ecosystems and is recognized as a valuable indicator of ecosystem functioning [98]. Massive outbreaks of jellyfish are a natural phenomenon, though human-related perturbations appear to exacerbate blooms [99]. Massive increases in their

Fig. 13 *Bolinopsis vitrea* in the Boka Kotorska Bay (photo: V. Mačić)

population size may have a wide range of economic and ecological implications, including reduction and structural changes of mesozooplankton populations, impairment of fish eggs and larvae, alteration of carbon and matter fluxes in food webs, clogging of fish nets, and impact on the tourist industry [100]. Recent decades' evidence indicates that gelatinous zooplankton have increased in abundance throughout the world's oceans and blooms (outbreaks of tens to hundreds of medusa per cubic meter) now occur more frequently in many seas, including the Mediterranean Sea [101].

The first examples of jellyfish outbreaks in the Boka Kotorska Bay happened just recently, wither dense aggregate of the ctenophora *Bolinopsis vitrea* (Fig. 13) observed in spring 2009 [24]. The ctenophore *B. vitrea* previously has been rarely observed in the Mediterranean Sea [102]. Ctenophores were found in the inner part of the Bay, below 5 m depth only. This mass occurrence of *B. vitrea* had a great impact on the Bay ecosystem. Their predation on copepods reduced grazing pressure on phytoplankton, favoring an uncommon bloom of the latter. It is evident that *B. vitrea* are capable of altering rapidly the composition and biomass of coastal plankton communities when present in large masses. This first evidence of such events for this species may indicate changes in the functioning of marine ecosystems.

During the last few years, previously unknown outbreaks of some schyphomedusa species have been reported in the Boka Kotorska Bay. *Discomedusa lobata* is a rare schyphomedusa (Fig. 14), known from the Eastern Atlantic Ocean and the Mediterranean Sea. It is commonly found in the Gulf of Trieste [103]. The first reliable record of this species in the Boka Kotorska Bay was in 2013 when its specimens were found sporadically from early March to mid-July in the inner part of the Bay. The first bloom, estimated at 100 individuals per 10 m^2, was noted in April 2014, with another in mid-May, and followed by blooms in February and March 2015 (Pestorić, personally communication).

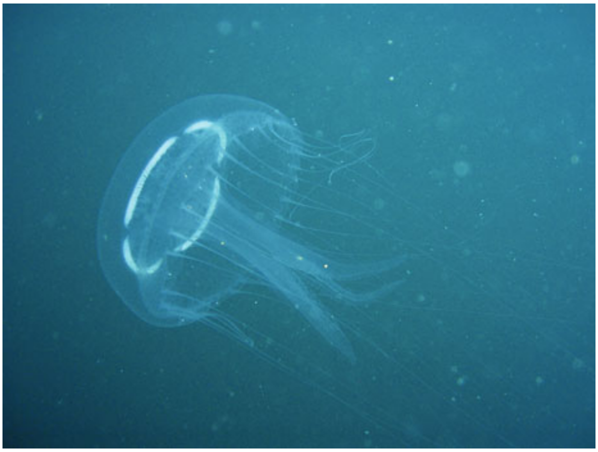

Fig. 14 *Discomedusa lobata* in the Boka Kotorska Bay (photo: V. Mačić)

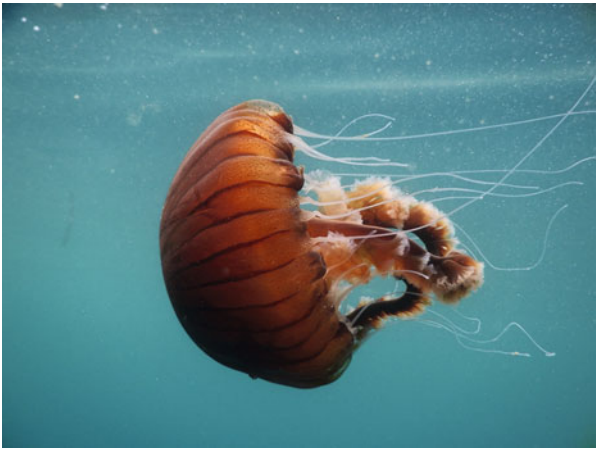

Fig. 15 *Chrysaora hysoscella* in the Boka Kotorska Bay (photo: V. Mačić)

Chrysaora hysoscella (Fig. 15) was found for the first time in the Boka Kotorska Bay in 2002 [17] as individual organism. In higher abundances *Chrysaora hysoscella* was observed during April 2014, while in March 2015 this species was noted in aggregation with *Discomedusa lobata* in low salinity area near fresh water source. In period from February to early May 2015 *C. hysoscella* was continuously present in the Bay in small number (Pestorić, personal communication).

Among native schyphomedusae found in the Mediterranean, which may grow to a larger size, is the species *Drymonema dalmatinum* [104]. Despite its conspicuous size this medusa has been very rarely observed in any Mediterranean area. Stiasny [105] suggested an ~30-year periodicity for this species based on records of *Drymonema* in the Adriatic since its description till 1940. There is no information about this species for Adriatic Sea in the period 1937–1984 [106]. On the other side, there were several observations since 2000 in the Northern, Central, and Southern Adriatic with majority of sightings in the Southern Adriatic. In the North-Eastern

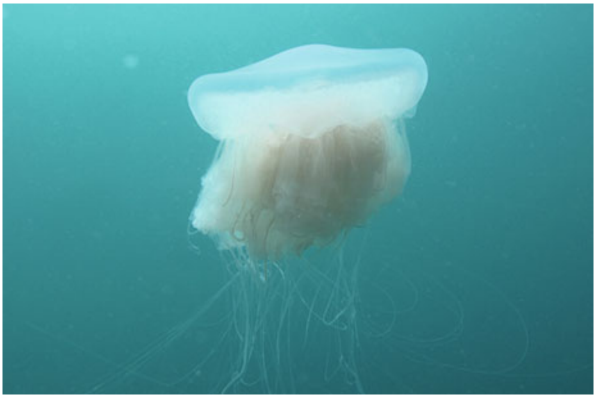

Fig. 16 *Drymonema dalmatinum* in the Boka Kotorska Bay (photo: V. Mačić)

part of the Kotor Bay *Drymonema dalmatinum* (Fig. 16) was noted four times in 2001 and once in 2014 [106].

19 Merozooplankton

Many juveniles and adults stages of marine organisms are part of benthos, but gametes or larvae are released into the water column [107]. These planktonic gametes and larvae grow in water column through one or more larval stages and make the most of meroplankton including different taxa and forms of planktonic larvae of benthic and planktonic species [108, 109]. That kind of development allows better distribution in the greater distances [110].

Average monthly abundance of meroplankton was the highest in the Kotor Bay with 973 ind. m^{-3} in February 2010 [20]. In the Tivat Bay, the highest mean monthly abundance of 533 ind. m^{-3} was recorded in April 2009. In the Herceg Novi Bay, the maximum number of meroplanktonic organisms was recorded in April 2009 with 281 ind. m^{-3} [20].

Throughout the year, average percentage of meroplanktonic larvae in zooplankton in the Kotor Bay was 2.3%. The highest value (~50%) was observed in the area of the Kotor Bay in February [20]. Bivalvia larvae dominated during research all areas accounting for more than 50% of the total meroplankton. That is common occurrence in shallow coastal areas where benthic communities are well developed [84]. Highest percentage of Bivalvia in the total meroplankton number was recorded in the Kotor Bay (62%), followed by the Tivat (52%), and the Herceg Novi Bays (30%) (Table 13). Gastropods accounted for 23% of the total number of meroplanktonic organisms in the Kotor Bay, followed by the Tivat with 27% in total number and 22% for the Herceg Novi Bay. Among other meroplankton, only decapods were significant in number. They were dominant in the Herceg Novi Bay (38%). Furthermore, Polychaetes and fish larvae were represented with 1% in the total number. Other meroplanktonic organisms have occasionally occurred in small numbers (Table 16). Historical data show that some species of decapods are higher

Table 16 Composition of meroplankton taxa in the Boka Kotorska Bay, with their maximum abundance values (max: ind. m^{-3}), average abundances (av ± SD; ind. m^{-3}), and mean percentage of the total meroplankton abundance (mean %)

Species	Kotor Bay			Tivat Bay			Herceg Novi Bay		
	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %	Max.	Mean ± SD	Mean %
Bivalvia	5051.73	178.3 ± 549.02	62.66	477.87	86.43 ± 116.58	52.07	256.00	41.27 ± 81.61	30.95
Gastropoda	409.6	50.37 ± 88.48	23	341.33	60.38 ± 91.86	27	51.20	13.94 ± 17.55	22
Decapoda larvae	51.20	7.06 ± 11.38	9.04	80.77	9.74 ± 15.80	14.57	173.60	19.24 ± 44.96	37.94
Polychaeta	68.27	5.32 ± 15.48	2.46	68.27	6.65 ± 14.07	3.5	12.8	1.82 ± 3.42	2.57
Pisces	51.20	2.57 ± 7.77	0.9	8.53	1.79 ± 2.89	1.38	38.40	3.83 ± 10.12	3.44
Bipinnaria	136.53	3.15 ± 14.56	0.8	102.4	5.71 ± 18.54	0.99	–	–	–
Ova Pisces	68.27	1.88 ± 7.45	0.48	25.60	1.61 ± 5.54	0.37	9.60	1.22 ± 2.66	1.06
Ophiopluteus	40.96	2.03 ± 7.45	0.31	34.13	0.93 ± 5.06	0.03	–	–	–
Echinopluteus	34.13	0.43 ± 3.40	0.01	34.13	1.21 ± 5.59	0.05	–	–	–

in number during spring and summer [111], which concurs with the results of our investigation. There is a strong link between phytoplankton bloom and development of certain meroplanktonic organisms [107].

20 Conclusions

The study indicates that fast-occurring changes in hydrographic and production parameters in the enclosed and eutrophic Boka Kotorska Bay significantly influence the density of zooplankton populations.

These variations are particularly strongly affected the composition and abundance of microzooplankton. Non-loricate ciliates were the most numerous microzooplankton, with the highest values at the surface, which is strongly influenced by a layer of fresh water. Tintinnid values were low and similar to those recorded in the open Adriatic Sea. Tintinnid species diversity was considerably high, and twenty-three species were recorded for the first time in Boka Kotorska Bay.

Copepods were the most numerous mesozooplankton group, dominated by small cyclopoids species (Oncaea like cyclopoids and *Oithona nana*). High abundance of the cladocera *Penilia avirostris* during summer are in accordance with the eutroficated status of area, and were among the highest values noted for the Adriatic.

Comparing our results with a previous research of the Boka Kotorska Bay some changes in the composition and abundance of zooplankton were observed: dominance of small copepod species; prevalence of alien species *Muggiaea atlantica* over to indigenous species *M. kochi*, especially in the inner part of the Bay; changes in the composition and abundance of meroplanktonic hydromedusans fauna; the first recorded mass occurrence of ctenophore *Bolinopsis vitrea* in the Mediterranean Sea; and frequent and more numerous before rare schyphozoan species. Our results suggest the possibility of permanent fauna changes in the Boka Kotorska Bay that could be associated with global warming and generally climate change.

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References

1. Roemmich D, McGowan J (1995) Climatic warming and the decline of zooplankton in the California current. Science 267:1324–1326
2. Kiørboe T (1997) Population regulation and role of mesozooplankton in shaping marine pelagic food webs. Hydrobiology 363:13–27

3. Calbet A (2008) The trophic roles of microzooplankton in marine systems. ICES J Mar Sci 65:325–331
4. Beaugrand G, Brander KM, Lindley JA, Souissi S, Reid PC (2003) Plankton effect on cod recruitment in the North Sea. Nature 426:661–664
5. Beaugrand G (2005) Monitoring pelagic ecosystems using plankton indicators. ICES J Mar Sci 62:333–338
6. Eloire D, Somerfield PJ, Conway DVP, Halsband-Lenk C, Harris R, Bonnet D (2010) Temporal variability and community composition of zooplankton at station L4 in the Western Channel: twenty years of sampling. J Plankton Res 32:657–679
7. Car L (1896) Copepodni plankton iz Jadranskog mora. Glasnik hrvatskog naravoslovnog društva 8:145–150
8. Gamulin T (1938) Prilog poznavanju planktonskih kopepoda Boke Kotorske. Oceanografski institut, Godišnjak 1:110–122
9. Vukanić D (1971) Kopepodi Bokokotorskog zaliva. Stud Mar 5:21–60
10. Vukanić D (1979) La recherches sur la Zooplanktons dans la baie de Kotor. Nova Thalassia 3 (1):249–255
11. Vukanić V (2010) Studies on Copepoda in Bay of Kotor–Coastal waters of Southern Adriatic. Nat Montenegrina 9(3):457–467
12. Vukanić D, Dutina M (1983) Sastav i brojnost planktonskih veslonožaca za vrijeme cvatnje Dinoflagelata u Kotorskom zalivu s osvrtom na hidrografske karakteristike. Stud Mar 13–14:127–139
13. Benović A, Onofri V (1983) Prilog poznavanju mrežnog zooplanktona Kotorskog zaliva. Stud Mar 13–14:119–125
14. Vukanić D, Dutina M, Vuksanović N (1989) Contribution to the investigations of the ecological characteristics and plankton of the bay of Kotor. Period Biol 94(1):125–126
15. Skaramuca B, Bender A (1983) Zimsko–proljetni aspekt populacije *Apendiculariaa* u Kotorskom zalivu. Stud Mar 13–14:111–117
16. Vukanić V, Vukanić D (2004) Zooplankton studies in the Boka Kotorska Bay during 2002 – Chaetognatha. Rapp Comm Int Mer Mediterr 37:459
17. Vukanić V (2006) A zooplankton study of the Boka Kotorska Bay during 2002 - hydromedusae (Cnidaria). Nat Montenegrina 5:37–47
18. Vukanić V (2006b) One-year observation on the population structure of Cladocera in Boka Kotorska Bay (Coastal waters of Southern Adriatic). Proceedings of MWWD Conference, , Antalya, Turkey, 6–10 November 2006.
19. Vukanić V (2007) Thecosome pteropod on the Bokakotorska Bay (Southern Adriatic). Rapp Comm Int Mer Mediterr 38:633
20. Pestoric B (2013) Dynamics of zooplankton communities in Boka Kotorska Bay. Dokoctoral thesys, University of Belgrade, Faculty of Biology, p 208
21. Pestorić B, Lučić D, Joksimović D (2011) Cladocerans spatial and temporal distribution in the coastal south Adriatic waters (Montenegro). Stud Mar 25:101–120
22. Pestorić B, Krpo-Ćetković J, Gangai B, Lučić D (2012) Pelagic cnidarians in the Boka-Kotorska Bay (Montenegro, South Adriatic). Acta Adriat 53(2):291–302
23. Pestorić B, Miloslavić M, Drakulović D, Lučić D (2014) Chaetognaths in Boka Kotorska Bay. Stud Mar 27(1):109–130
24. Lučić D, Pestorić B, Malej A, Lopez-Lopez L, Drakulović D, Onofri V, Miloslavić M, Gangai B, Onofri I, Benović A (2012) Mass occurrence of the ctenophore *Bolinopsis vitrea* (L. Agassiz, 1860) in the nearshore soutern Adriatic Sea (Kotor Bay, Montenegro). Environ Monit Assess 184:4777–4785
25. Kršinić F, Viličić D (1989) Microzooplankton in the Kotor Bay (the southern Adriatic). Stud Mar 20:1–20
26. Lučić P (2014) Microzooplankton in the costal region of the South Adriatic Sea and in the Boka Kotorska Bay. Master Thesis. University of Zagreb, Faculty of Science, Division of Biology, p 63

27. Kršinić F (1980) Comparison of methods used in microzooplanktonresearch in neritic waters of the eastern Adriatic. Nova Thalassia 4:91–106
28. Giesbrecht W (1892) Systematik und Faunistik der pelagische Copepoden des Golfes von Neapel und der angrenzenden Meeres-Abschnitte. Zoologische Station zu Neapel, XIX. Monographie, Friedländer & Sohn, Berlin, p 831
29. Sars GO (1924) Copépodes particulièrement bathypélagiques provenent des Campagnes Scietifiques du Prince Albert Ier de Monaco. Résultats de Campagnes Scientifiques Accomplies par le Prince Albert I. Monaco 69:1–408
30. Rose M (1933) Faune de France, v. 26: Copépodes pélagiques. Paris, Librairie de la Faculté des Sciences, p 374
31. Park T (1995) Taxonomy and distribution of the marine calanoid family Euchaetidae. Bull Scripps Inst Oceanogr Univ California 29I-IX:1–203
32. Razouls C, de Bovée F, Kouwenberg J, Desreumaux N (2005–2011) Diversity and geographic distribution of marine planktonic copepods. Available at: http://copepodes.obs-banyuls.fr/en.
33. Calbet A, Landry MR (2004) Phytoplankton growth, microzooplankton grazing, and carbon cycling in marine systems. Limnol Oceanogr 46:1824–1830
34. Calbet A, Saiz E (2005) The ciliate–copepod link in marine ecosystems. Aquat Microb Ecol 38:157–167
35. Sherr EB, Sherr BF (2002) Significance of predation by protists in aquatic microbial food webs. Antonie Van Leeuwenhoek 81:293–308
36. Sanders RW (1987) Tintinnids and other microzooplankton–seasonal distribution and relationship to resources and hydrography in a Maine estuary. J Plankton Res 9:65–77
37. Dolan JR, Coats DW (1990) Seasonal abundances of planktonic ciliates and microflagellates in mesohaline Chesapeake Bay waters. Estuar Coast Shelf Sci 31:157–175
38. Revelante N, Gilmartin M, Smodlaka N (1985) The effects of Po River induced eutrophication on the distribution and community structure of ciliated protozoan and micrometazoan populations in the northern Adriatic Sea. J Plankton Res 7:461–471
39. Kršinić F (1995) Changes in the microzooplankton assemblages in the northern Adriatic Sea during 1989 to 1992. J Plankton Res 17:935–953
40. Bojanić N, Šolić M, Krstulović N, Marasović I, Ninčević Ž, Vidjak O (2001) Seasonal and vertical distribution of the ciliated protozoa and micrometazoa in Kaštela Bay (central Adriatic). Helgol Mar Res 55:150–159
41. Fonda Umani S, Milani L, Borme D, de Olazabal A, Parlato S, Precali R, Kraus R, Lučić D, Njire J, Totti C, Romagnoli T, Pompei M, Cangini M (2005) Inter-annual variations of planktonic food webs in the northern Adriatic Sea. Sci Total Environ 353(1–3):218–231
42. Dolan JR (2000) Tintinnid ciliate diversity in the Mediterranean Sea: longitudinal patterns ralated to water column structure in late spring-early summer. Aquat Microb Ecol 22:69–78
43. Pitta P, Giannakourou A (2000) Planctonic ciliates in the oligotrophic Eastern Mediterranean: vertical, spatial distribution and mixotrophy. Mar Ecol Prog Ser 194:269–282
44. Kršinić F, Grbec B (2006) Horizontal distribution of tintinnids in the open waters of the South Adriatic (Eastern Mediterranean). Sci Mar 70:77–88
45. Cariou JB, Dolan JR, Dallot S (1999) A preliminary study of tintinnid diversity in the NW Mediterranean Sea. J Plankton Res 21:1065–1075
46. Dolan JR, Montagnes DJS, Agatha S, Coats DW, Stoecker DK (2013) The biology and ecology of tintinnid ciliates: models for marine plankton. Wiley-Blackwell, Chichester, UK
47. Revelante N, Gilmartin M, Smodlaka N (1985) The effects of Po River induced eutrophication on the distribution and community structure of ciliated protozoan and micrometazoan populations in the northern Adriatic Sea. J Plankton Res 7:461–471
48. Rudenjak–Lukenda M (1990) Annual vertical distribution of microzooplankton in the Bay of Mali Ston, Southern Adriatic (1983–1984). Acta Adriat 31:99–116

49. Vidjak O, Bojanić N, Kušpilić G, Ninčević Gladan Ž, Tičina V (2007) Zooplankton community and hydrographical properties of the Neretva Channel (eastern Adriatic Sea). Helgol Mar Res 61:267–282
50. Nielsen TG, Kiørboe T (1994) Regulation of zooplankton biomass and production in a temperate, coastal ecosystem. 2. Ciliates. Limnol Oceanogr 39:508–519
51. Kršinić F (2010) Tintinnids (Tintinnida, Choreotrichia, Ciliata) in the Adriatic Sea, Mediterranean. Part II ecology. Acta Adriat (special edition), p 113
52. Monti M, Minocci M, Milani L, Fonda Umani S (2012) Seasonal and interannual dynamics of microzooplankton abudances in the Gulf of Trieste (Northern Adriatic Sea, Italy). Estuar Coast Shelf Sci 115:149–157
53. Cabrini M, Fornasaro D, Cossarini G, Lipizer M, Virgilio D (2012) Phytoplankton temporal changes in a coastal northern Adriatic site during the last 25 years. Estuar Coast Shelf Sci 115:113–124
54. Bernardi Aubry F, Cossarini G, Acri F, Bastianini M, Bianchi F, Camatti E, De Lazzari A, Pugnetti A, Solidoro C, Socal G (2012) Plankton communities in the northern Adriatic Sea: patterns and changes over the last 30 years. Estuar Coast Shelf Sci 115:125–137
55. Čalić M, Carić M, Kršinić F, Jasprica N, Pećarević M (2013) Controlling factors of phytoplankton seasonal succession in oligotrophic Mali Ston Bay (south-eastern Adriatic). Environ Monit Assess 185(9):7543–7563
56. Mozetič P, Solidoro C, Cossarini G, Socal G, Precali R, Francé J, Bianchi F, De Vittor C, Smodlaka N, Fonda Umani S (2010) Recent trends towards oligotrophication of the northern Adriatic: evidence from chlorophyll *a* time series. Estuaries Coasts 33:362–375
57. Smayda TJ (1980) Phytoplankton species succession. In: Morris I (ed) The physiological ecology of phytoplankton, Blackwell Scientific Publications, Oxford, p 493–570
58. Boni L (1983) Red tide off the coast of Emilia Romagna (north-western Adriatic sea) from 1975 to 1982. Informatore Botanico Italiano 15:18–23
59. Dela-Cruz J, Ajani P, Lee R, Tim Pritchard T, Suthers I (2002) Temporal abundance patterns of the red tide dinoflagellate Noctiluca scintillans along the southeast coast of Australia. Mar Ecol Prog Ser 236:75–88
60. Fonda Umani S, Beran A, Parlato S, Virgilio D, Zollet T, De Olazabel A, Lazzarini B, Cabrini M (2004) Noctiluca scintillans (Macartney) in the Northern Adriatic Sea: long-term dynamics, relationships with temperature and eutrophication, and role in the food web. J Plankton Res 26(5):545–561
61. Elbrächter M, Qi ZY (1998) Aspect of Noctiluca (Dinophyceae) population dynamics. In: Anderson DM, Cembella AD, Hallegraeff MG (eds) Physiological ecology of harmful algal blooms. NATO ASI Series, vol. G 41. Springer-Verlag, Berlin, pp 315–335
62. Nakamura Y (1998) Biomass, feeding and production of Noctiluca scintillans in the Seto Inland Sea, Japan. J Plankton Res 20:2213–2222
63. Boero F, Bouillon J, Gravili C, Miglietta MP, Parsons T, Piraino S (2008) Gelatinous plankton: irregularities rule the word (sometimes). Mar Ecol Prog Ser 356:299–310
64. Brotz L, Cheung WLW, Kleisner K, Pakhomov E, Pauly D (2012) Increasing jellyfish populations: trends in large marine ecosystems. Hydrobiologia 690(1):3–20
65. Purcell JE, Arai MN (2001) Interactions of pelagic cnidarians and ctenophores with fish: a review. Hydrobiologia 451:27–44
66. Bouillon J, Medel MD, Pages F, Gili JM, Boero F, Gravili C (2004) Fauna of the Mediterranean hydrozoa. Sci Mar 68(2):1–449
67. Babnik P (1948) Hidromeduze iz srednjeg in južnog Jadrana v letih 1939. in 1940 (in Slovenian with English summary). Acta Adriat 3:1–76
68. Purcell JE (1981) Dietary composition and diel feeding patterns of epipelagic siphonophores. Mar Biol 65:83–90
69. Graham WM, Page's F, Hamner WM (2001) A physical context for gelatinous zooplankton aggregations: a review. Hydrobiologia 451:199–212

70. Kršinić F, Njire J (2001) An invasion by Muggiaea atlantica Cunningham 1982 in the northern Adriatic Sea in the summer of 1997 and the fate of small copepods. Acta Adriat 42(1):49–59
71. Atienza D, Saiz E, Skovgaard A, Trepat I, Calbet A (2008) Life history and population dynamics of the marine cladoceran *Penilia avirostris* (Branchiopoda: Cladocera) in the Catalan Sea (NW Mediterranean). J Plankton Res 30:345–357
72. Onbé T (1977) The biology of marine cladocerans in a warm temperate water. In: Proc symp warm water zoopl spec publ natn inst oceanogr. UNESCO, Goa, pp 383–398
73. Marazzo A, Valentin JL (2001) Spatial and temporal variations of *Penilia avirostris* and *Evadne tergestina* (Crustacea, Branchiopoda) in a Tropical Bay, Brazil. Hydrobiologia 445:133–139
74. Tang KW, Chen QC, Wong CK (1995) Distribution and biology of marine cladocerans in the coastal waters of southern China. Hydrobiologia 307(1–3):99–107
75. Fonda Umani S, Franco P, Ghirardelli E, Malej A (1992) Outline of oceanography and the plankton of the Adriatic Sea. In: Colombo G, Ferrari I, Ceccherelli VV, Rossi R (eds) Marine eutrophication and population dynamics. Olsen & Olsen, Fredensborg, pp 347–365
76. Wong CK, ChangALC, Tang, KW (1992) Natural ingestion rates and grazing impact of marine cladoceran *Penilia avirostris* Dana in Tolo Harbour, Hong Kong. J Plankton Res 14:1757–1765
77. Lipej L, Mozetič P, Turk V, Malej A (1997) The trophic role of the marine cladoceran *Penilia avirostris* in the Gulf of Trieste. Hydrobiologia 360:197–203
78. Leandro SM, Morgado F, Pereira F, Queiroga H (2007) Temporal changes of abundance, biomass and production of copepod community in a shallow temperate estuary (Ria de Aveiro, Portugal). Estuar Coast Shelf Sci 74:215–222
79. Marques SC, Azeiteiro UM, Martinho F, Viegas I, Pardal MA (2009) Evaluation of estuarine mesozooplankton dynamics at a fine temporal scale: the role of seasonal, lunar and diel cycles. J Plankton Res 31(10):1249–1263
80. Howlett R (1998) Sex and the single copepod. Nature 394:423–424
81. Kršinić F, Lučić D (1994) Mesozooplankton sampling experiments with the ‘Adriatic’ sampler: differences of catch between 250 and 125 μm mesh netting gauze. Estuar Coast Shelf Sci 38:113–118
82. Calbet A, Garrido S, Saiz E, Alcaraz M, Duarte CM (2001) Annual zooplankton succession in coastal NW Mediterranean waters: the importance of the smaller size fractions. J Plankton Res 23:319–331
83. Gallienne CP, Robins DB (2001) Is Oithona the most important copepod in world’s oceans? J Plankton Res 23:1421–1432
84. Miloslavić M, Lučić D, Žarić M, Gangai B, Onofri I (2015) The importance of vertical habitat gradients on mesozooplankton distribution in a semi-enclosed marine environment (South Adriatic Sea). Mar Biol Res 11(5):462–474
85. Vidjak O, Bojanić N, Kušpilić G, Marasović I, Ninčević GŽ, Brautović I (2006) Annual variability and trophic relations of the mesozooplankton community in the eutrophicated coastal area (Vranjic Basin, eastern Adriatic Sea). J Mar Biol Assoc UK 86:19–26
86. Viličić D, Kršinić F, Carić M, Jasprica N, Bobanović-Ćolić S, Mikuš J (1995) Plankton and hydrography in a moderately eastern Adratic Bay (Gruž Bay). Hydrobiologia 304:9–22
87. Lučić D, Kršinić F (1998) Annual variability of mesozooplankton assemblages in Mali Ston Bay (Southern Adriatic). Period Biol 100:43–52
88. Rampal J (1975) Les thécosomes. Systématique et evolution. Ecologie et biogéographie méditerranéennes. These Doctoral. Université Aix-Marseille I, pp. 1-485.
89. Batistić M, Kršinić F, Jasprica N, Carić M, Viličić D, Lučić D (2004) Gelatinous invertebrate zooplankton of the South Adriatic: species composition and vertical distribution. J Plankton Res 26(4):459–474

90. Reeve MR, Cosper TC, Walter MA (1975) Visual observations of the process of digestion and the production of faecal pellets in the chaetognath *Sagitta hispida* Conant. J Exp Mar Biol Ecol 17:39–46
91. Pearre S Jr (1974) Ecological studies of three West-Mediterranean chaetognaths. Invest Pesquera 38:325–369
92. Stuart V, Verheye HM (1991) Diel migration and feeding patterns of the chaetognath, *Sagitta federici,* off the west coast of South Africa. J Mar Syst 49:493–515
93. Ghirardelli E, Specchi M (1965) Chaetognathes et Cladodocceres du Golfe de Trieste (Recherches préliminaires). Rapp Comm Int Mer Méditerr 18:403–407
94. Graeffe E (1905) Ubersicht der Fauna des Golfes von Triest, X. Vernes. Arb. Zool. Inst, Wien 15:317–332
95. Bone Q (1998) The biology of pelagic tunicates. Oxford University Press, Oxford
96. Spada F, Steen H, Troedsson C, Kallesoe T, Spriet E, Mann M, Thompson EM (2001) Molecular patterning of the oikoplastic epithelium of the larvacean tunicate Oikopleura dioica. J Biol Chem 276:20624–20632
97. Thompson EM, Kallesøe T, Spada F (2001) Diverse genes expressed in distinct regions of the trunk epithelium define a monolayer cellular template for construction of the oikopleurid house. Dev Biol 238:260–273
98. Official Journal of the European Union (2010) Commission decision on criteria and methodological standards on good environmental status. 232/14 of 1 September 2010
99. CIESM 2001 Gelatinous zooplankton outbreaks: theory and practice. CIESM Workshop Series 14, Monaco, p 112
100. Boero F (2013) Review of Jellyfish blooms in the Mediterranean and Black Sea. Studies and reviews. General Fisheries Commission for the Mediterranean. No. 92. FAO, Rome, p 53
101. Licandro P, Conway DVP, Daly Yahia MN, Fernandez de Puelles ML, Gasparini S, Hecq JH, Tranter P, Kirby RR (2010) A blooming jellyfish in the northeast Atlantic and Mediterranean. Biol Lett. doi:10.1098/rsbl.2010.0150
102. Shiganova T, Christou ED, Bulgakova JV, Siokou-Frangou I, Zervoudaki S, Siapatis A (2004) Distribution and biology of Mnemiopsis leidyi in the northern Aegean Sea, and comparison with indigenous Bolinopsis vitrea. In: Dumont H, Shiganova T, Niermann U (eds) Aquatic invasions in the Black, Caspian, and Mediterranean Seas, NATO Science Series, 4, Earth and Environmental Sience, Kluwer, Dordrecht, pp 113–135
103. Rottini-Sandrini L, Bratina E, Avian M (1986) Aspetti ultrastrutturali della gametogenesi in *Discomedusa lobata* (Claus). Nova Thalassia 8(suppl 2):59–66. In Italian; English abstract
104. Haeckel E (1880) System der Acraspeden. Zweite Halfte des System der Medusen. Verlag von Gustav Fischer, Jena, p 361–672
105. Stiasny G (1940) Über *Drymonema dalmatinum* Haeckel. Zool Jb Abt Anat 66:437–461
106. Malej A, Vodopivec M, Lucic D, Onofri I, Pestoric B (2014) The lesser-known medusa Drymonema Dalmatinum Haeckel 1880 (Scyphozoa, Discomedusae) in the Adriatic Sea. Ann Ser Hist Nat 24(2):79–86
107. Highfield JM, Eloire D, Conway D, Lindeque PK, Attrill MJ, Somerfield PJ (2010) Seasonal dynamics of meroplankton assemblages at station L4. J Plankton Res 32:681–691
108. Marcus NH, Boero F (1998) Minireview: the importance of benthic-pelagic coupling and the forgotten role of life cycles in coastal aquatic systems. Limnol Oceanogr 43(5):763–768
109. Pechenik JA (1999) On the advantages and disadvantages of larval stages in benthic marine invertebrate life cycles. Mar Ecol Prog Ser 177:269–297
110. Livi S, Cordisco C, Damiani C, Romanelli M, Crosetti D (2006) Identification of bivalve species at an early developmental stage through PCR-SSCP and sequence analysis of partial 18S rDNA. Mar Biol 149:1149–1161
111. Lučić D (1998) Annual variability of decapod larvae community in the shallow waters of the southern Adriatic. Acta Adriat 39(1):29–30

Characteristics of the Zoobenthos in Boka Kotorska Bay

Slavica Petović and Olivera Marković

Abstract Description of the basic characteristics of the zoobenthos assemblages at the seafloor of the Boka Kotorska Bay was created by compiling available data from the scientific and gray literature, and they are a result of research on this area during the last 55 years. All data on the benthic fauna of the Boka Kotorska Bay, up until the middle of the last century, are very rare and can be found in publications resulting from the study of the Adriatic Sea by international scientists. With the establishment of the Institute for Marine Biology in Kotor, more intensive research of marine biodiversity of this particular area has started.

Available data indicate the presence of a large number of species of seabed fauna which has adapted to specific environmental conditions. Among the identified taxonomy, there are many species protected by national and international regulations. Most of these species are builders of coralligenous biocoenosis that makes this space *unicum*. These communities are particularly distributed in the inner part of the Boka Kotorska Bay (the Bay of Kotor and Risan) where they are distributed to the relatively shallow depths (12–30 m).

Since the area of the Boka Kotorska Bay is abundant with underground springs, many species have adapted to life in the brackish environment with reduced salinity. From the species that inhabit the sea bottom of this area, there is a large number of endemic species of the Mediterranean, especially from the group of molluscs and echinoderms.

The area of the Boka Kotorska Bay as well as whole Mediterranean zone is under strong human influence, so the presence of invasive species has been reported, some of which become domesticated. This number is certainly not final and has the tendency to increase.

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Contents

1 Introduction

The area of the Boka Kotorska Bay is a complex semi-enclosed basin, consisting of four smaller bays, which conditionally make up the inner part of the Bay (Bay of Kotor and the Bay of Risan) and outer part (Bay of Tivat and the Bay of Herceg Novi) (Fig. 1). Since communication with the open sea is limited, it is noticeable that it is significantly different from the open part of the coast, when it comes to climate, geomorphological, and physical-chemical characteristics. Boka Kotorska Bay enters deep into the mainland, so the individual Bays differ with one another according to values of abiotic factors and the characteristics of the seabed. The bottom of the Bay is mostly covered by thick layers of fine mud. In the Bay of Kotor and Risan, as well as in the Verige Channel, the seabed is covered with clay, with sandy clay directly in front of Risan [1]. In the Bay of Tivat, clay is predominant, and to a lesser extent clay-loamy sand and clay loam. In the Bay of Herceg Novi, aside from the clay, the seafloor is covered with clay loam, clay sand, and sand.

Relief of the sea bottom is very complex and is not always symmetrical. Depth in Bays increases toward the center, except in the Bay of Kotor, where the maximum depth is near the northern coast of the Bay (Perast). The average depth of the entire Bay is 27.6 m and maximum one – 64 m (Bay of Kotor) [2]. Boka Kotorska Bay is surrounded by mountain ranges, which often cause significant cooling in winter months and the appearance of ice on the sea surface. This is an area of intense rainfall, which causes large amounts of fresh water to flow into the Bay in the period from November to April, particularly in its inner part. Such a combination of environmental conditions has caused for the development of specific benthic assemblages [3].

Historical data said that relatively small area of the Boka Kotorska Bay is characterized by high biodiversity of sessile or slow motion organisms [4]. More

Fig. 1 Boka Kotorska Bay

intensive studies of the Boka Kotorska Bay fauna began in the mid-1970s of the twentieth century, with the establishment of the Institute for Marine Biology in Kotor. Data on the zoobenthos diversity of this area can be found in the papers of the world's scientists as part of the benthic fauna of the Adriatic Sea [5–8]. Depending on the objective of the research project, as well as the available experts, we could say that during the last century, the area of the Bay was very well examined for macromolluscs [9], especially group of cephalopods [10, 11], than polychaetes [12] and anthozoans [13]. The study of echinoderms started during the 1980s [14], just to be intensified during the last 10 years [15]. Data on other zoobenthos organisms that are contained in the papers deal with research of the present benthic biocoenosis [3, 16, 17].

In this chapter, we describe zoobenthos species composition and present benthic assemblages in the area of the Boka Kotorska Bay, based on literature data during the last 55 years, zoobenthos species distribution in relation to the four bays, and checklist of invasive species for the given area.

2 Benthic Biocoenosis in the Boka Kotorska Bay

As it was already pointed out that the Boka Kotorska Bay was characterized by specific values of physical-chemical parameters of the environment, the presence of benthic biocoenosis was specific in relation to the open coast. Occurrence and depth of spread of benthic communities are what makes this area specific. Analysis of the benthic organisms in the area of the Boka Kotorska Bay showed the presence of the *biocoenosis of coastal terrigenous muds* and elements of other biocoenosis on movable and solid substrate [3]. This biocoenosis occupies more than 87% of the sea bottom in the area of the Bay of Kotor and Risan [17]. *Biocoenosis of coastal terrigenous muds* is developed along the entire eastern coast of the southern Adriatic, especially in the areas of quiet and weakened bottom currents [18]. In Boka Kotorska Bay, this biocoenosis occupies the largest, mostly central part of the Bay and is only modified in areas where an inflow of fresh water exists (springs, streams, and small rivers which flow into the sea) [18, 19]. Different groups of ascidians are characteristic for this biocoenosis: *Diazona violacea*, *Ascidia virginea*, *Ascidia mentula*, *Phallusia mammillata*, and others. This biocoenosis is also characterized by soft coral *Alcyonium adriaticum*; cephalopods *Sepia officinalis*, *Sepia elegans*, *Sepia orbignyana*, *Loligo vulgaris*, *Eledone moschata*, *Eledone cirrhosa*, *Alloteuthis media*, *Octopus vulgaris*, *Sepiola rondeleti*, *and Sepieta oweniana*; and sea cucumber *Eostichopus regalis* [18, 19].

The *biocoenosis of coastal detritic bottom* was recorded at the border between infralittoral and circalittoral steps. Nature of detritic elements is very different and depends on the composition of the shore or from a nearby seabed and surrounding biocoenosis; these are fragments of rock, shards of shells and other skeletal elements, parts of bryozoans, calcareous algae, etc. Within this biocoenosis, there are representatives of sponges *Bubaris vermiculata*; numerous *Polychaeta*; snails *Turritella tricarinata f. communis* and *Turritella triplicata*; shells *Pteria hirundo*, *Pecten jacobaeus*, *Pandora pinna*, *Acanthocardia deshayesii*, *Moerella donacina*, *Venus casina*, etc.; and echinoderms *Labidoplax digitata*, *Leptopentacta elongata*, *L. tergestina*, *Eostichopus regalis*, *Anseropoda placenta*, *Psammechinus microtuberculatus*, etc. The rest of the sea bottom belongs to the *biocoenosis of muddy sands* [3].

Coralligenous biocoenoses are the best developed in the area of the Bay of Kotor and Risan on a solid substrate in circalittoral layer, in more or less darken conditions, at the shaded area below the underwater meadows of sea grass, as well as in significantly shallower parts of the seabed [17]. Facies *Savalia savaglia* and facies *Leptogorgia sarmentosa* can be distinguished within this biocoenosis. The dominant ones are incrusted algae, corals, and species from the group of *Bryozoa*, *Polychaeta*, and *Echinodermata*. It is the most important biodiversity area of the Bay of Kotor and Risan. On the movable sandy-muddy infralittoral substrate, there have developed the *biocoenosis of seagrass meadows* (*Posidonia*, *Zostera*, and *Cymodocea*). The leaves of *Posidonia* are often populated by various species of *Bryozoa*, *Hydrozoa*, *Polychaeta*, crabs, and snails. Inside of this biocoenosis as vary important live component are echinoderms (species from genus *Holothuria*, *Echinaster sepositus*, *Paracentrotus lividus*, *Sphaerechinus granularis*). This biocoenosis is suitable for fish eggs; there are cephalopods and other animals, because in the meadows, the young are protected from predators [3].

Biocoenoses of photophilic algae develop on a solid surface in the upper infralittoral zone, where the light penetration is the strongest and where the variation of temperature and salinity is the most prominent in few-meters-wide zone. This biocoenosis occurs in the form of several facies, but the characteristic species of animals are crabs *Acanthonyx lunulatus and Clibanarius erythropus*; molluscs *Patella pellucida* and *Cerithium vulgatum*; echinoderms *Paracentrotus lividus*, *Arbacia lixula*, *and Echinaster sepositus*; and others [20]. Big haul of fish often swim above algae.

Biocoenoses of the muddy bottom at the Bay are characterized by a huge number of irregular sea urchin *Brissopsis lyrifera*, so it can be considered as a particular form of the biocoenosis of coastal terrigenous muds. At the same time, coral *Veretillum cynomorium* is part of this community, otherwise rare in the Adriatic Sea [16].

Recent studies [21] confirm the benthic communities in the infralittoral part of the Bay of Kotor and Risan as unique, due to large presence of communities on moving substrate (soft substrate) and the presence of coralligenous biocoenosis at Dražin Vrt at a depth of 12–30 m.

Area of the Bay of Kotor and Risan is characterized by a very steep rocky coast, and movable bottom has been very close to the coastline, at a depth of 15–25 m, and covers a considerable part of the Bay; below 30–40 m of depth, the seabed has a slight slope and slightly deeper areas that are characterized by the presence of depressions [17].

3 The Diversity of Zoobenthos Assemblages

The inflow of large amounts of fresh water, the presence of underground springs, specific combination of temperature, salinity, and amount of light had a decisive role in the diversity and distribution of benthic fauna. Collected data show the presence of all zoobenthos groups [4] at the seafloor of the Boka Kotorska Bay.

Generally, the inner part of the Boka Kotorska Bay is much better explored than the outer part. Recent studies [17] show that the inner part of the Bay, i.e., the Bay of Kotor and Risan is characterized by a wealth of animal life. This primarily refers to a solid substrate with 124 species recorded, while soft substrates are inhabited by 77 species. *Mollusca* is the most abundant phylum with a total of 46 taxa, followed by *Annelida* (38 taxa) and *Porifera* (37 taxa). *Porifera*, *Bryozoa*, and *Tunicata* are exclusively found on the hard bottom, while *Annelida* dominates on the soft bottom. Comparing the obtained data with historical records relating to the entire Boka Kotorska Bay (Appendix 1), it is notable that the number of recorded molluscs is significantly lower than in the entire Boka Kotorska Bay, while the number of

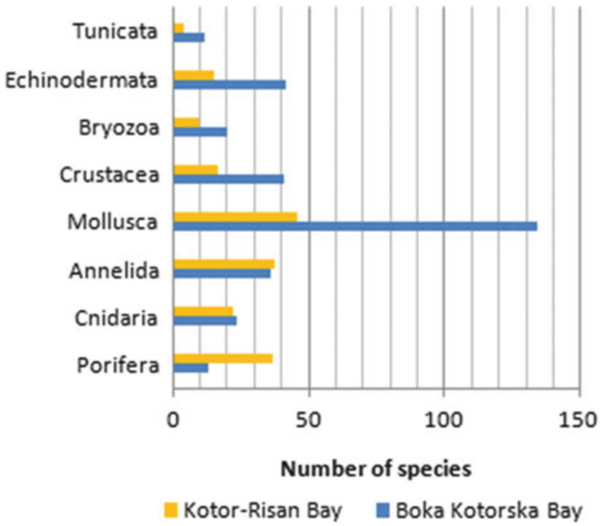


Fig. 2 Relation of recently data of zoobenthos species recorded in the area of the Bay of Kotor and Risan and historical records of the total number of species in the Boka Kotorska Bay

species of *Porifera*, *Cnidaria*, and *Annelida* is higher than the total number of species recorded during previous research in the area of the entire Boka Kotorska Bay (Fig. 2). This points to the fact that the older studies included only certain groups of organisms and only certain areas so that the least data were collected from two outward parts of the Bay (Bay of Tivat and the Bay of Herceg Novi).

More recently results of the study performed in the inner part of the Boka Kotorska Bay confirmed that the benthic assemblages of the infralittoral represent a *unicum*, because of the large percentage of soft bottom assemblages and the presence of coralligenous assemblages [21]. In particular, at Dražin Vrt, a coralligenous assemblage was found between 12 and 30 m of depth. Large colonies of *Cladocora caespitosa* reefs were present and were associated with a rich assemblage of large-sized sponges and cnidarians, notably massive colonies of the false black coral, *Savalia savaglia*, gorgonian *leptogorgia* cfr. *sarmentosa,* and yellow cluster anemone *Parazoanthus axinellae* [21].

Seabed of the Bay of Tivat is inhabited by different groups of animals, such as *Porifera*, *Cnidaria*, *Annelida*, *Crustacea*, *Mollusca*, and *Echinodermata* [22]. As common species were recorded *Axinella brondstedi*, *Aplysina aerophoba*, and *Suberites domuncula* from phylum *Porifera*. The most present coral is *Cladocora caespitosa*. From the group of worms, *Spirobranchus triqueter* dominated on the soft bottom, while *Protula* sp. populated on the hard bottom, presented by a large stone or a solid waste. The seafloor of the Tivat Bay is populated by echinoderms *Brissopsis lyrifera*, *Amphiura chiajei*, *Marthasterias glacialis*, *Ophiothrix fragilis*, *Holothuria tubulosa*, *Holothuria polii*, *Holothuria mammata*, *Mesothuria intestinalis*, *Antedon mediterranea*, *Echinaster sepositus*, *Ocnus planci*, *and Sphaerechinus granularis* [23]. Economically important species of marine organisms are presented by cephalopods *Sepia officinalis* and *Loligo vulgaris* and then molluscs *Nucula nucleus*, *Mytilus galloprovincialis*, *Lithophaga lithophaga*, *Luria lurida*, *Venus verrucosa*, *Tonna galea*, *Pecten jacobaeus*, and *Ostrea edulis* [24].

Within the Tivat aquatorium, there is an especially interesting area of the former Naval-Repair Institute Arsenal. Due to specific environmental conditions, it is considered as a separate entity. Benthic organisms in the aquatorium are under great influence of the grit deposited on the bottom as well as waste water from municipal sewage. Survey conducted in 2007 [22] showed the presence of 38 invertebrate species attached on the walls of the piers (Appendix 1). Dominant species were *Mytilus galloprovincialis*, *Spirobranchus triqueter*, *Phallusia mammillata*, *Schizobrachiella sanguinea*, *Sabella spallanzanii*, *Amphibalanus eburneus*, and *Protula tubularia*. Fauna of the soft bottom (epi- and endo-biocoenosis of soft sediments) is significantly poor compared to the communities at the piers. Majority of these species are organisms of solid substrates that have found a favorable habitat in various solid wastes on the seafloor. Generally, the substrate is muddy covered with a layer of detritus, while black anaerobic mud is observed in some sites, but it is mostly the case of *biocoenosis of detritic* and *terrigenous mud*. As specific species are recorded *Antedon mediterranea*, *Myxicola infundibulum*, *Pecten jacobaeus*, *Ostrea edulis*, *Upogebia pusilla*, *Aplysina aerophoba*, *Spirobranchus triqueter*, and *Protula* sp. which were frequent on boulders and other types of solid surfaces, which actually represents solid waste (car, tires, etc.) [22]. More recently research conducted in the same area identified 53 species inhabiting the piers (Appendix 1). Classified by groups, the following were identified: 5 species of *Porifera*, 5 species of *Cnidaria*, 20 species of *Mollusca*, 5 species of *Annelida*, 3 species of *Arthropoda*, 4 species of *Bryozoa*, 4 species of *Echinodermata*, and 7 species of *Tunicata*. The most numerous were molluscs *Mytilus galloprovincialis* and *Ostrea edulis* and tunicates *Clavelina lepadiformis*, *Phallusia fumigata*, and *Phallusia mammillata* [25].

Analyses of benthic fauna in the Bay of Herceg Novi show the presence of all major groups of macrozoobenthos [3]. The largest part of recorded species belongs to the phylum *Mollusca*. In this Bay, just as in the entire BKB number of settlements *Pinna nobilis* is increased. Recorded species are relatively small in size, which points to the fact that settlements are relatively young. Presence of *Cladocora caespitosa* and *Spongia officinalis* is very significant. Some sites are characterized by abundant populations of this species, as well as *Dysidea avara*. Also genus *Ircinia* and *Chondrilla nucula* are very common. On the locality in the Bay of Herceg Novi, the snail *Tylodina perversa* has been registered.

During the last decade, special attention is paid to the study of echinoderms [23]. In the area of the Boka Kotorska Bay, the presence of 42 species was identified [15]. Among the identified species, there are six Mediterranean endemics (*Antedon mediterranea*, *Holothuria (Holothuria) mammata*, *Astropecten spinulosus*,

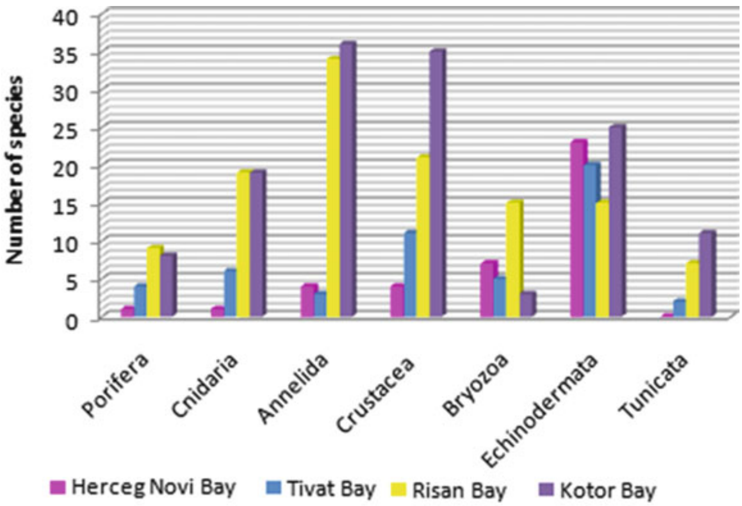


Fig. 3 Number of species of the main marine zoobenthic phylum collected from the four bays

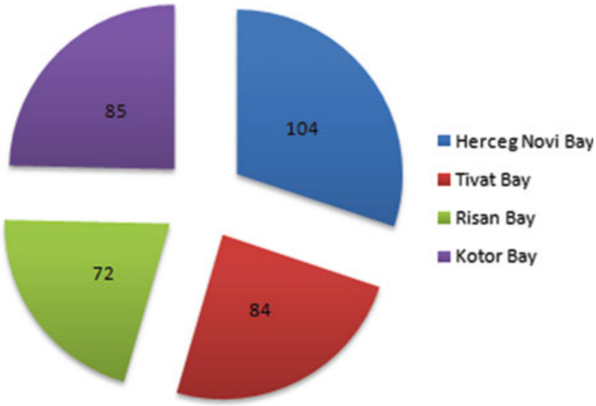
Leptopentacta tergestina, *Ocnus syracusanus*, *Astropecten irregularis pentacanthus*) and two Mediterranean subendemics (*Schizaster canaliferus*, *Echinocardium fenauxi*).

The study of the distribution of species from phylum *Porifera* shows presence of genus *Axinella* (A. *damicornis*, A. *verrucosa* and A. *cannabina*) in the BKB [26].

Analysis of the zoobenthos species composition on the basis of the total number recorded species, with the exception of phylum *Mollusca*, showed that the Bay of Kotor is the richest in species from the group *Annelida*, *Crustacea*, *Echinodermata*, and *Tunicata*, followed by the Bay of Risan (Fig. 3). In the area of the Bay of Herceg Novi, echinoderms stood out as the most frequent group. These results do not necessarily represent the actual situation, but point to the fact that inner bays are better explored, compared to the Bay of Tivat and the Bay of Herceg Novi.

In terms of distribution of molluscs through bays, we can conclude that most species collected from the Bay of Herceg Novi (104), the Bay of Kotor (85), and the Bay of Risan (84) are almost equal, while the least species have been recorded in the area of the Bay of Risan (72) (Fig. 4, Appendix 2).

Fig. 4 Number of species of molluscs through the bays



4 Non-indigenous (Alien or Nonnative) Species

The biggest threat to marine ecosystems comes from four main negative anthropogenic factors, such as pollution from land (and sea), overfishing, destruction of habitat (especially coastal ones), and introduction of alien species [27]. Introduction of species in a habitat outside their natural distribution (allochthonous species) is a growing problem, primarily because it is almost impossible to predict the behavior of introduced species and its impact on autochthonous species and communities.

Introduction of new species is difficult to prevent especially when you take into account the attractiveness of Boka Kotorska Bay as a tourist destination, which is being visited by a large number of cruise ships and yachts during the year, which are an important vector in the transmission of introduced species [28]. In order to make a good assessment of the impact and risk of the introduced species to a particular ecosystem, it is necessary to have basic knowledge of the origin of the species, its biology and ecology, as well as the manner and place of entry. Timely detection of these species is one of the prerequisites of a successful response in order to protect the environment.

Conducted study showed the presence of five alien species for the area (Table 1). For the area of Boka Kotorska Bay, the presence of introduced species dates back to the mid-1980s of the last century, when the *Crassostrea gigas* (oyster) was intentionally introduced for mariculture purposes [29]. Except in this area, it has been introduced for the same reasons in many other parts of the Mediterranean Sea, where it is now fully domesticated.

Nonnative species snail *Bursatella leachii* was recorded at several locations in the inner part of the Bay, so it can be expected that this type becomes domesticated and significantly more numerous than it is now known [30].

For other introduced species listed in Table 1, single appearance is known, and they are probably not present in huge numbers. However, experience from the region indicates to rapid growth of populations of some of the introduced species [31], meaning with more intensive research, it would be possible to register a more

Table 1 Checklist of introduced species of zoobenthos in the Boka Kotorska Bay

Species	Origin	Possible ways of introduction
Mollusca		
Gastropoda		
Bursatella leachii De Blainville 1817	Circumtropical	Through the Suez Canal and by ships
Aplysia dactylomela Rang 1828	Circumtropical	Through the Suez Canal and by ships
Bivalvia		
Crassostrea gigas Thunberg 1793	Pacific	Mariculture
Crustacea		
Decapoda		
Callinectes sapidus Rathbun, 1896	Atlantic	By ships
Farfantepenaeus aztecus (Ives, 1891)	Atlantic	By ships

number of individuals. This applies particularly to the blue crab (*Callinectes sapidus*), which was noted in the area of Port Milena in 2006, Jaz in 2009, Oblatno in 2011 (out of the Boka Kotorska Bay), and in 2013 in the Bay of Tivat [32].

Species *Farfantepenaeus aztecus* was recorded for the first time in of the Bay of Tivat [33].

5 Threats to Zoobenthic Diversity and Protection

Boka Kotorska Bay has limited communication with the open sea and therefore is a very sensitive system. The Bay is surrounded by towns and cities, which represents a major threat to sea biodiversity, direct or indirect.

Even during the 1970s of the last century, it was noted that the declining number of *Mollusca*, especially in the coastal zone of Boka Kotorska Bay, may be due to the large influx of oil and its products into the sea, as well as a variety of toxic chemical compounds from various warehouses, warships, some factories, and increasing amounts of waste water from urban sewage flowing into the sea [9].

Tendency of the Bay to develop into a well-known and popular tourist destination leads to the great anthropogenic pressure on the coastal strip. The fact that within the Bay of Kotor there is a port for mega cruise ships, in the Bay of Tivat a marina for mega yachts, and a large number of small marinas scattered around the Boka Kotorska Bay shows the presence of the impact of nautical tourism on marine biodiversity. Analyses of seabed in the Bay of Kotor and Risan showed clear traces of anchoring on the seafloor and disturbance of benthic biocoenosis in these places [17]. Based on the number and composition of phytoplankton, we can speak of eutrophication of certain areas [34–36].

The main human activities and threats to the coastal and marine environment are fishing [21]. We should particularly note the dangers coming from overfishing; illegal fishing, which refers to the collection of protected species; and the use of illegal means. Another possible threat to marine environment in the area is the dumping of soil from road construction or improvement. The last 20 years have been characterized by a building boom, especially in the narrow coastal zone. During the construction of a large number of apartments and catering facilities, reckless builders discharge large amounts of waste material directly into the sea, leading to a direct threat to communities of photophilic algae that inhabit the shallow narrow zone. The obtained data showed that coralligenous communities in the Bay of Kotor and Risan are located on the small depths which poses a great danger to their preservation. Considering that these communities are one of the main characteristics of the Boka Kotorska Bay, a major threat is global warming as well, human pressure like pollution and coastal development, as well as the presence of introduced species [37].

The invasive red alga *Womersleyella setacea* could be another potential threat to the Boka Kotorska Bay's biodiversity. Studies confirm that the presence of this invasive species changes the assemblage structure and reduces species richness in coralligenous communities, particularly decreasing the diversity and abundance of other turf algae [38].

In order to reduce the negative impact on marine biodiversity, it should be approached with the following:

– Limit and control construction activities and control tourism development.
– Develop regulations addressed to protect the sensitive species and habitats identified in the Bay.
– Avoid uncontrolled sewage.
– Regulate and control soil dumping in the Bay from road construction and waste materials from construction sites.
– Regulate recreational fishery and the use of fishing gear.

6 Conclusion

Area of the Boka Kotorska Bay is a complex semi-enclosed basin with limited communication with the open sea. Large indentation of the Bay into the mainland, the influx of large amounts of fresh water, and the presence of underwater springs make this aquatorium a specific habitat for plant and animal marine life. Within these specific environmental conditions, benthic biocoenosis had developed, and their composition and distribution make this area particular. The presence of *biocoenosis of photophilic algae* is reduced to a narrow upper part of the infralittoral and is quite reduced in areas where the coast of the Bay descends steeply into the depths. *Biocoenosis of marine phanerogams* has been in retreat in the last years, compared to historical data, as a result of anthropogenic impact. The largest part of the Bay, i.e., its central part, is occupied by the *biocoenosis of coastal terrigenous mud*. *Coralligenous biocoenosis* stands out as extremely important in terms of biodiversity and vulnerability. They are characterized by the presence of a large number of species, mostly sponges and corals. Their presence at a relatively shallow depth (12–30 m) in the Bay of Kotor and Risan represents *unicum* and imposes the obligation of their protection.

Preview of the state of zoobenthos species composition in the area of the Boka Kotorska Bay included the compilation of all available literature data for the last 55 years, both from the scientific and gray literature. Obtained results show that certain areas examined in more detail in relation to the rest of the Bay. This primarily refers to the inner part, i.e., the Bay of Kotor and Risan, which was much more the subject of the study, both of plant and animal diversity. Another conclusion to be reached by processing available data is that certain groups of animals have been much better studied, such as molluscs and echinoderms, which may be due to the presence of certain scientists at the Institute of Marine Biology.

Available data on zoobenthos species populated in the territory of the Boka Kotorska Bay show the richness of animal life that occupies the specific and heterogeneous habitats in this relatively small area. Among the identified species, we find a large number of protected species (*Pinna nobilis, Lithophaga lithophaga, Savalia savaglia*, *Aplysina aerophoba, Axinella cannabina, Spongia officinalis, Maya squinado*) and Mediterranean endemics (*Antedon mediterranea, Holothuria (Holothuria) mammata, Astropecten spinulosus, Leptopentacta tergestina, Ocnus syracusanus, Astropecten irregularis pentacanthus, Schizaster canaliferus, Echinocardium fenauxi*), species that have adapted to life in brackish water and low salinity.

The presence of introduced species indicates that this area was not spared from the trend of development of modern society. The presence of five species has been recorded so far (*Bursatella leachii*, *Aplysia dactylomela*, *Crassostrea gigas*, *Callinectes sapidus*, and *Farfantepenaeus aztecus*), some of which are already common. This number is certainly not definitive, and each subsequent research may indicate the presence of some new alien species.

Appendix 1: List of Zoobenthos Species Diversity from the Boka Kotorska Bay According to Literature Data

Species	Herceg Novi Bay	Tivat Bay	Risan Bay	Kotor Bay
Porifera				
Acanthella acuta	x		x	x
Agelas oroides			x	x
Anchinoe fictitious			x	x
Anchinoe tenacior			x	x
Aplysina aerophoba cfr.	x	x	x	x
Aplysina cavernicola			x	x
Axinella cannabina			x	x
Axinella damicornis			x	x
Axinella verrucosa			x	x
Cacospongia scalaris			x	

(continued)

Species	Herceg Novi Bay	Tivat Bay	Risan Bay	Kotor Bay
Calyx niceaensis			x	x
Chondrilla nucula	x		x	x
Chondrosia reniformis			x	x
Clathrina cfr. *cerebrum*			x	x
Clathrina coriacea	x	x		
Cliona celata			x	x
Cliona schmidti			x	x
Cliona sp.			x	x
Cliona viridis			x	x
Crambe crambe	x		x	x
Dictyonella incisa			x	x
Dysidea fragilis			x	x
Dysidea avara	x	x	x	x
Geodia cydonium			x	x
Haliclona cratera				x
Haliclona fulva			x	x
Haliclona mucosa			x	x
Hexadella racovitzai			x	x
Ircinia oros			x	x
Ircinia variabilis		x	x	x
Mycale massa			x	x
Petrosia ficiformis			x	x
Poecilosclerida spp.			x	x
Raspailia viminalis			x	x
Sarcotragus cfr. *foetidus*			x	x
Sarcotragus spinosulus			x	x
Spirastrella cunctatrix	x	x	x	x
Spongia officinalis	x		x	x
Suberites carnosus			x	
Suberites domuncula		x	x	x
Suberitidae n.i.			x	x
Tethya aurantium			x	x
Tethya citrina			x	x
Cnidaria				
Actinia equina			x	x
Aiptasia mutabilis		x	x	x
Alcyonium brioniense			x	x
Alcyonium coralloides			x	x
Alcyonium palmatum	x	x	x	x
Anemonia sulcata	x		x	
Balanophyllia europaea	x		x	x
Balanophyllia italica			x	x
Bugula aquilirostris				x

(continued)

Species	Herceg Novi Bay	Tivat Bay	Risan Bay	Kotor Bay
Calliactis parasitica			x	x
Caryophyllia cfr. *inornata*			x	x
Caryophyllia cfr. *smithii*			x	x
Caryophyllia clavus			x	x
Caryophyllia spp.			x	x
Cerianthus membranaceus			x	x
Cladocora caespitosa	x	x	x	x
Condylactis aurantiaca	x		x	x
Corallium rubrum			x	
Epizoanthus cfr. *arenaceus*			x	x
Epizoanthus mediterraneus			x	x
Epizoanthus sp.			x	x
Eunicella cavolini			x	x
Eunicella stricta			x	x
Gerardia savaglia			x	x
Hoplangia durotrix cfr.			x	x
Hydractinia inermis			x	x
Hydrozoa n.i.			x	x
Leptogorgia sarmentosa			x	x
Madrepora oculata				x
Nemertesia antennina		x		x
Nemertesia ramosa		x	x	x
Obelia sp.			x	x
Parazoanthus axinellae			x	x
Pennatula phosphorea		x		
Phyllangia mouchezi			x	x
Plumularia setacea			x	x
Pteroeides spinosum		x		
Phymanthus pulcher			x	x
Savalia savaglia			x	x
Scleractinia n.i.			x	x
Veretillum cynomorium		x	x	x
Annelida				
Amage adspersa				x
Ampharete grubei			x	x
Amphicteis gunneri			x	x
Amphictene auricoma				x
Bispira volutacornis			x	x
Brada villosa		x	x	x
Ceratonereis hircinicola			x	x
Chaetopterus variopedatus			x	x
Chaetozone sp.			x	x
Dervillea rubrovittata			x	x
Drilonereis filum			x	x

(continued)

Species	Herceg Novi Bay	Tivat Bay	Risan Bay	Kotor Bay
Eteone siphonodonta			x	x
Eunice torquata			x	x
Eunice vittata			x	x
Eupolymnia nebulosa			x	x
Glycera rouxii			x	x
Hermonia hystris			x	x
Hydroides norvegica			x	x
Jasmineira elegans			x	x
Lagis koreni			x	x
Lanice conchilega			x	x
Leanira yhleni			x	x
Lumbriconereis latreilli			x	x
Lumbrineris cf. *tetraurata*			x	x
Lumbrineris latreilli			x	x
Lysidice ninetta			x	x
Maldane globifex			x	x
Marphysa bellii			x	x
Melinna palmata			x	x
Nematonereis unicornis			x	x
Nephthys hystricis			x	x
Nereis irrorata			x	x
Notomastus latericeus			x	x
Onuphis conchylega			x	x
Pontobdella muricata		x	x	x
Pomatoceros triqueter	x	x	x	x
Praxillella gracilis			x	x
Protula sp.	x	x	x	x
Sabella spallanzani	x	x	x	x
Serpula vermicularis	x	x	x	x
Spirographis	x		x	x
Spirorbis sp.				x
Sternaspis scutata	x	x	x	x
Sthenolepis sp.			x	x
Syllidae 1			x	x
Terebellida n.i.			x	x
Crustacea				
Alpheus cf. *glaber*			x	x
Alpheus dentipes			x	x
Anapagurus bicorniger			x	x
Anapagurus breviaculeatus			x	x
Callianassa minor			x	x
Carcinus mediterraneus				x
Diogenes pugilator				x

(continued)

Species	Herceg Novi Bay	Tivat Bay	Risan Bay	Kotor Bay
Dorippe lanata		x		
Ebalia granulosa				x
Eriphia spinifrons		x	x	x
Ethusa mascarone				x
Eurynome aspera			x	x
Galathea nexa		x	x	x
Galathea squamifera		x	x	x
Gonoplax angulata	x			
Galathea intermedia		x	x	
Ilia nucleus				x
Inachus dorsettensis				x
Inachus leptocheirus				x
Inachus thoracicus			x	
Macropipus arcuatus			x	x
Macropipus pusillus		x	x	x
Macropodia longirostris			x	x
Macropodia rostrata		x		x
Maia squinado		x	x	x
Mysidacea sp.			x	x
Paguristes oculatus			x	x
Pagurus alatus				x
Pagurus cuanensis			x	x
Palaemon adspersus				x
Palaemon serratus				x
Parthenope massena				x
Penaeus trisulcatus	x	x	x	
Periclimenes amethysteus			x	x
Periclimenes scriptus cfr.			x	x
Pilumnus hirtellus		x	x	x
Pisidia bluteli				x
Pisidia longimana		x	x	
Processa canaliculata				x
Squilla mantis	x	x	x	x
Sicyonia carinata				x
Tanaidacea unid.			x	x
Upogebia deltaura				x
Upogebia litoralis	x	x	x	x
Upogebia typica				x
Xantho poressa				x
Bryozoa				
Beania magellanica			x	x
Bugula aquilirostris	x			x
Bugula sp.		x	x	x

(continued)

Species	Herceg Novi Bay	Tivat Bay	Risan Bay	Kotor Bay
Cellaria fistulosa		x	x	
Celleporina caminata			x	
Cribilaria radiata			x	
Crisia sp.				x
Disporella hispida			x	
Frondipora reticulata	x	x	x	
Frondipora verrucosa			x	x
Hippothoa flagellum			x	
Idmonea sp.			x	
Lichenopora radiata			x	x
Margareta cereoides			x	
Microporella marsupiata			x	
Myriapora truncata	x		x	x
Myriozoum truncatum	x			
Pherusella tubulosa			x	
Phoronis sp.				x
Porella cervicornis	x		x	
Porella compressa cfr.			x	x
Retepora beaniana	x	x	x	
Reteporella cfr. *grimaldi*			x	x
Schizobrachiella sanguinea	x	x	x	x
Schizomavella mamillata			x	x
Sertella sp.			x	
Schizoporella magnifica			x	
Schizoporella sanguine	x	x		
Echinodermata				
Amphiura chiajei	x	x	x	x
Amphiura filiformis			x	x
Amphiuridae juv. unid.			x	x
Anseropoda placenta		x	x	x
Antedon mediterranea	x	x	x	x
Arbacia lixula	x			
Astropecten auranciacus		x	x	x
Astropecten irregularis pentacanthus			x	x
Astropecten spinulosus	x			x
Brissus unicolor	x			x
Brissopsis lyrifera	x	x	x	x
Cidaris cidaris	x			
Coscinasterias tenuispina	x			
Echinaster sepositus	x	x	x	x
Echinocardium cordatum	x			
Echinocardium fenauxi	x			
Echinocyamus pusillus		x		x

(continued)

Species	Herceg Novi Bay	Tivat Bay	Risan Bay	Kotor Bay
Eostichopus regalis		x		x
Hacelia attenuata	x			
Holothuria (Panningothuria) forskali				x
Holothuria mammata				x
Holothuria polii	x	x		x
Holothuria tubulosa	x	x		x
Labidoplax digitata			x	x
Lepidoplx digitata		x	x	
Leptopentacta elongata	x	x	x	x
Leptopentacta tergestina	x	x	x	x
Marthasterias glacialis	x	x	x	x
Mesothuria intestinalis		x		
Ocnus planci		x	x	x
Ocnus syracusana				x
Ophidiaster ophidianus	x			
Ophioderma longicauda	x			
Ophiomyxa pentagona		x	x	x
Ophiothrix fragilis	x	x		x
Ophiura alba		x	x	x
Ophiura ophiura			x	
Paracentrotus lividus	x			
Psammechinus microtuberculatus				x
Schizaster canaliferus	x			
Spatangus purpureus	x			
Sphaerechinus granularis	x	x		x
Tunicata				
Amaroucium proliferum				x
Ascidia mentula		x	x	x
Ascidiella aspersa			x	x
Ascidiella scabra				x
Ciona intestinalis		x		x
Didemnum candidum			x	
Didemnum maculosum				x
Diplosoma spongiforme			x	x
Eugira arenosa				x
Halocynthia papillosa	x		x	x
Microcosmus sp.		x	x	x
Molgula appendiculata			x	x
Phallusia fumigata		x	x	x
Phallusia mammillata	x	x	x	x
Polycarpa gracilis			x	
Styela plicata		x		x

Appendix 2: List of Macromollusca from the Boka Kotorska Bay (*Source*: Stjepčević, 1967)

Vrsta	Herceg Novi Bay	Tivat Bay	Risan Bay	Kotor Bay
Aloidis gibba Olivi	x	x	x	x
Anomia ephippium L.	x	x	x	x
Aplysia dactylomela	x			
Aporrhais pespelecani L.	x	x	x	x
Arca barbata L.	x	x	x	x
Arca diluvii Lamk.	x	x		x
Arca lactea L.	x	x	x	x
Arca noae L.	x	x	x	x
Arca tetragona Poli	x			
Astraea rugosa L.	x	x		x
Avicula tarentina Lamk.	x		x	
Buccinulum corneum L.	x			
Bursatella leachii	x	x		x
Calliostoma conulus L.	x	x	x	x
Calliostoma laugieri Payr	x	x		
Calliostoma zizyphinum L.	x	x	x	x
Calyptraea chinensis L.	x	x	x	x
Cantharidus striatus L.	x			
Capulus hungaricus L.	x			
Cardium echinatum L.	x			x
Cardium edule L.	x	x	x	x
Cardium exiguum Gmel.	x	x	x	x
Cardium paucicostatum Sowerby	x	x	x	x
Cardium tuberculatum L.	x	x	x	x
Cassidaria echinophora L.			x	x
Cerithium rupestre Risso	x	x	x	x
Cerithium vulgatum Brug.	x	x	x	x
Chama gryphina Lamk.		x		
Chama lamellosa Lamk.		x		
Chiton olivaceus Speng.	x	x	x	x
Chlamys glabra L.	x			
Chlamys opercularis L.	x	x		
Chlamys varia L.	x	x	x	x
Clanculus corallinus Gm.	x	x		
Columbella rustica L.	x	x	x	x
Conus mediterraneus Brug.	x	x	x	x
Crepidula moulinsii Mich.	x	x	x	x
Cuspidaria (Neaera) cuspidata Olivi			x	x

(continued)

Vrsta	Herceg Novi Bay	Tivat Bay	Risan Bay	Kotor Bay
Cypraea lurida L.			x	
Cypraea pyrum Gm	x			
Cypraea spurca L.	x			
Dentalium (Antalis) dentale L.	x	x	x	x
Dentalium (Antalis) vulgare da Costa	x	x		
Diodora gibberula Lamk.	x	x	x	x
Diodora graeca L.	x	x	x	x
Divaricella divaricata L.		x		
Dolium galea L.	x	x		
Donacilla cornea Poli				x
Dosinia lupina L.			x	x
Eledone moschata Leach.	x	x	x	x
Emerginula fissura L.	x			
Fucus pulchellus Phil.	x			
Fusinus rostratus Olivi	x	x	x	x
Fusinus syracusanus L.	x			
Gibbula divaricata L.	x	x		x
Gibbula magus L.	x	x	x	x
Gibbula obliquata Gm.	x			
Gibbula umbilicalis L.	x			
Glycymeris glycymeris L.	x			
Glycymeris pilosa L.	x			x
Glycymeris violacescenns Lamk.	x			
Haliotis lamellosa Lamk.	x			
Hiatella arctica L.	x	x		
Hiatella rugosa L.	x	x	x	x
Irus irus L.		x		
Isocardia cor L.	x		x	x
Laevicardium oblongum Gmel.	x			
Leda fragilis Shem.		x	x	
Leda pella L.	x	x	x	x
Leptotyra sanguinea L.	x			
Lima hians Gmel.	x			
Lima lima L.	x	x		
Lithophaga lithophaga L.	x	x	x	x
Littorina neritoides L.	x	x	x	x
Loligo vulgaris Lamk.	x	x	x	x
Loripes lacteus L.	x	x		
Mactra corallina L.			x	x
Mitra ebenina Lamk.	x			
Modiolus barbatus L.	x	x	x	x
Monodonta turbinata Born	x	x	x	x
Murex brandaris L.	x	x	x	x

(continued)

Vrsta	Herceg Novi Bay	Tivat Bay	Risan Bay	Kotor Bay
Murex trunculus L.	x	x	x	x
Mytilus galloprovincialis Lamk.	x	x	x	x
Nassa costulata Renijer				x
Nassa neritea L.	x			
Nassarius mutabilis L.	x			
Nassarius pygmaeus Lamk.	x	x	x	x
Nassarius reticulatus L.	x	x	x	x
Natica hebraea Mart	x	x	x	x
Natica josephina Risso	x			
Natica millepunctata Lamk.	x			x
Nucula nucleus L.	x	x	x	x
Octopus vulgaris Lamk.	x	x	x	x
Ostrea edulis L.	x		x	x
Patella caerulea L.	x	x	x	x
Patella lusitanica Gmel.	x	x	x	x
Patella vulgata L.	x	x	x	x
Pecten jacobaeus L.	x		x	
Pharus legumen L.	x	x	x	
Philine aperta				x
Pinna nobilis L.	x	x	x	x
Pinna pectinata L.	x	x		x
Pisania maculosa Lamk.	x	x	x	x
Pitar rudis Poli				x
Polynices (Lunatia) alderi Forbes				x
Primovula adriatica Sow	x			
Psammobia depressa Pennant			x	x
Pteria hirundo L.	x			x
Scala communis lamk.	x			x
Scrobicularia plana da Costa		x	x	x
Sepia elegans D'Orb.	x	x	x	x
Sepia officinalis L.	x	x	x	x
Sepiola oweniana D'Orb.	x	x		
Sepiola petersii Ststrp.	x	x		
Sepiola rondeletii Leach.	x	x	x	x
Solen vagina L.	x	x	x	x
Solenocurtus pelucidus L.			x	x
Spondylus gaederopus L.	x	x	x	x
Strombiformis subulata Don.				x
Tellina distorta Poli	x			
Tellina pulchella Lamk.	x			
Teredo navalis L.	x	x	x	x
Thracia combulordea de Bl.				x
Tritonalia erinacea L.			x	

(continued)

Vrsta	Herceg Novi Bay	Tivat Bay	Risan Bay	Kotor Bay
Trivia adriatica Monten	x			
Turritella tricarinata Risso	x	x	x	x
Venerupis aureus Gmel.		x		
Venerupis decussata L.	x	x	x	x
Venus fasciata Donov.				x
Venus gallina L.	x	x	x	x
Venus verrucosa L.	x	x	x	x
Vermetus (Petaloconchus) subcancellatus Biv.	x			
Vermetus (Serpulorbis) arenarius L.	x	x		x

References

1. Lepetić V (1965) Sastav i sezonska dinamika ihtiobentosa i jestivih avertebrata u Bokokotorskom zalivu i mogućnosti njihove eksploatacije (Composition and seasonal dynamics of ihtiobentosa and edible avertebrata in the Bay of Kotor and the possibility of their exploitation). Studia Marina 1:1–164
2. Stjepčević J (1974) Ekologija dagnje (*Mytilus galloprovincialis* LAMK.) i kamenice (*Ostrea edulis* L.) u gajilištima Bokokotoroskog zaliva (Ecology of mussels (*Mytilus galloprovincialis* LAMK.) and oysters (*Ostrea edulis* L.) in farms of Boka Kotorska Bay). Studia Marina 7:5–164
3. Karaman G, Gamulin-Brida H (1970) Contribution aux recherches des bicenoses benthiques du Golfe de Boka Kotorska. Studia Marina 4:3–42
4. Petović S, Bataković M (2014) Marine biodiversity of Boka Kotorska bay pilot project on testing Ecosystem Approach (EcAp) application in Boka Kotorska bay: Executive summary. Ed. RAC/SPA, Tunis. 46 pp + Appendices
5. Olivi G (1792) Zoologia Adriatica, ossia catalogo regionato degli animali del Golfo e delle lagune di Venezia. Bassano
6. Heller C (1863) Untersuchungen uber die Litoralfauna des Adriatischen Meeres. Sber K Akad Wiss Wien 46:415–448
7. Heller C (1868) Zoophyten und Echinodermen des Adriatischen Meeres. Druck Von Carl Ueberreuter, Wien, pp 47–86
8. Kolosváry G v (1938) Echinodermata iz Boke Kotorske (Echinoderms from the Boka Kotorska Bay). Godišnjak Oceanografskog Instituta Kraljevine Jugoslavije 1:121–125
9. Stjepčević J (1967) Biologija i tehnološki proces uzgoja jadranske kamenice (*Ostrea edulis* L.) (Biology and technological process of growing oysters (Ostrea edulis L.). Poljoprivreda i šumarstvo XIII 4:33–48
10. Stjepčević J (1970) Kvalitativno-kvantitativni sastav i distribucija Cephalopoda Bokokotorskog zaliva u jednogodišnjem sezonskom aspektu (Qualitative and quantitative composition and distribution of Cephalopoda in the Bay of Kotor in the one- seasonal aspect). Studia Marina 4(1):43–71
11. Mandić S (1984) Cephalopoda južnog Jadrana (Cephalopoda of the south Adriatic). Studia Marina 15–16:3–77

12. Stječević J, Parenzan P, Mandić S, Stjepčević B (1984) Kvalitativno-kvantitativna istraživanja Polychaeta unutrašnjeg dijela Bokokotorskog zaliva (Qualitative and quantitative research of Polychaeta in inner part of the Bay of Kotor). Studia Marina 15–16:79–95
13. Stjepčević J, Gašić M, Kljajić Z, Stjepčević B, Dogović M, Muller EGW, Zahn R (1986) Prilog proučavanju faune Anthosoa unutrašnjeg dijela Bokokotorskog zaliva (Contribution to the study of fauna Anthosoa in inner part of the Bay of Kotor). Studia Marina 17–18:21–37
14. Milojević S (1979) Biocenotički pregled faune Echinodermata u Bokokotorskom zalivu (Biocenotic review of fauna of Echinodermata in the Kotor Bay). Paper presented at the 2nd Congress of ecologists of Yugoslavia, Zagreb, pp 1859–1868
15. Petović S (2011) Contribution to the knowledge of echinodermata of the Boka Kotorska Bay. Studia Marina 25(1):137–158
16. Gamulin-Brida H (1983) Crnogorsko primorje – specifični dio Jadrana s gledišta bentoskih biocenoza i njihove zaštite (Coast of Montenegro - a specific part of the Adriatic Sea from the viewpoint of the benthic biocenosis and their protection. Studia Marina 13–14:205–214
17. UNEP - MAP - RAC/SPA (2013) Ecological study to strengthen the creation processes and the management of marine protected areas in Montenegro-Report No. 12508420857
18. Gamulin-Brida H (1974) Biocoenoses benthiques de la mer Adriatique – Bentoske biocenoze Jadranskog mora. Acta Adriat 15(9):1–102
19. Gamulin-Brida H (1962) Biocenoze dubljeg litorala u kanalima srednjeg Jadrana = Biocoenoses du littoral plus profond (Circalittoral) dans les canaux de l'Adriatique moyenne. Acta Adriat 9:1–196
20. Pérès JM, Gamulin-Brida H (1973) Biološka oceanografija (Biological oceanography). Školska knjiga, Zagreb
21. Badalamenti F, Treviño-Otón J (2012) Development of Marine and Coastal Protected Areas (MPAs) in the Republic of Montenegro. Ed. RAC-SPA
22. Mandić S, Joksimović A, Joksimović D, Mačić V, Kašćelan S, Đurović M (2007) Report 1. Estimate of environmental impact - marine ecology. CUW-UK
23. Kašćelan S, Mandić S, Radović I, Krpo-Ćetković J (2009) An annotated checklist of Echinodermata of Montenegro (the south Adriatic Sea). Zootaxa 2275:21–40
24. Local Biodiversity Action Plan for the Municipality Tivat for the period from 2013 to 2018. http://www.opstinativat.com/cg/images/stories/prostornourbanistickiplan/lbap%20opstina%20tivat1.pdf
25. University of Montenegro-Institute of Marine biology (2016) Porto Montenegro-monitoring report. Kotor
26. Mačić V, Petović S, Backović S (2015) Contribution to the knowledge of protected *Axinella* (Porifera, Demospongiae) species along the Montenegrin coast. Studia Marina 28(1):9–20
27. Galil BS (2007) Loss or gain? Invasive aliens and biodiversity in the Mediterranean Sea. Mar Pollut Bull 55(7–9):314–322
28. Statistical yearbook of Montenegro 2015. http://www.monstat.org/userfiles/file/publikacije/godisnjak%202015/GODISNJAK%202015-%20REDAKCIJA,%20RADA%20SISEVIC,%2028.%20DEC.pdf
29. Stjepčević J, Mandić S, Dragović R (1977) Mogućnost industrijskog uzgoja jestivih školjkaša u Bokokotorskom zalivu i uvonenja novih vrsta u proces uzogja (Possibility of industrial cultivation of edible shellfish in the Bay of Kotor and the introduction of new species in the process). Ichthyologia 9(1):107–120
30. Mačić V (2013) Contribution to the knowledge of *Bursatella leachii* (de Blainville, 1817) distribution and reproduction in the Boka Kotorska Bay (Montenegro). Studia Marina 26 (1):119–128
31. Zenetos A, Gofas S, Verlaque M, Çinar ME, García Raso E, Bianchi CN, Morri C, Azzurro E et al (2010) Alien species in the Mediterranean Sea by 2010. A contribution to the application of European Union's Marine Strategy Framework Directive (MSFD). Part I. Spatial distribution. Mediterr Mar Sci 11(2):381–493

32. Marković O, Đurović M (2014) First documented record of the American blue crab, *Callinectes sapidus* Rathbun, 1896 in the Boka Kotorska Bay, Southern Adriatic Sea, Montenegro p. 208–209. In: Kapiris et al., 2014 New Mediterranean marine biodiversity records. Mediterr Mar Sci 15(1):198–212. doi:10.12681/mms.737
33. Marković O, Gokoglu M, Petović S, Mandić M (2014) First record of the Northern brown shrimp, Farfantepenaeus aztecus (Ives, 1891) (Crustacea: Decapoda: Penaeidae) in the South Adriatic Sea, Montenegro. Mediterr Mar Sci 15(1):165–167
34. Krivokapic S, Stankovic Z, Vuksanovic N (2009) Seasonal variations of phytoplankton biomass and environmental conditions in the inner Boka Kotorska Bay (eastern Adriatic Sea). Acta Bot Croat 68(1):45–55
35. Krivokapić S, Pestorić B, Drakulović D (2010) Temporal variability of nutrients and chlorophyll a in Boka Kotorska Bay, Eastern Adriatic Sea. BALWOIS
36. Drakulović D, Vuksanović N, Joksimović D (2010) Dynamics of phytoplankton in Boka Kotorska Bay. Studia Marina 25(1):1–20
37. Kruzic P, Benkovic L (2008) Bioconstructional features of the coral Cladocora caespitosa (Anthozoa, Scleractinia) in the Adriatic Sea (Croatia). Mar Ecol 29:125–139
38. Piazzi L, Balata D, Cinelli F (2007) Invasions of alien macroalgae in Mediterranean coralligenous assemblages. Cryptogam Algol 28(3):289–301

Composition and Distribution of Ichthyoplankton in the Boka Kotorska Bay

Milica Mandić, Ana Pešić, Mirko Đurović, Aleksandar Joksimović, and Slobodan Regner

Abstract This paper provides an overview of all the data available on qualitative composition and distribution of ichthyoplankton in the area of the Boka Kotorska Bay. Although the research activities were not conducted continuously, the results showed a high level of diversity and abundance of certain species and proved that the Boka Kotorska Bay is one of the most important spawning areas and feeding grounds for juveniles of a number of pelagic fish species. Analysis of the plankton material resulted in identification of spawning of 40 different species from 7 genera and 20 families. Ichthyoplankton communities' diversity was analysed by two diversity indices: Shannon's diversity index (H') and Simpson's index (D). Early developmental stages of fish are one of the most sensitive phases in the fish lifecycle, so ichthyoplankton research is one of the main tasks of fisheries biology.

Keywords Biodiversity, Ichthyoplankton, South Adriatic, The Boka Kotorska Bay

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1 Introduction

Although the research of fish eggs and larvae had begun more than a century ago, the main research topics have not changed much since and they mainly concern the estimate of the adult population biomass and spatial distribution of eggs and larvae. Also, one of the main motives of these research activities is also to understand the influence of environmental factors, as well as their effect on changes in growth, survival and richness in the species under research. Factors that have an effect on fish juveniles, particularly those that influence survival of fish eggs and larvae are of particular importance for such research activities.

The most renowned work of a group of ichthyoplanktonologists in the early twentieth century (1905) resulted in issuing one of the most important publications – a monograph under the title *Uova, Larve e Stadi Giovanili di Teleostei* published under the serial *Fauna e Flora di Golfo di Napoli* [1]. There were 4 volumes, issued in several editions over the period of 25 years. Most of the material for the monograph was collected by Lo Bianco; however, his name did not appear as an author in any part of the monograph. The authors whose work contributed to making of this monograph are Sanzo, De Gaetani, Spartà, Cipria, Sella and Ciacchi.

In the early periods of ichthyoplankton research, in addition to these authors, the composition, quantity and distribution of the total ichthyoplankton or plankton stages of certain fish species or families were studied also by [2–5].

The ichthyoplankton research activities in the Adriatic date back to the early twentieth century. The earliest ichthyoplankton research were focused mainly on the plankton stages of certain fish species, with very few works dedicated to qualitative composition and total ichthyoplankton abundance. Gamulin [6] presented the data on pilchard eggs in the vicinity of Split, as well as in the entire Dalmatian Archipelago area. Apart from the data on pelagic and benthic fish populations, the expedition under the name Hvar, organised by the Institute for Oceanography and Fisheries from Split and the Institute for Marine Biology from Rovinj, provided the data on phyto- and zoo-plankton but also on ichthyoplankton in central and northern Adriatic. Gamulin and Hure [7] described the length of embryonic developmental stage of pilchard in the Central Adriatic, while in 1983 [8] presented the data on spawning and spawning sites for a number of pelagic fish species (*Sardina pilchardus*, *Engraulis encrasicolus*, *Scomber scombrus*, *Sardinella aurita* and *Sprattus sprattus sprattus*) in the Adriatic. Karlovac [9–11] presented the data on planktonic stages of pilchard but also on the composition of larval stages of fish of the total ichthyoplankton for the Central Adriatic. Varagnolo [12] provided a "comparative calendar" of the occurrence of pelagic eggs of Teleost eggs in the plankton of Chioggia (north Italy), and the same year [13] presented the data on daily variations in the presence of different developmental stages of a number of marine Teleosts in the same region. In 1965 he described the distribution of pelagic eggs of Teleosts in the North Adriatic [14].

Data on long-term changes of the total ichthyoplankton composition for the Central Adriatic were presented by Vučetić [15] who also analysed long-term changes in the total number of larval stages of fish in the open sea and in the coastal waters, but without determining the species. Regner [16] presented the data on anchovy post-larvae nutrition in the Central Adriatic, while in 1977 he presented the data for post-larvae of the species *Serranus hepatus* (L.) and *Cepola macrophthalma* (L.), as well as for planktonic stages of the round sardinella (*Sardinella aurita*) [17, 18]. The data on the larval stages of certain fish species in the coastal area of the Kaštela Bay, as well as description of zooplanktonic predators of planktonic fish stages, were presented by the same author [19, 20], while in 1982, he presented the data on changes in quantitative and qualitative composition of larvae and post-larvae of fish in the open sea of the Central Adriatic [21]. In 1985, the same author presented the data on ecology of planktonic stages of anchovy for the Central Adriatic region [22]

Regner et al. [23] presented the data on spawning of sardine (*Sardina pilchardus* Walb.) in the Adriatic under the upwelling conditions. Regner and Dulčić [24] estimated growth parameters for anchovy post-larvae based on the number of otolith annuli, while [25] presented the data on anchovy spawning in the Central Adriatic in the course of 1989, which was the year of intensive blooming of phytoplankton and benthic diatoms.

In 1992, Dulčić [26], in his master thesis, presented the data on growth parameters of pilchard post-larvae (*Sardina pilchardus* Walb.) based on otolith annuli, while in 1997 he estimated the anchovy post-larvae (*Engraulis encrasicolus* L.) growth parameters in the North Adriatic, also on the basis of otolith annuli. The same author, in 1993, presented the data on embryonal and larval development of the species *Scorpaena porcus* L. grown under laboratory conditions by artificial insemination of females. In 1994, a group of authors led by Dulčić described early developmental stages of the species *Serranus hepatus* in the Central Adriatic, also grown under artificial conditions [26–28]. In 1990s, Dulčić presented the data on embryonal development of a number of species from the following families Scombridae, Carangidae and Centrolophidae [29–31].

The first ichthyoplankton research in the South Adriatic and the area of the Boka Kotorska Bay dates back to 1966 [32], when spatio-temporal dynamics of pilchard spawning (*Sardina pilchardus*) was determined, and soon after, a research on distribution and density of anchovy eggs in the area of the Boka Kotorska Bay [33] was conducted. No research was conducted on ichthyoplankton for a long time afterwards, and only in 2006, the research on qualitative and quantitative composition of ichthyoplankton in the area of the Boka Kotorska Bay was resumed [34–38]. This same year, regular annual analysis of abundance of early developmental stages of anchovy (*E. encrasicolus*) in the open sea of Montenegro's coast began with the objective of biomass estimation by DEP method [38].

2 Study Area

The Boka Kotorska Bay is the most indented bay the Adriatic Sea. It is situated in the southernmost part of the eastern Adriatic coast, in the contact zone between Montenegro and Croatia. At the entry of the bay, Cape Oštra is to the west and Cape

Mirišta to the east, with the passage between leading into the Herceg Novi Bay – the first of the four bays of the Boka Kotorska. The Herceg Novi Bay then continues to the Tivat Bay through the Kumbor Strait, further to the bays of Risan and Kotor, through the Verige Strait. These bays form an enclosed basin connected with the open seas of the Adriatic by the passage Cape Oštra – Cape Mirišta. The specific position results in specific properties of each of the bays but also of the Boka Kotorska Bay as a whole.

The relief of the Boka Kotorska Bay is quite complex. Two areas are distinct in the seabed relief: coastal plain and continental shelf, while other areas – continental slope and abyssal plain – are not present due to small area and limited depths.

Taking into account the structure and vertical stretch of the coastal zone, it can be said that there is not even a coastal plain in the entire Bay of Kotor (except for a small, narrow strip on the eastern side), Risan and Tivat (except for a part on the eastern side – coves Kukuljina and Krtole) and Herceg Novi (except for a small part of the northern side) as rocky steep slopes descend to the very surface of the sea and shoreline, and in these parts, the steep continental area spreads to the very bottom of the bay.

In all of the bays, depths increase towards their central part, although in the Kotor Bay, the maximum depth is not in the central part of the bay, but along its northern coast (Dražin Vrt). A depression, more than 50 m in depth, was noted in the Kotor Bay and in the bays of Tivat and Herceg Novi, another one, also more than 40 m in depth. In a recent exploration of the Boka Kotorska Bay by the Hydrographical Institute of Montenegro's Navy, the maximum depth of 64 m was determined as a narrow indentation in the Kotor Bay [39].

3 Trophic Status

Results of a long-term research of coastal waters of the Montenegro's coast, where more than 20 different parameters indicating the seawater quality were analysed (transparency, colour, chemical parameters and biological characteristics), show that coastal waters of Montenegro are eutrophic, with particularly pronounced eutrophication in the Boka Kotorska Bay [40]. Phytoplankton biomass expressed as chlorophyll *a* in the Boka Kotorska Bay has 2 peaks – spring and autumn – when maximum microphytoplankton values were determined, particularly in the Kotor Bay. In the period March–April and September–December, the Kotor Bay becomes hypereutrophic [41]. Research activities conducted in the winter and early spring (March) showed notable water column stratification, with high microphytoplankton values on the seawater surface, which is typical of extremely eutrophic waters [42].

4 Materials and Methods

The exploration of the qualitative and quantitative ichthyoplankton composition in the area of the Boka Kotorska Bay were done by vertical tows using two plankton net types – PairOVET (modified CalVet) net with cylinder diameter of 25 cm, total mouth opening of 0.098 m^2 and mesh size of 1.6×10^{-4} mm. This net was used during explorations conducted by seasonal dynamics in the total of 18 stations in the period July 2006 to January 2009. Surface temperature and salinity values were recorded only for four seasons (July 2006, December 2006, April 2007 and August 2007); there are no data on abiotic factors for other seasons due to a probe failure.

WP2 plankton net, with a mesh size of 0.200 mm and mouth opening of 57 cm, was used in the investigation of ichthyoplankton abundance and composition in a part of the aquatorium of the Tivat Bay, where in the period March 2015 to February 2016, ichthyoplankton was sampled in three stations, on monthly basis (Fig. 1). Data on surface temperature and salinity were recorded during the investigation.

Nets were towed vertically at the speed of 0.5–1 m/s, 5 m above the maximum bottom depth to the surface. Temperature and salinity were recorded from each of the investigated locations. The ichthyoplankton samples collected were kept in a 2.5% formaldehyde solution in seawater and analysed using magnifier NIKON SMZ 800 with a MOTIC camera attached. Ichthyoplankton was determined to the level of the species where possible, and where not, only to the level of genus.

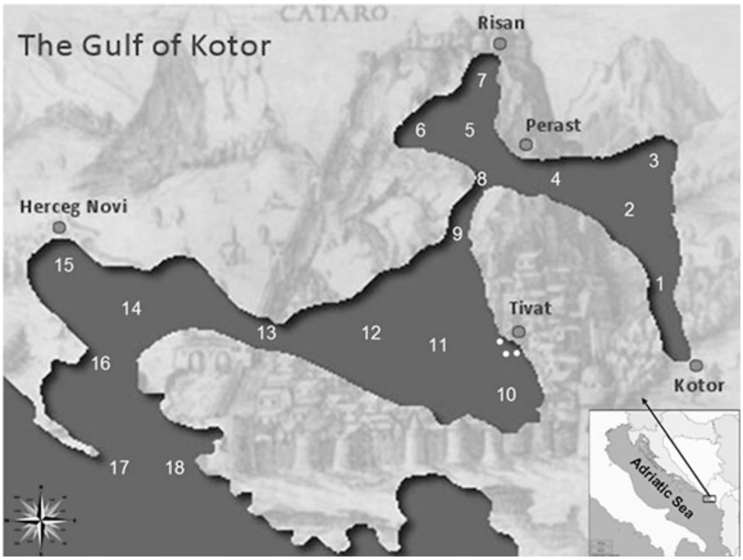

Fig. 1 The Boka Kotorska Bay with locations where ichthyoplankton was investigated (2006–2009 – numbers; 2015–2016 – dots)

Ichthyoplanktonic communities' diversity was analysed by two diversity indices: Shannon's diversity index (H') and Simpson's index (D). Diversity analysis was done for each location under research separately, by seasons, and the average value of total diversity for all locations was analysed as well, by seasons. The diversity in species for the area of the Tivat Bay was calculated by months, due to a very small distance between the locations surveyed. Shannon's diversity index is one of the most frequently used diversity indices as it includes both the species richness and components of the evenness with which individuals are distributed among species. It is also the index that is the most sensitive to changes in presence of rare species in the sample. Calculations are done with the following formula [43]:

$$H' = -\sum_{i=1}^{s} (p_i)(\log_2 p_i)$$

where p_i is the proportion of the ith species in the sample and S is the total number of species in the sample. Shannon's index increases as the species number increases. In practice, it proved that for biological communities H' value does not exceed 5.0 [43].

Simpson's index gives the probability of any two individuals randomly drawn belonging to the same species. When expressed as reciprocal value ($D = 1/C$), the index value grows as the evenness of the community grows [44]. Reciprocal Simpson's index is calculated using the following formula [43]:

$$D = 1/C \quad C = \sum_{i=1}^{s} p_i^{\,2}$$

where p_i is the proportion of the ith species in the sample and s number of species in the sample. Values of this index range from 1 to s.

5 Results

In the entire investigated area, the total of 1400 fish eggs and 354 larvae and post-larvae was found (Table 1), and 40 different species, 7 genera and 20 families were identified:

Family: Sparidae

Diplodus puntazzo (Cetti, 1777) – Sharpsnout seabream

Diplodus annularis (Linnaeus, 1758) – Annular seabream

Diplodus sargus (Linnaeus, 1758) – White seabream, Sargo

Pagellus acarne (Risso, 1827) – Axillary seabream

Table 1 Presence of planktonic fish stages, by seasons (+ – presence)

No.	Species	Summer	Autumn	Winter	Spring
1	*Diplodus puntazzo*	+	+		
2	*Diplodus annularis*	+			+
3	*Diplodus sargus*	+			+
4	*Pagellus acarne*	+			
5	*Boops boops*				+
6	*Spondyliosoma cantharus*				+
7	*Pagrus pagrus*	+			
8	*Lithognathus mormyrus*	+	+		+
9	*Engraulis encrasicolus*	+	+	+	+
10	*Sardina pilchardus*			+	+
11	*Sardinella aurita*	+			
12	*Coris julis*	+			+
13	*Labrus merula*				+
14	*Arnoglossus laterna*	+		+	
15	*Arnoglossus thori*			+	+
16	*Trachurus mediterraneus*	+			
17	*Trachurus trachurus*				+
18	*Seriola dumerili*	+			
19	Gobius sp.	+	+	+	+
20	Trigla sp.			+	+
21	Labrus sp.	+			
22	Mugil sp.	+			
23	Arnoglossus sp.		+		
24	Trachinus sp.			+	
25	*Serranus hepatus*	+			+
26	*Serranus scriba*				+
27	*Serranus cabrilla*				+
28	*Callionymus risso*	+			+
29	*Callionymus lyra*	+			+
30	*Callionymus maculatus*			+	
31	*Callionymus festivus*	+	+		
32	*Callionymus pusillus*	+			
33	*Auxis rochei*				+
34	*Gadiculus argenteus*	+			+
35	*Trisopterus minutus*			+	
36	*Scomber scombrus*		+	+	+
37	*Scomber japonicus*	+			
38	*Sarda sarda*	+			
39	*Trachinus draco*	+			
40	*Dicentrarchus labrax*			+	
41	*Ophisurus serpens*				+
42	*Gaidropsarus mediterraneus*	+			

(continued)

Table 1 (continued)

No.	Species	Summer	Autumn	Winter	Spring
43	*Mugil cephalus*	+			
44	*Scorpaena porcus*	+			
45	*Sparisoma cretense*	+	+		
46	*Sciaena umbra*	+			

Boops boops (Linnaeus, 1758) – Bogue

Spondyliosoma cantharus (Linnaeus, 1758) – Black seabream

Pagrus pagrus (Linnaeus, 1758) – Red porgy

Lithognathus mormyrus (Linnaeus, 1758) – Striped seabream

Family: Engraulidae

Engraulis encrasicolus (Linnaeus, 1758) – European anchovy

Family: Clupeidae

Sardina pilchardus (Walbaum, 1792) – European pilchard

Sardinella aurita (Valenciennes, 1847) – Round sardinella

Family: Labridae

Coris julis (Linnaeus, 1758) – Mediterranean rainbow wrasse

Labrus merula (Linnaeus, 1758) – Brown wrasse

Labrus sp.

Family: Bothidae

Arnoglossus laterna (Walbaum, 1792) – Mediterranean scaldfish

Arnoglossus thori (Kyle, 1913) – Thor’s scaldfish

Arnoglossus sp.

Family: Carangidae

Trachurus mediterraneus (Steindachner, 1868) – Mediterranean horse mackerel

Trachurus trachurus (Linnaeus, 1758) – Atlantic horse mackerel

Seriola dumerili (Risso, 1810) – Greater amberjack

Family: Gobiidae

Gobius spp.

Family: Triglidae

Trigla spp.

Family: Serranidae

Serranus hepatus (Linnaeus, 1758) – Brown comber

Serranus scriba (Linnaeus, 1758) – Painted comber

Serranus cabrilla (Linnaeus, *1758)n* – Comber

Family: Callionymidae

Callionymus risso (Lesueur, 1814) – Risso's dragonet

Callionymus lyra (Linnaeus, 1758) – Common dragonet

Callionymus maculatus (Rafinesque, 1810) – Spotted dragonet

Callionymus festivus (Pallas, 1814) – Festive dragonet

Callionymus pusillus (Delaroche, 1809) – Sailfin dragonet

Family: Gadidae

Gadiculus argenteus (Guichenot, 1850) – Silvery pout

Trisopterus minutus (Linnaeus, 1758) – Poor cod

Family: Scombridae

Scomber scombrus (Linnaeus, 1758) – Atlantic mackerel

Scomber japonicus (Houttuyn, 1782) – Chub mackerel

Sarda sarda (Bloch, 1793) – Atlantic bonito

Auxis rochei (Risso, 1810) – Bullet tuna

Family: Scaridae

Sparisoma cretense (Linnaeus, 1758) – Mediterranean parrotfish

Family: Sciaenidae

Sciaena umbra (Linnaeus, 1758) – Brown meagre

Family: Trachinidae

Trachinus draco (Linnaeus, 1758) – Greater weaver

Trachinus sp.

Family: Moronidae

Dicentrarchus labrax (Linnaeus, 1758) – European sea bass

Family: Ophichthidae

Ophisurus serpens (Linnaeus, 1758) – Serpent eel

Family: Lotidae

Gaidropsarus mediterraneus (Linnaeus, 1758) – Shore rockling

Family: Mugilidae

Mugil cephalus (Linnaeus, 1758) – Flathead grey mullet

Mugil sp.

Family: Scorpaenidae

Scorpaena porcus (Linnaeus, 1758) – Black scorpionfish

6 Ichthyoplankton Diversity

Average value of the Shannon's diversity index in July 2006 was 0.85, while Simpson's reciprocal index was 2.38. July 2006 was the season with the highest diversity of all the seasons covered by the research, whereby average diversity value was $H = 0.85$ and $D = 2.38$, i.e. diversity values ranged from $H = 0$–2.35 and $D = 1$–7.74. In December 2006, the average value of the Shannon's index was 0.38, while the average value of the Simpson's index was 1.26 ($S = 0$–1.01, $D = 1$–2.57). April 2007 had significant diversity of species, although values were somewhat lower than in July 2006 (average values $H' = 1.09$, $D = 2.86$, total $S = 0$–1.99, $D = 1$–5.77). August 2007 (average values $H' = 1.32$, $D = 3.36$, total $S = 0.5$–1.99, $D = 1.47$–5.77) and April 2008 (average values $H' = 0.96$, $D = 2.55$, total $S = 0.2$–1.83, $D = 1.1$–5.76) had quite similar diversity values, while in July 2008 average values were $H' = 0.84$ and $D = 2.21$, with total $S = 0$–1.33, $D = 1$–3.57 (Figs. 2 and 3).

The highest value of species richness by stations was 5 (December 2006), 7 (April and July 2008) and 9 (April and August 2009), with the highest number of species in a single station recorded in July 2006.

Diversity index analyses were not done for seasons October 2008 and January 2009 due to very poor qualitative and quantitative composition of species.

Average surface temperature in July was 22.9°C, with the maximum temperature recorded 25.8°C at the station No. 5 (the Risan Bay) and 25°C at the station No. 2 (the Kotor Bay). In August 2007, the maximum surface temperature was recorded in the Kotor Bay (Station No. 3) reaching 25.2°C (Figs. 4 and 5).

The lowest surface temperature values were recorded in April 2007, while values measured in December 2006 were by approximately 1.5°C higher than those in April 2007. The lowest temperature in April 2007 was recorded at the

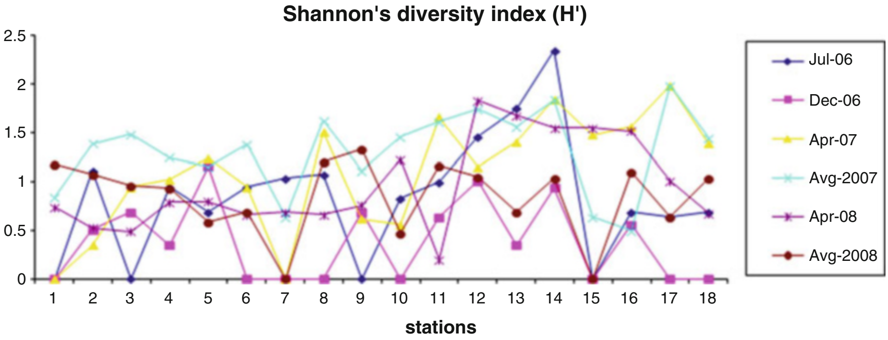

Fig. 2 Shannon's diversity index analysed by seasons [37]. See station location in Fig. 1

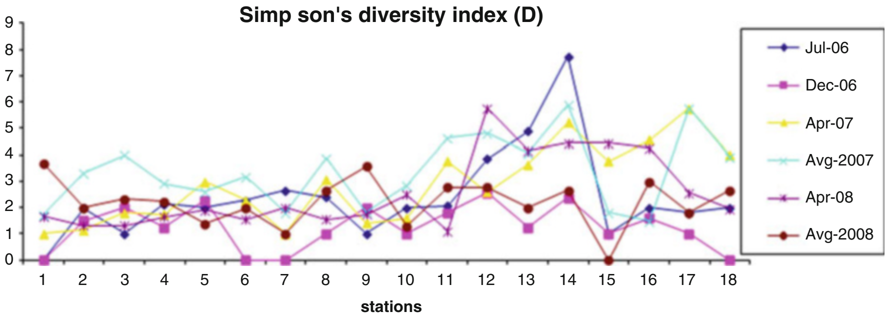

Fig. 3 Simpson's reciprocal index analysed by seasons [37]. See station location in Fig. 1

station No. 8 (Verige) 14.6°C, while the lowest temperature in December was 16.3°C at the station No. 17 (the Herceg Novi Bay).

The average surface salinity value in all stations under survey in July was 33.6‰. The lowest value of 30.36‰ was recorded at the station No. 6 (the Risan Bay), while the maximum value measured at the very exit of the Bay, at the station No. 17, reaching 36.7‰.

In December 2006, average salinity value was 34.99‰. The lowest value of 33.54‰ was recorded at the station No. 3 (the Kotor Bay), while the highest value of 37.85‰ was noted at the station No. 18 (Mamula).

In April 2007, average value was somewhat higher than for previous seasons, reaching 35.21‰. The lowest value of 34.06‰ was recorded at the station No. 7 (the Risan Bay), while the highest was 38.2‰, at the station No. 18.

In August 2007, average value was 36.25‰, the lowest was 33.4‰ at the station No. 7, and the highest value of 38.8‰ was recorded at the station No. 18.

The research conducted for the area of the Tivat Bay (in the period from March 2015 to March 2016) showed diversity rates of $S = 0$–1.88 and $D = 1$–4.28, with

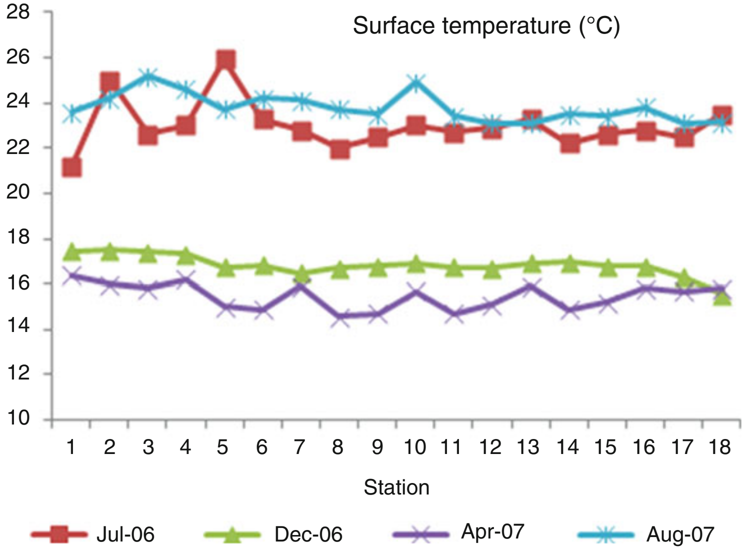

Fig. 4 Sea surface temperature, presented by seasons. See station location in Fig. 1

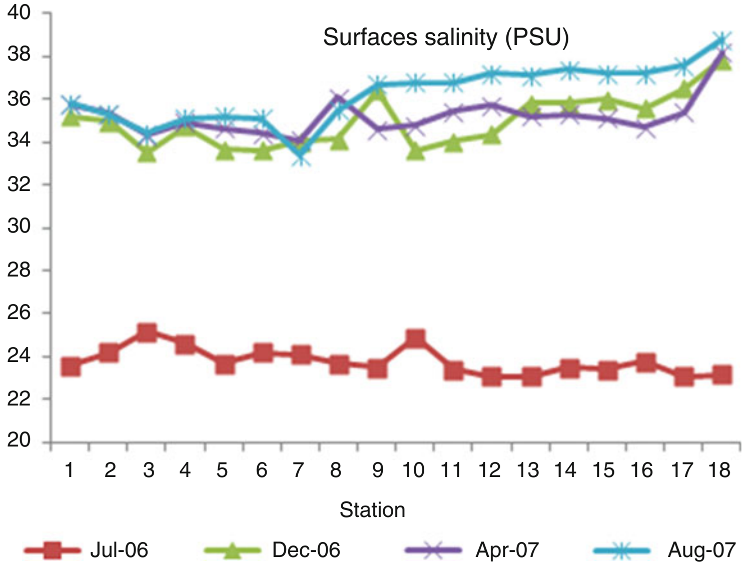

Fig. 5 Sea surface salinity, presented by seasons. See station location in Fig. 1

higher diversity rates during July and September 2015, while diversity of species in other months was at a relatively low level (Fig. 6).

The highest number of species per station was found in the area of the Tivat Bay – 13 in July 2015 – while in other months, the species richness by stations was

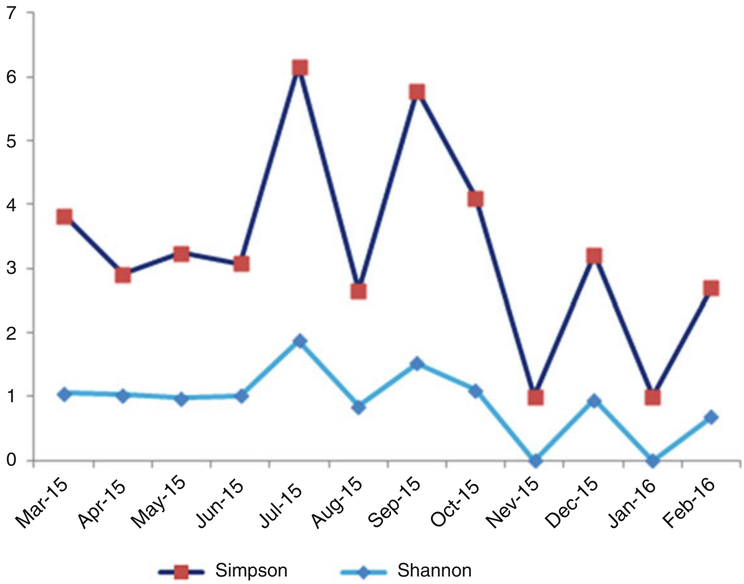

Fig. 6 Diversity indices in a part of the Tivat Bay aquatorium (March 2015–February 2016)

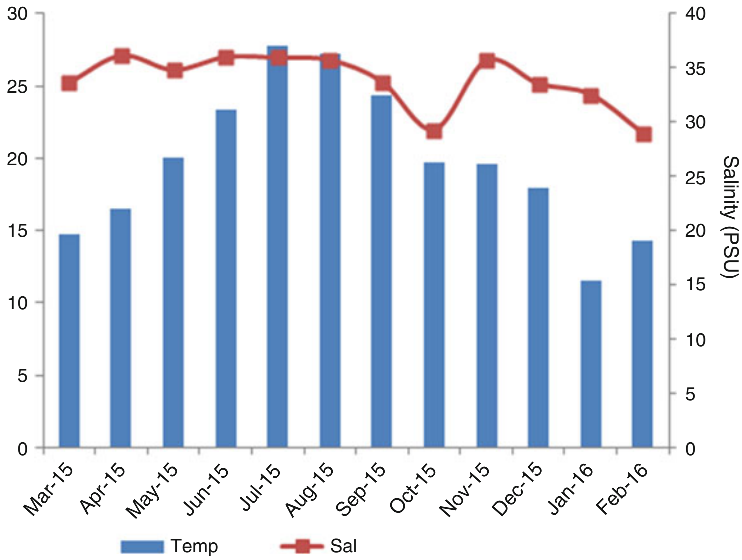

Fig. 7 Surface temperature and salinity values (March 2015–February 2016)

7 (June), 6 (April, May and August) and 5 (September), while in their months, the species diversity ranged from 1 to 3 species per station. After each tow of the pelagic net, data on surface temperature and salinity were recorded (Fig. 7).

7 Discussion

The investigation on ichthyoplankton composition and abundance in the Boka Kotorska Bay has shown presence of a significant number of pelagic species spawning within the Bay. After decades of long pause in analysing abundance of early developmental stages of anchovy in the Bay [33], this is, at the same time, the first investigation on diversity of ichthyoplankton species in this part of the south Adriatic.

The investigation showed dominance of certain species, such as anchovy (*Engraulis encrasicolus*), rainbow wrasse (*Coris julis*), annual seabream (*Diplodus annularis*), white seabream (*Diplodus sargus*), pilchard (*Sardina pilchardus*) and mackerel (*Scomber scombrus*) (Fig. 8).

Considering that during the entire investigation period the same species dominated the same seasons, such situation leads to conclusion that the Boka Kotorska Bay is a very important feeding zone and/or spawning zone for these species. However, this cannot be applied to pilchard, since plankton stages of this species were found in larger numbers only in December 2006 [37].

The highest diversity values were recorded in summer, which points to the fact that majority of species spawned in that season. These findings are in concordance with earlier surveys of ichthyoplankton abundance and diversity, showing that late spring and early summer are transition periods for spawning of Mediterranean fish species, when diversity and richness of species reach their maximum [45–48]. Furthermore, it was noted that the highest level of species diversity was recorded in stations with intensive seawater circulation (the Kumbor Strait and Verige), and under the influence of the open sea (Mamula). Relatively low diversity values in most of the stations included in the investigation are most probably the result of the dominance of the species, but they can also be the result of anthropogenic influence, particularly notable in summer months, due to intensive influx of tourists. Considering that diversity indices are mathematical expression of the relationship between qualitative and quantitative composition of the community, their value will be

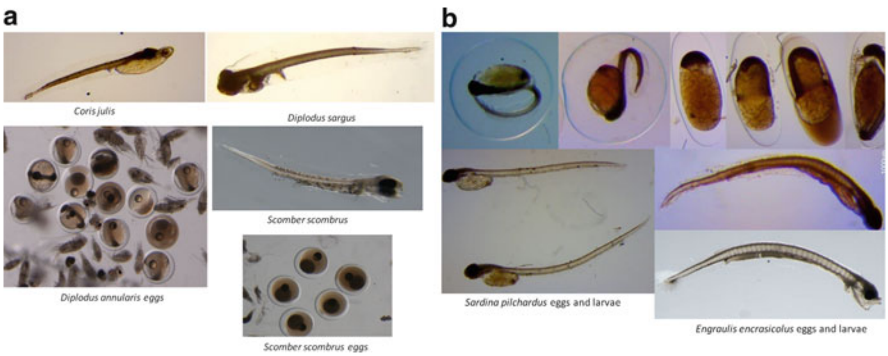

Fig. 8 Some of the most dominant species of ichthyoplankton

significantly higher in a station that has no dominant species, even though the qualitative composition is the same.

All determined species have pelagic eggs and the general pattern of ichthyoplankton assemblages of the area seems to be closely related to the adult fish assemblage and the spawning locations of adult populations [49].

Total number of determined species in a relatively small area of the Boka Kotorska Bay indicates significant species diversity, especially when compared to similar studies carried out in the Northern Adriatic Sea and other parts of the Mediterranean. During the investigation carried out in Northeast Adriatic, in the Kornati Archipelago and Murter Sea during a 12-month cycle, the total of 28 families and 52 species were identified [50]. Investigations of qualitative and quantitative composition of the larval fish stages in the plankton at the open sea of the Central Adriatic Sea during 6-year cycle (1971–1977) showed presence of 56 different species and 14 genera [21]. In Northern Ionian Sea, the study of spatial distribution, abundance and composition of fish larvae carried in March 2000 showed the presence of 46 different species of Teleost early stages, belonging to 38 genera and 22 families [51]. Survey carried out in the Central Cantabrian Sea shelf (southern Bay of Biscay) showed presence of 34 taxa of fish larvae during the summer cruise [52]. Composition of ichthyoplankton from the Mar Menor lagoon (south East Spain) during the investigation carried out from February to December 1997 showed the presence of 14 families, 22 genera and 36 different species [53]. Survey of larval fish assemblages in the coastal waters of central Greece (Ionian and Aegean Seas) during 1998 and 1999 showed presence of 74 larval taxa [54]. The results of this study could have implications for the management of marine resources as well as indicate the importance of Boka Kotorska Bay as a nursery and spawning ground for significant number of economically important fish species, due to the fact that this investigation confirmed our assumption that Boka Kotorska Bay is the nursery and spawning ground for most pelagic fish species [37].

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References

1. D'Ancona U (1956) Uova, larve e stadi giovanili di Teleostei. Fauna e flora di Golfo di Napoli. Monogr Staz Zool Napoli 38:1–1064
2. Graeffe E (1888) Übersicht der Seethierfauna des Golfes von Triest nebst Notizen über Vorkommen, Lebensweise, Erscheinungs und Fortpflanzungzeit der einzelnen Arten. Pisces 4. Arb Zool Inst 7:445–470
3. Steuer A (1910) *Planktonkunde*. Leipzig. In Regner S (1996). Effects of environmental changes on early stages and reproduction of anchovy in the Adriatic Sea. Sci Mar 60(Suppl. 2):167–177

4. Stiasny G (1910) Beobachtungen über die marine Faune des Triester Golfes in Jahre 1909. Zool Anz 35. In Regner S (1985) Ecology of planktonic stages of the anchovy, Engraulis encrasicolus (Linnaeus, 1758), in the central Adriatic. Acta Adriat 26(1), Series Monographiae 1:1–113
5. Vatova A (1928) Compendio della Flora e Fauna del Mare Adriatico presso Rovigno. Mem R Com Talassogr 143. In Regner S (1985) Ecology of planktonic stages of the anchovy, *Engraulis encrasicolus* (Linnaeus, 1758), in the central Adriatic. Acta Adriat 26(1), Series Monographiae 1:1–113
6. Gamulin T (1940) Observations on the occurrence of fish eggs in the surroundings of split. Godišnjak Oceanogr Inst 2:73–91
7. Gamulin T, Hure J (1955) Contribution à la connaissance de l'écologie de la ponte de la sardine (*Sardina pilchardus*) dans l'Adriatique. Acta Adriat 8(8):3–24
8. Gamulin T, Hure J (1983) Mriješćenje i mrijestilišta riba u Jadranskom moru (*Sardina pilchardus, Engraulis encrasicolus, Scomber scombrus, Sardinella aurita i Sprattus sprattus*). Acta Adriat 24(1/2):97–131
9. Karlovac J (1953) Sternoptychidae, Stomiatidae and Scopelidae in the Adriatic Sea. Reports on the R/V "Hvar" cruises researches into Fisheries Biology, Institute of Oceanography and Fisheries, Split 5(2B):1–45
10. Karlovac J (1964) Mriješćenje srdele (*Sardina pilchardus* WALB.) u srednjem Jadranu u sezoni 1956–1957 (Spawning of sardine (*Sardina pilchardus* WALB.) in middle Adriatic in season 1956–1957). Acta Adriat 10(8):3–40
11. Karlovac J (1967) Etude de I'ecologie de lasardine. *Sardina pilchardus* Walb., dans la phase planctonique de sa vie en Adriatique moyenne. Acta Adriat 13(2):109
12. Varagnolo S (1964) Calendario di comparse di uova pelagiche di Teleostei marini nel plancton di Chioggia. Arch Oceanogr Limnol 13:240–279
13. Varangolo S (1964) Variazioni diurne della presenza degli stadi di sviluppo di alcuni Teleostei marini nel plancton de Chioggia. Boll Zool 31:1037–1047
14. Varagnolo S (1965) Alcune osservazioni sulla distribuzione delle uova gallegianti di Teleostei nell'Alto Adriatico. Boll Zool 32:849–858
15. Vučetic T (1971) Fluctuations à long terme du macrozooplancton dans l'Adriatique centrale: oeufs de *Sardina pilchardus* Walb., *d'Engraulis encrasicholus* L. et larves de differentes poissons. Arch Oceanogr Limnol 17(2):141–156
16. Regner S (1971) Contribution to the knowledge of the feeding of anchovy, *Engraulis encrasicolus* (Linnaeus, 1758), postlarvae in the Middle Adriatic (in Serbo-Croatian). Ekologija 6:157–164
17. Regner S (1977) On the feeding of *Serranus hepatus* (L.) and *Cepola macrophthalma* (L.) postlarvae in the central Adriatic. Rapp Congr CIESM 24(5):87–88
18. Regner S (1977) On the plankton stages of gilt sardine, *Sardinella aurita* Valenciennes, in the central Adriatic. Acta Adriat 17:1–12
19. Regner S (1980) The larval stages of fish in the Kaštela Bay. Acta Adriat 21(2):123–136
20. Regner S (1980) On some zooplankton predators of plankton fish stages. Bilješke Notes 39:6
21. Regner S (1982) Investigations of qualitative and quantitative composition of the larval fish stages in the plankton at the high sea of the central Adriatic. Studia Marina 11–12:45–60
22. Regner S (1979/85), Regner S (1979) Ecology of planktonic stages of the anchovy, *Engraulis encrasicolus* (Linnaeus, 1758), in the central Adriatic (in Serbo-Croatian). Ph.D. Thesis, Univ. Belgrade, 188. Same as: Regner S (1985): Ecology of planktonic stages of the anchovy, *Engraulis encrasicolus* (Linnaeus, 1758), in the central Adriatic. Acta Adriat 26(1), Series Monographiae 1:1–113
23. Regner S, Regner D, Marasović I, Kršinić F (1987) Spawning of sardine, *Sardina pilchardus* (Walbaum, 1792), in the Adriatic under upwelling conditions. Acta Adriat 28(1/2):161–198
24. Regner S, Dulčić J (1990) Growth parameters of anchovy post larvae in the Adriatic estimated from otolith growth rings. Bilješke Notes 76:1–8

25. Regner S (1994) Spawning of the anchovy in the Northern Adriatic in 1989, the year of intensive phytoplankton and benthic diatoms blooms. Bios (Macedonia, Greece) 2:47–52
26. Dulčić J (1992) Procjena parametara rasta postlarvi srdele, *Sardina pilchardus* (Walbaum, 1792) na osnovu broja prstenova u otolitima. Postdiplomski studij prirodnih znanosti, Oceanologija. Sveučilište u Zagrebu 52
27. Dulčić J, Kraljević M (1993) Preliminarni podaci o embrionalnom i larvalnom razvitku škrpuna (*Scorpaena porcus*, Linnaeus, 1758). Bilješke - Notes, 78. Institut za oceanografiju i ribarstvo, Split. 1–8
28. Dulčić J, Kraljević M, Jug-Dujaković J (1994) Parametri rasta postličinki vučića *Serranus hepatus* (L.) u srednjem Jadranu. Morsko Ribarstvo 46:12–14
29. Dulčić J (1996) Early life history stages of family Scombridae in the Eastern Adriatic. Annales 9:9–16
30. Dulčić J (1998) Early life history stages of the family Carangidae in the Eastern Adriatic. Annales 13:55–64
31. Dulčić J (1999) Early life history stages of family Centrolophidae in the Eastern Adriatic. Annales 9(2):223–228
32. Merker K (1971) Some preliminary observation on findings of spawning areas of sardine (*Sardina pilchardus* WALB) in South Adriatic area. (in Montenegrin). Studia Marina 5:61–74. Hydrobiologia 612:185–199
33. Merker K, Vujošević M (1972) Density and distribution of anchovy (*Engraulis encrasicolus* L.) eggs in the Bay of Boka Kotorska (in Serbo-Croatian). Poljoprivreda i šumarstvo 18:15–27
34. Mandić M (2011) Seasonal aspects of ichthyoplankton diversity in the Boka Kotorska Bay. Ph. D. Theses, University of Belgrade, 169
35. Mandić M, Đurović M, Pešić A, Joksimović A, Regner S (2013) Boka Kotorska Bay – spawning and nursery area for pelagic fish species. Studia Marina 26(1):33–46
36. Mandić M, Regner S, Joksimović A, Pešić A (2013) Spawning of sardine, *Sardina pilchardus* WALB. In Boka Kotorska Bay (South Adriatic Sea). Natura Montenegrina 12(3–4):895–907
37. Mandić M, Regner S, Gačić Z, Đurović M, Marković O, Ikica Z (2014) Composition and diversity of ichthyoplankton in the Boka Kotorska Bay (South Adriatic Sea). Acta Adriat 55 (1):229–244
38. Mandić M, Regner S, Đurović M, Joksimović A, Pešić A, Krpo-Ćetković J (2015) Distribution and abundance of eggs and estimation of spawning stock biomass of anchovy, Engraulis encrasicolus (Linnaeus, 1758), in the south-eastern Adriatic Sea. J Mar Biol Assoc UK 1–9. doi:10.1017/S002531541400215X, Published online by Cambridge University Press 23 Jan 2015
39. DerMap Project Report (2011) Satellite Spectral Analyses of the Bay of Kotor, Montenegro 2010–2011, p 94
40. Regner D, Vuksanović N, Stjepčević B, Joksimović D (2005) Perennial ecological investigations in coastal Montenegrin waters and their significance for evaluation of sea quality. In: The 34th annual conference of the Yugoslav water pollution control society “WATER 2005”. Conference Proceedings, pp 329–335
41. Krivokapić S, Vuksanović N, Stanković Ž (2005) Trophic level and chlorophyll *a* in Kotor Bay (in Montenegrin). In: The 34th annual conference of the Yugoslav water pollution control society, WATER 2005. Conference Proceedings, pp 351–354
42. Vuksanović N, Krivokapić S (2005) Contribution to the knowledge of phytoplankton in Kotor Bay in winter season 2004 (in Montenegrin). In: The 34th annual conference of the Yugoslav water pollution control society “WATER 2005”. Conference Proceedings, pp 347–350
43. Krebs CJ (1999) Ecological methodology, 2nd edn. Addison Wesley Longman, San Francisco, p 620
44. Magurran AE (2004) Measuring biological diversity. Blackwell Publishing, Oxford, p 256
45. Sabates A (1990) Distribution pattern of larval fish populations in the Northwestern Mediterranean. Mar Ecol Prog Ser 59:75–82

46. Sabates A, Maso M (1992) Unusual larval fish distribution pattern in a coastal zone of the western Mediterranean. Limnol Oceanogr 37(6):1252–1260
47. Sabates A, Olivar MP (1996) Variation of larval fish distributions associated with variability in the location of a shelf-slope front. Mar Ecol Prog Ser 135:11–20
48. Somarakis S, Koutisikopoulos C, Machias A, Tsimenides N (2002) Applying the daily egg production method to small stocks in highly heterogeneous seas. Fish Res 55:193–204
49. Tsikliras A, Koutrakis TE (2010) Summer fish larval assemblages and station groups in the northern Aegean Sea. Acta Adriat 51:9–33
50. Dulčić J, Grebec B (2000) Composition and temporal fluctuations of ichthyoplankton community in the Kornati archipelago and Murter sea, eastern Adriatic. Vie et Milieu 50:163–170
51. Granata A, Cubeta A, Minutoli R, Bergamasco A, Guglielmo L (2011) Distribution and abundance of fish larvae in the northern Ionian Sea (Eastern Mediterranean). Helgoland Mar Res 65:381–398
52. Rodriquez JM, Gonzalez-Pola C, Lopez-Urrutia A, Nogueira A (2011) Composition and daytime vertical distribution of the ichthyoplankton assemblage in the Central Cantabrian Sea shelf, during summer: an Eulerian study. Cont Shelf Res 31:1462–1473
53. Pérez-Ruzafa A, Quispe-Becerra JI, Garcia-Charton JA, Marcos C (2004) Composition, structure and distribution of the ichthyoplankton in a Mediterranean coastal lagoon. J Fish Biol 64:202–218
54. Somarakis S, Isari S, Machias A (2011) Larval fish assemblages in coastal waters of central Greece: reflections of topographic and oceanographic heterogeneity. Sci Mar 75:605–618

Marine Invertebrates of Boka Kotorska Bay Unique Sources for Bioinspired Materials Science

Hermann Ehrlich, Vasilii Bazhenov, Stephan Meschke, Marcel Bürger, Andre Ehrlich, Slavica Petovic, and Mirko Durovic

Abstract Marine invertebrates from Boka Kotorska Bay represent a gold mine for both marine pharmacology and biotechnology as well as for bioinspired materials science. Especially sponges are highly perspective organisms due to their ability to grow under marine farming conditions and to synthetize biologically active secondary metabolites as well as diverse biopolymers. Their skeletal structures contain unique biocomposites made of organic templates and calcium carbonate, or silica phases. Studies on structural biopolymers like aminopolysaccharide chitin or proteinaceous keratin-like spongin are current topics of scientific interest today. Chitinous scaffolds of poriferan origin are discussed as unique templates for application in extreme biomimetics and tissue engineering.

Keywords Bioinspired materials science, Extreme biomimetic, Marine biotechnology, Marine invertebrates, Marine ranching, Sponges

Contents

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1 Introduction

It is well known that Boka Kotorska Bay is a habitat to numerous representatives of main taxons of marine invertebrates like Porifera, Cnidaria, Polychaeta, Mollusca, Crustaceae, Echinodermata, Bryozoa, and Tunicata (Fig. 1). The number of recorded invertebrate's species often reflects the number of studies and expeditions carried out in this marine area. Traditionally, the biodiversity of these organisms has been studied from the views of zoology, ecology, biogeography, seasonal dynamics, physiology, reproduction, and biochemistry (for review, see [1–10]). However, such novel scientific disciplines as bioinspired materials science and biomimetics use marine invertebrates, and especially their hierarchical biomineral-based skeletal structures, as a unique source to understand biomineralization mechanisms, and develop advanced composite materials for applications in biomedicine and technology. Recent research recognizes the importance of ever-finer scales of resolution for documenting and understanding the underlying processes and structures. Marine invertebrates are proving to be a critical group for evolutionary studies, and their early relationships and mineralogy are contentious. They also have a range of unique biomineral phases and structures. Consequently, invertebrates are particularly interesting model systems for the study of biomineralization phenomena like biosilicification (diatoms, sponges) and calcification (sponges, molluscs, corals, echinoderms, etc.) (for review, see [11]). The biomineral-based skeletons found in nature are, usually, nanoscale composites wherein the organic components (peptides, proteins, or polysaccharides) serve as mineral phase-forming templates and/or catalysts and at least partly become embedded into the matrix as functional parts of the skeleton. The design and synthesis of new, hierarchically organized composite materials often relies on ideas inspired by naturally occurring processes which are responsible for the formation of biocomposites; and give rise to the principles of biomimetic materials synthesis. The understanding of the underlying processes of self-organization and self-assembly is, therefore, of crucial importance for the design of novel synthesis strategies in vitro. Organic components are suggested to regulate the in vivo biomineralization in broad variety of marine invertebrate fauna. We hypothesize that a better understanding of how the organic structures of invertebrates are

Fig. 1 Diverse invertebrates were collected in Boka Kotorska Bay during the German-Montenegrin expedition in August 2008

assembled and mineralized may provide the basis for further in vitro production of protein and polysaccharide mineralized nano- and microstructures and composites.

2 Biocalcifiers

Biocalcification is one of the most studied subjects in modern biomineralogy [12]. The biocalcification response to ocean acidification and sea water chemistry is also a current topic of interest. Formation mechanisms of calcium-based phases like calcium carbonates (aragonite, calcite, vaterite, and amorphous calcium carbonate) and calcium phosphates (hydroxyapatite, tri-and dicalciumhydrogen phospates) in marine organisms on nano-, micro-, and macro-levels have been under intensive investigations over the last 50 years. However, most attention is paid to calcification in molluscs (nacre, pearl), corals, and echinoderms (sea urchins). Malacofauna of Boka Kotorska Bay including cephalopods [13], gastropods [14, 15], and bivalves [16–18] have been described; mostly from a systematization and ecological point of view with no attention paid to biomineralization. The same applies with crustaceans [19, 20] and representatives of Cnidaria [21–24].

Sea urchins have been investigated worldwide as model organisms in biomineralization [25, 26] due to their calcified spicules (spines) [27] and teeth [28]. In spite of several publications on echinoderms from Montenegro [29–31] including their populations from Boka Kotorska Bay [32] there is a lack of information about possible application of these biocalcifiers for bioinspired materials science. Corresponding scientific programs must be proposed at Institute of Marine Biology in Kotor, where long years' experience on sea urchins cultivation is well established.

3 Biosilica Producing Organisms

Unicellular eukaryotes like diatoms, radiolarians, and some protists, as well as multicellular eukaryotes like sponges (Porifera), represent examples of organisms that synthetize biological silica with diverse morphologies under sea water conditions (see, for review, [11, 33]).

Sponges are fascinating research subjects because of the hierarchical organization of their fibrous skeletons (Demospongiae) and mineralized spicules containing opaline silica (Demospongiae, Homoscleromorpha, and Hexactinellida) or calcium carbonate (Calcarea). That means, the skeletons of sponges are natural examples of hierarchically organized, rigid silica-based or calcium carbonate-based composites. For example, the skeleton of the hexactinellida Euplectella consists of an elaborate cylindrical lattice with at least six hierarchical levels [34] spanning the length scale from nanometers to centimeters. The basic building blocks are laminated spicules consisting of a central proteinaceous axial filament surrounded by alternating concentric layers of consolidated silica nanoparticles and organic interlayers [35]. Marine sponges turn out to be particularly inspiring for chemists and material scientists [36, 37]. The organic matrix within the glassy spicules of Hexactinellida sponges is especially interesting from the scientific point of view, as well as prospective technological applications, with the ultimate goal to identify design strategies for novel nanostructured synthetic materials. Numerous recent studies on biosilicification in vitro has been carried out using silicatein proteins, but only at the laboratory level because to the very limited amounts of material available [38] Therefore development of novel and alternative biomimetically designed bioinspired peptides, proteins, and polysaccharides with respect to silicification using computational modelling as well as genetic approaches is a challenging trend in modern materials science.

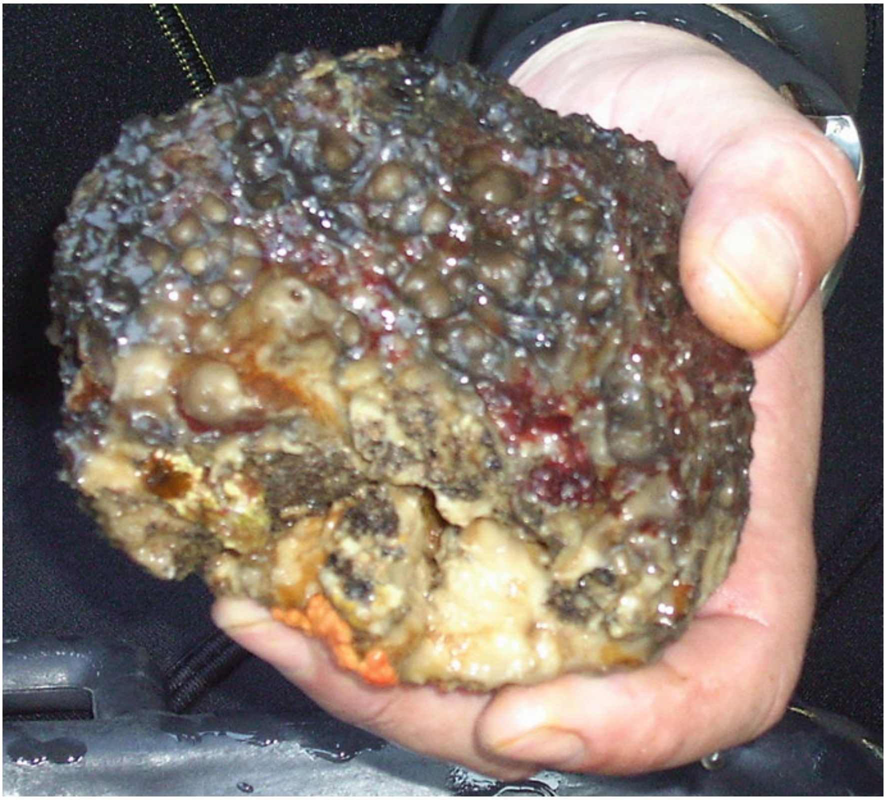

Fig. 2 Specimen of *Hippospongia communis*, spongin-based demosponge (Collected on 28.08.2008 in Boka Kotorska Bay)

Unfortunately, there are no representatives of glass sponges (Hexactinellida) in Adriatic Sea, consequently, only spicules from marine demosponges habituating in coastal waters of Montenegro can be used for scientific aims. In expectation of all representatives of Verongida order and some keratose sponges like *Hippospongia* sp. (Fig. 2) and *Spongia* sp. (Fig. 3), which contain no spicular structures, other demosponges may represent interest in biosilicification research. For example, such sponge as *Axinella cannabina* (Fig. 4) and related species [39] or *Suberites domuncula*, *Chondrilla nucula*, and *Agelas oroides*.

Fig. 3 Dried bath sponge *Spongia officinalis* is a good source for biological material sponging

Fig. 4 Demosponge *Axinella canabina* collected by Dr. Z. Kljajic on 28.08.2008 in Boka Kotorska Bay

4 Demosponges of Boka Kotorska Bay, and Their Biomimetic and Biotechnological Potential

Sponges are probably the earliest branching animals and their fossil record dates back to the Precambrian. These sessile marine invertebrates developed unique survival strategies based on their hard fibrous skeletons, with and without mineral phases, that are responsible for mechanical support and rigidity. Further survival strategies are based on chemical defenses, which are produced by biosynthesis of diverse secondary metabolites and have cytotoxic and antibiotic properties.

Systematic of demosponges from Adriatic Sea including species from Boka Kotorska Bay is well described since nineteenth century [40–45]. Numerous publications have been dedicated to pharmaceutical potential of selected sponges species. The definition "marine sponges as pharmacy" [46] has become well accepted in the scientific community today. For example, keratose demosponge *Dysidea avara* (Fig. 5) has been used as the source for isolation of avarol and related compounds [47–51] that showed antimitotic, antiviral, antibiotic, anticancer, anti-psoriatic, and anti-leukemic activity. Especially important were attempts to develop cell culture-based technology for the production of avarol by primmorphs from *D. avara* [49].

This demosponge also possesses interesting behavior concerning the stiffening of its proteinaceous (spongin-based) fibrous skeleton. Whether it is localized on hard (Fig. 6) or soft (Fig. 5b) substrates, it successfully incorporates foreign material (fragments of foreign spicules, sand particles) [52] to make skeletal fibers rigid. We suggest that these naturally occurring hard fillers (Fig. 7) can be used as markers for geological and sedimentological studies as well. The biological reason of the strategy developed by *D. avara* remains clear; however, there is a lack of information on how limiting this strategy may be for large scale marine farming of this sponge species. However, some attempts have been reported previously [53]. It seems that such experiments must be carried out at the sponge ranching facility in Boka Kotorska Bay in the near future.

More attention has been paid to keratose sponges of Verongida order, which are known as producers of diverse bromotyrosine related compounds [54–60] with high biological activity that is similar to that of avarol. Both are representatives of the Aplysinidae family (order Verongida) *Aplysina cavernicola* and *Aplysina aerophoba* (Fig. 8) [61], known to be a source of bromotyrosines, exist in Boka Kotorska Bay.

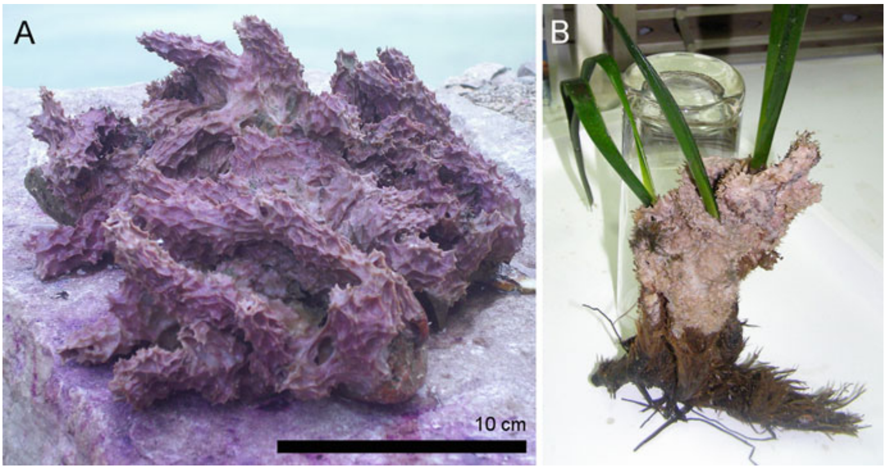

Fig. 5 Keratose demosponge *Desidea avara* (**a**) habituate in Boka Kotorska Bay. This organism also occupies such unusual "soft" substrates as seagrass *Posidonia oceanica* (**b**)

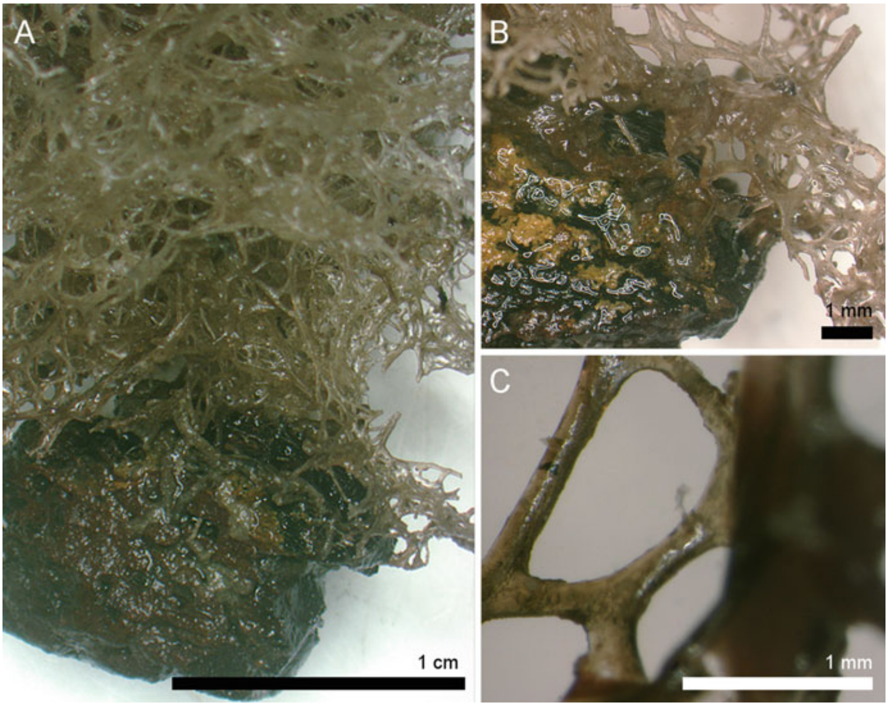

Fig. 6 Short alkali (1 h, 2 M NaOH, room temperature) treatment of *D. avara* that is strongly attached to the rocky substrate (**a**, **b**) led to the loss of mesohyl. Rigid skeletal fibers become well visible

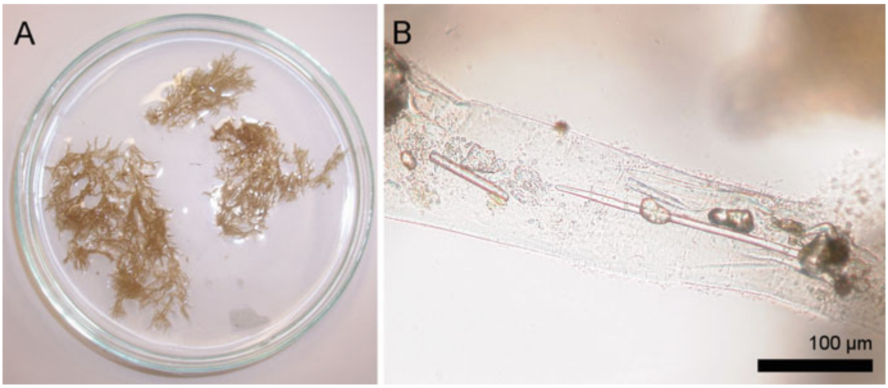

Fig. 7 Skeletal spongin-based fibers of *D. avara* (**a**) are rigid because of incorporation of the foreign microparticles and spicule fragments from other sponges (**b**)

Since discovery of Aeroplysinin-1 in 1970 [62, 63] and after its extraction from *A. aerohoba* sponges, numerous publications have been dedicated to investigations of cytotoxic, antimicrobial, and anticancer activities of this compound [64–68]. According to some reports [69–71] this derivative of

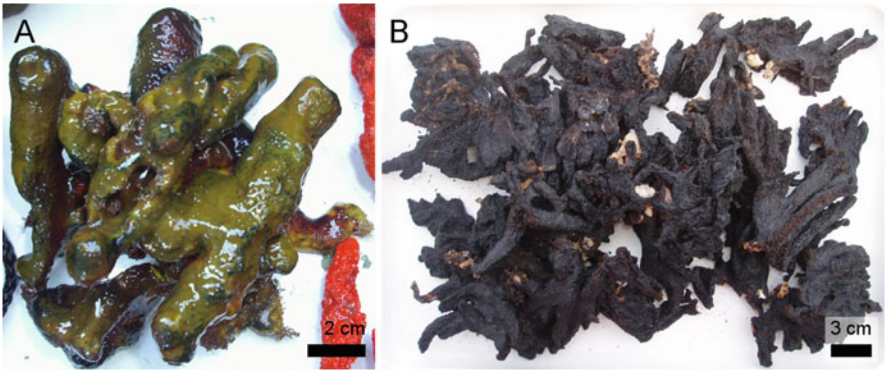

Fig. 8 Verongiid demosponge *Aplysina aerophoba* (**a**) can be successfully cultured under marine ranching conditions in Boka Kotorska Bay with the aim of obtaining industrial amounts of dried material (**b**)

bromotyrosines is localized within *A. aerophoba* sponge from the biosynthetic activity of its symbiotic bacteria. However, from our own observations as well as those from other authors [59, 72], we suggest that Verongiid sponges are able to synthetize bromotyrosines – including Aeroplysinin-1 – using their spherulous cells, which are located within chitinous skeletal fibers. The origin of these very special cells still remains unknown.

Additionally to Aeroplysinin-1, *A. aerophoba* sponge is known as a source of a structurally complex bromotyrosine termed Isofistularin. Both substances are commercially available with a price that ranges around 500 Euro per milligram (see, for review, http://www.brommarin.de). The high prices for bromotyrosines stimulated researchers to develop different biotechnological approaches for cultivation of *A. aerophoba* and related sponges under laboratory [73, 74] and marine ranching conditions in the Mediterranean Sea [53, 75, 76].

Another way to obtain high yield of bromotyrosines from Verongiid sponges is the development of novel, more effective technologies for extraction of these compounds. Recently, we proposed [77, 78] and patented [79] the method for isolation of both bromotyrosines and chitinous skeletal frameworks from selected sponges; without disruption of the skeletons in the mortar, this being the traditional procedure [62, 63] for extraction. Thus, bromotyrosines and chitin-based scaffolds could be isolated from the sponge skeletons using a stepwise extraction procedure mainly based on the use of NaOH [77]. This procedure results in the removal (hydrolysis) of biomolecules other than chitin from the skeletal formations; whereas the chitin-based scaffolds withstand this treatment [78, 80, 81]. It should be noted that the NaOH concentration of 2.5 M is well below the critical concentration where the base-induced transformation of α-chitin in β-chitin starts to takes place [82]. Therefore, the crystal structure of the chitin-based scaffolds is not influenced by this kind of extraction. The effect of the procedure is demonstrated in Fig. 9 for the three-dimensional chitin-based scaffold of the marine demosponge

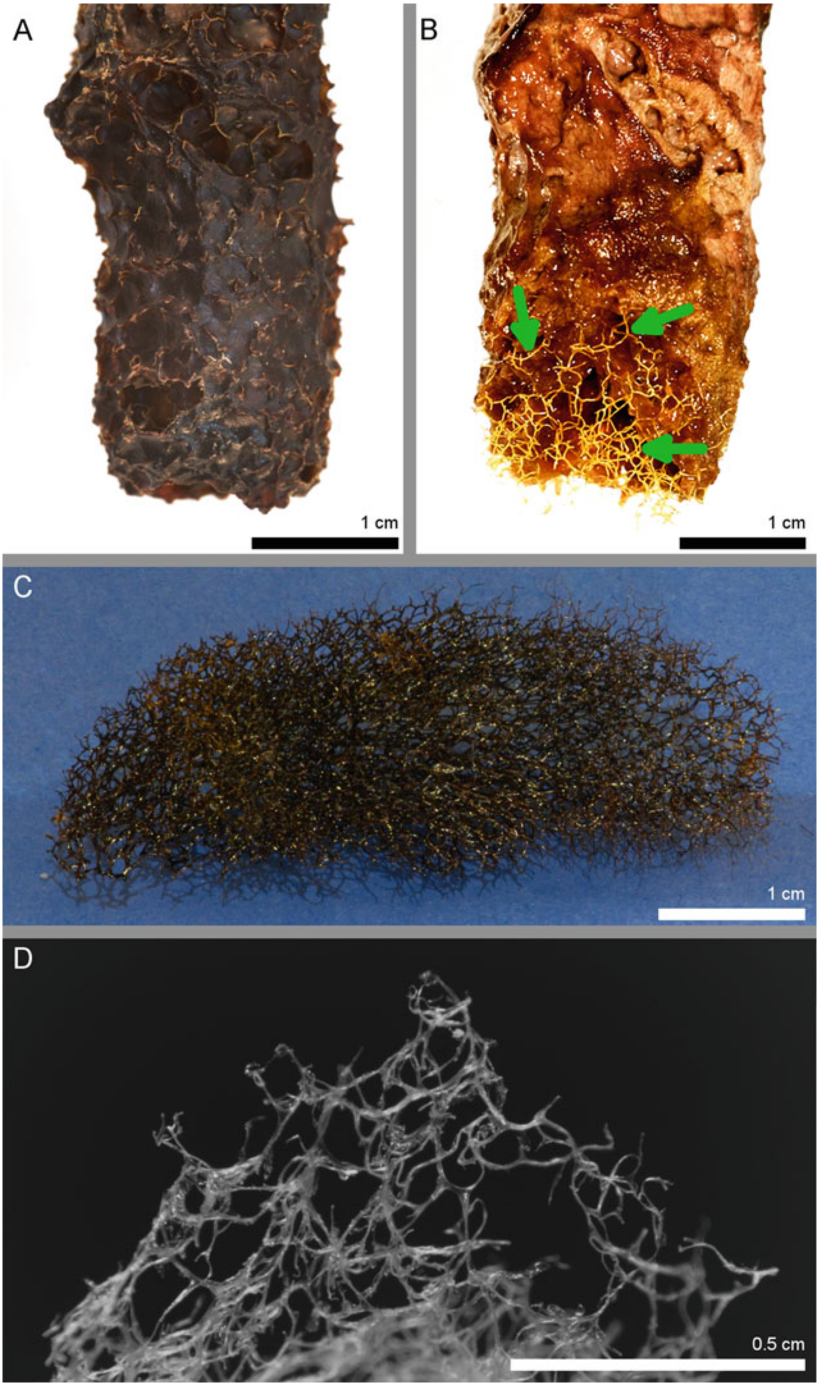

Fig. 9 From sponge to chitinous scaffold. Even insertion of dried *A. aerophoba* sponge fragment (**a**) into 2.5 M NaOH at room temperature lead to dissolution of cells, discoloration, and appearance of skeletal fibers (*arrows*) (**b**). After several treatments (see, for details, [77, 78])

A. aerophoba. While the untreated sponge skeleton consists of a variety of organic compounds, the characteristic signals due to chitin dominate the spectrum after the three extraction steps (see, for example, [81]). After a final H_2O_2 purification, clean white scaffolds remain which mainly consist of chitin.

It should be noted that the chitin-based sponge scaffolds are of potential interest in materials science since the processing of chitin into sponge-like materials or foams is technologically difficult. Since Verongida sponges can be grown in marine ranching stations, their scaffolds may provide a natural source for such materials with applications, e.g., in biomedicine. The morphological and physico-chemical characterization of these scaffolds planned within the future projects is, therefore, not only a matter of fundamental research. These studies will also be of practical value with respect to possible applications of the chitinous sponge scaffolds in Montenegro.

5 Spongin and Chitin as Structural Biopolymers with Perspectives of Application in Biomedicine and Technology

Approximately 95% of extant sponges (phylum Porifera) belong to the class Demospongiae, which consists of 14 taxonomic orders. The skeleton of sponges from the orders Verongida, Dictyoceratida, and Dendroceratida, jointly referred to as “keratose demosponges,” not exhibit primary siliceous spicules. Instead, these sponges possess the so-called spongin fibers as their primary skeleton. This common property has led to the classification of the aforementioned orders as being part of the class Demospongiae, although their relationships remain uncertain [83]. Up to today, chitin in the form of chitin–spongin biohybrid was found only in Verongida sponges. Spongin is the keratin-like structural biopolymer that contains bromine, iodine, and sulfur. The chemical formula and detailed structure of sponging, including the amino acids sequences, are still unknown. Traditionally sponging, as a biological material, was used since ancient centuries in the form of bath sponges. Consequently, all bath sponges (see Figs. 2 and 3) contain proteinaceous spongin that possesses excellent mechanical properties for cosmetic and household use. Recently spongin has found applications in tissue engineering [84], waste treatment [85], and extreme biomimetics as a thermostable substrate for the development of novel composite materials using hydrothermal synthesis [86]. Interest in

Fig. 9 (continued) cell-free skeleton of this sponge can be isolated (**c**). Further purification steps lead to the translucent, tube-like chitinous scaffold (**d**) that can be used for practical application in biomedicine and technology bath sponge farming has increased over the last 80 years [87–92]. We suggest that due to recent novel fields of practical application reported for spongin, the development of bath sponge farming facilities in Boka Kotorska Bay would have many benefits.

Chitin, the main structural aminopolysaccharide that is widely distributed within skeletal structures of fungi, yeasts, protists, diatoms, and practically all invertebrates taxons were discovered in sponges only in 2007 [77]. The observation of chitin-based scaffolds as an integral part of recent sponge skeletons suggests the presence of chitin several 100 million years before the appearance of this important biopolymer in arthropod skeletons. Recently, we successfully discovered 505-million-year-old chitin in the basal demosponge *Vauxia gracilenta* [93]. Our results confirm that Vauxia is a “keratose” demosponge rather than a demineralized spicular sponge. Morphological considerations assign the Vauxiidae as likely being in the Verongida, or alternatively to a stem-group of “keratosan” demosponges. The Vauxiidae are therefore likely to be the most basal definitive demosponge group known, despite the abundance of protomonaxonid “demosponges” in the Cambrian fossil record. In addition, the chitinous character of the Vauxia skeleton would refute the previous suggestion that a keratose skeleton secondarily and independently arose twice among the demosponges, through the loss of spicules and subsequent development of spongin fibers.

The biomimetic potential of chitin-based composite biomaterials of poriferan origin is analyzed in detail in recently published monograph entitled “Biomimetic biomaterials: structure and applications” [94]. Furthermore, for the first time, we proposed sponge chitin as a thermostable template for the development of a new generation of biocomposites using “extreme biomimetic conditions” via hydrothermal synthesis routes (Figs. 10 and 11) (see, for details, [95–101]).

Also, sponge chitin has been used for the first time as a membrane for supercapacitors [102].

Additionally, we showed that sponge chitin could be successfully used for uranium adsorption from contaminated waters [103]. After the first success in tissue engineering of chondrocytes on chitin scaffolds of poriferan origin [80], we continued our experiments for the practical application of these scaffolds for cultivation of different human stromal cells (Fig. 12) [104, 105].

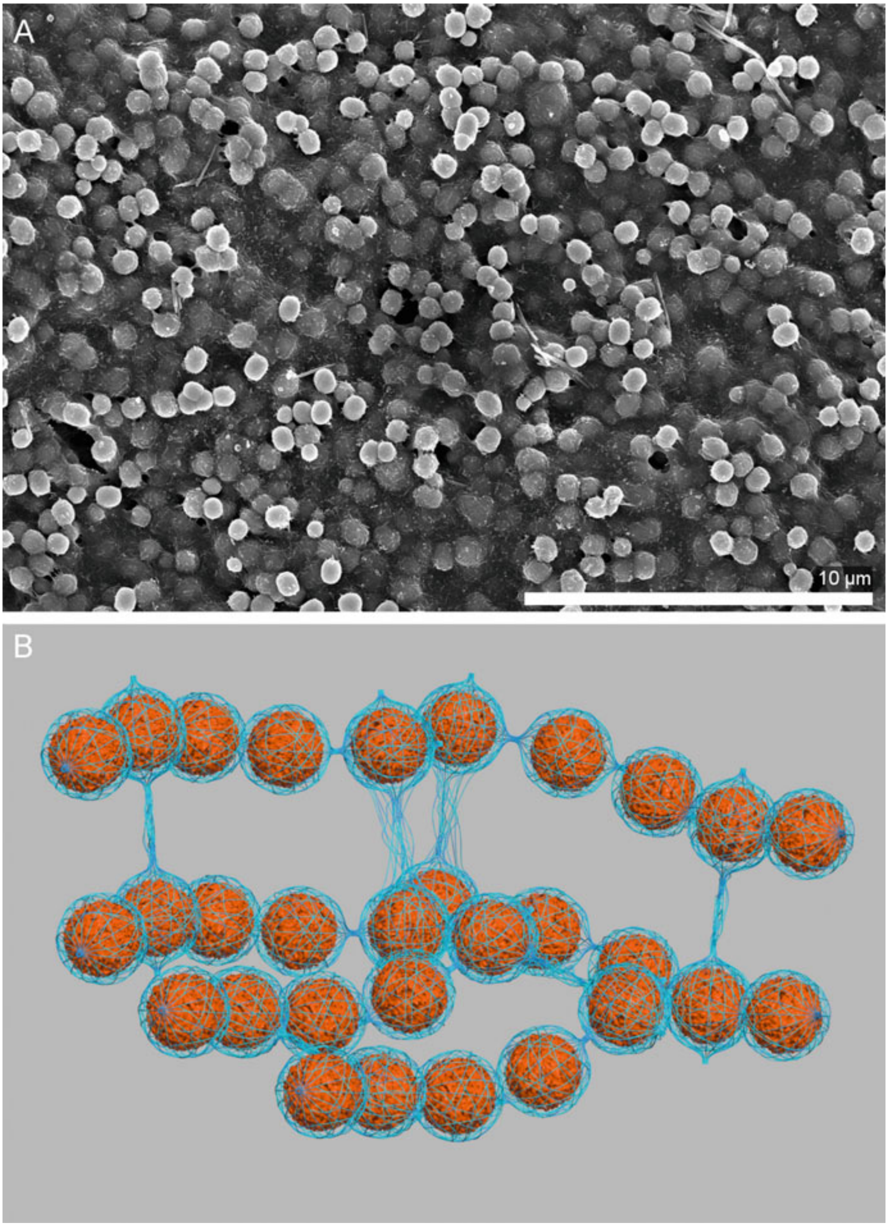

Fig. 10 Growth of hematite nanoparticles on sponge chitin under hydrothermal conditions is well visible using scanning electron microscopy (SEM) (**a**). The possible templating activity of chitin nanofibers is represented in schematic view (**b**)

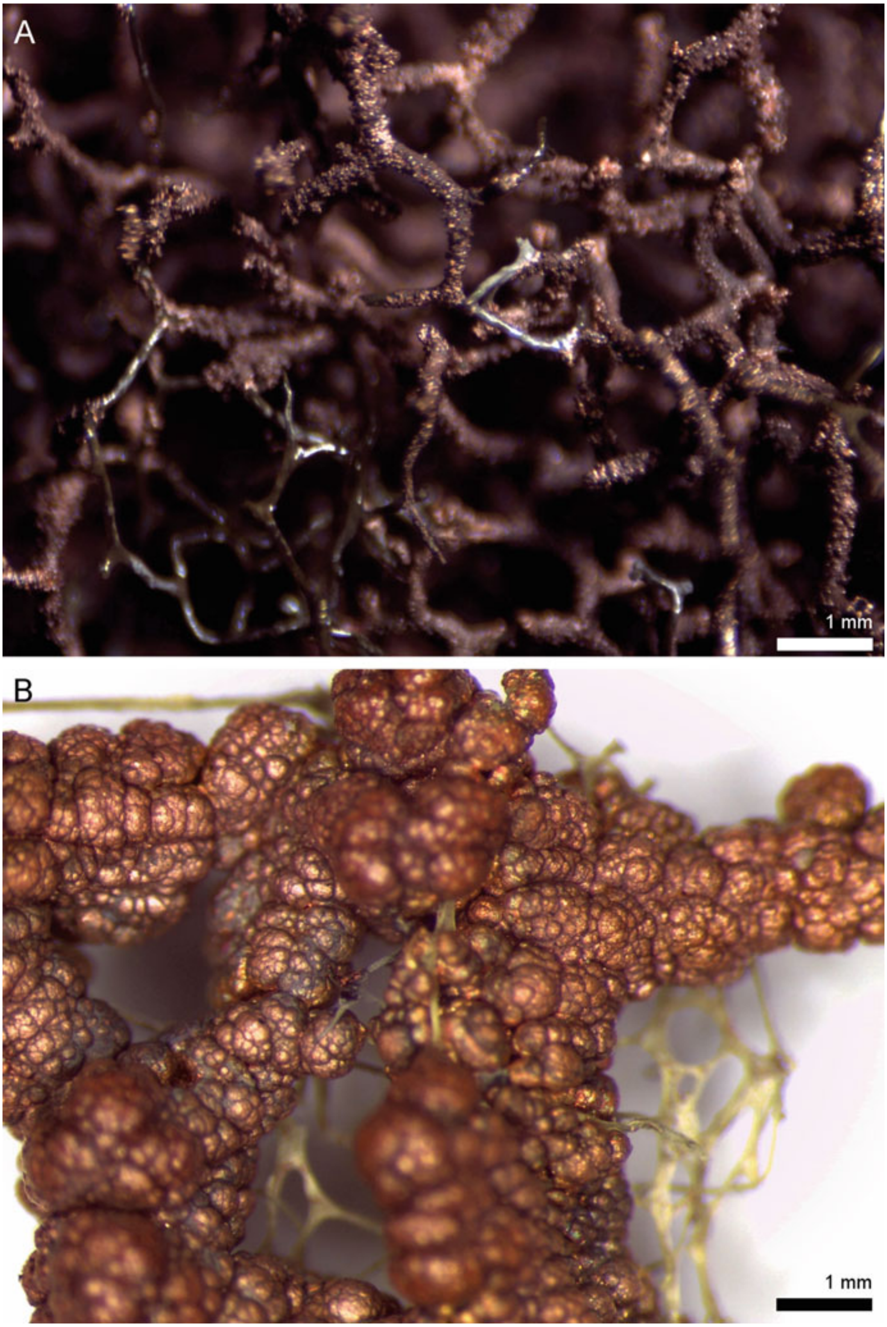

Fig. 11 Electrochemical metallization of *A. aerophoba* chitinous scaffolds using copper leads to formation of mysterious copper-chitin composite materials with 3D architectures (**a**, **b**)

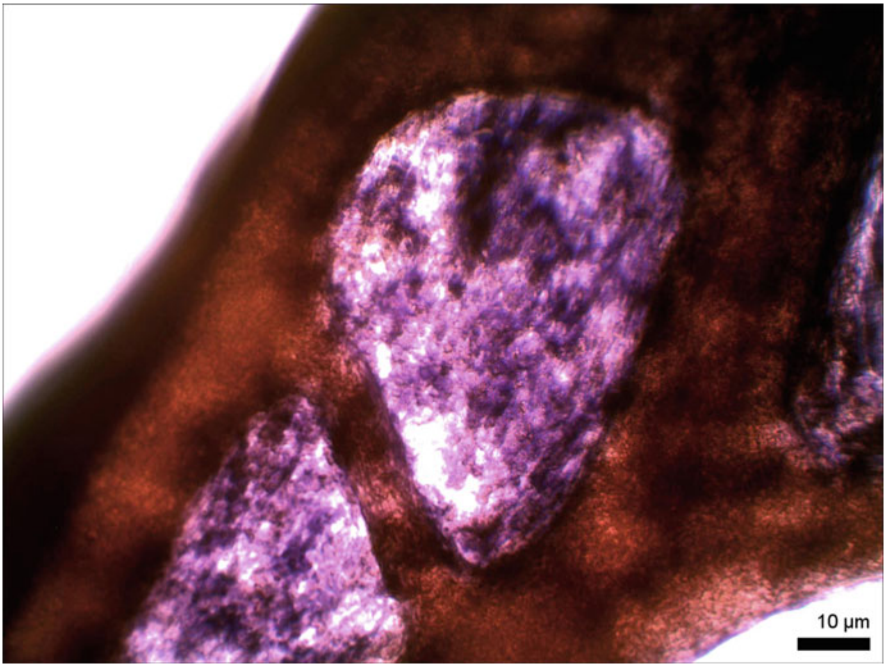

Fig. 12 3D scaffolds of sponge origin can be used for tissue engineering of human mesenchymal stromal cells

6 Conclusions

Sponges are probably the most investigated marine invertebrates today because of their unique secondary metabolites and as a source of biological materials like spongin and chitin. These organisms are known as a goldmine for both marine pharmacology and bioinspired materials science. Over a long time, chitin was not recognized as an integral part of certain sponge skeletons. The first observations of chitin-based scaffolds in Verongida sponge skeletons were reported recently by our group. The goal of the future studies is the systematic investigation of representative keratose sponge species from the orders Verongida, Dictyoceratida, and Dendroceratida in Montenegro with respect to the presence of chitinous scaffolds in their skeletons. These scaffolds must be characterized by various bioanalytical and physico-chemical techniques in order to determine their morphology, composition, and structure. In particular, different extraction techniques must be used with respect to chitin isolation and purification. Furthermore, the regeneration of sponge chitin in selected sponges in situ must be studied within the future projects for the first time. The future projects will thus contribute to the understanding of the modern marine ranching principles for cultivating sponges as renewable sources of chitinous scaffolds. The comprehensive study of the species-specific morphology and structure of the chitin-based scaffolds will also be important for practical applications because the processing of chitin into synthetic sponge-like materials of comparable structure and morphology is rather complicated. Finally, the biomedical and technological potential of marine sponges in Montenegro, and especially in Boka Kotorska Bay, as well as conditions for development of sponge related marine ranching industry in this country must be established.

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References

1. Gamulin-Brida H (1963) Prilog istraživanju bentoskih biocenoza južnog Jadrana. Bilješke-Notes Inst Oceanogr Rib Split 20:1–3
2. Gamulin-Brida H (1967) The benthic fauna of the Adriatic Sea. Oceanogr Mar Biol Annu Rev 5:535–568
3. Gamulin-Brida H (1974) Biocoenoses benthiques de la mer Adriatique – Bentoske biocenoze Jadranskog mora. Acta Adriat 15(9):1–102
4. Gamulin-Brida H (1983) Crnogorsko primorje – specifični dio Jadrana s gledišta bentoskih biocenoza i njihove zaštite. Stud Mar 13–14:205–214
5. Lepetić V (1965) Sastav i sezonska dinamika ihtiobentosa i jestivih invertebrata u Bokokotorskom zalivu i mogućnosti njihove eksploatacije. Stud Mar 1:3–127
6. Karaman G, Gamulin-Brida H (1970) Contribution aux recherches des bicenoses benthiques du Golfe de Boka Kotorska. Stud Mar 4:3–42
7. Eusebio A, Bordin R, Jarre R et al (2007) Recenti esplorazioni speleosubacquee nel golfo di Kotor (Montenegro). Thalassia Salentina 30:25–37
8. Badalamenti F, Treviño-Otón J (2012) Development of marine and coastal protected areas (MPAs) in the Republic of Montenegro. Contract n° 05/ RAC/SPA /2011 MedMPAnet. 57 pp
9. Thessalou-Legaki M, Aydogan Ö, Bekas P et al (2012) New Mediterranean biodiversity records. Mediterr Mar Sci 13:312–327
10. RAC/SPA - UNEP/MAP (2014) Marine biodiversity of Boka Kotorska bay - Pilot project on testing Ecosystem Approach (EcAp) application in Boka Kotorska bay (Montenegro) - Executive summary. By Petovic S. and Batakovic M. Ed. RAC/SPA - MedMPAnet Project, Tunis. 25 pp
11. Ehrlich H, Demadis KD, Pokrovsky OS et al (2010) Modern views on desilicification: biosilica and abiotic silica dissolution in natural and artificial environments. Chem Rev 110:4656–4689
12. Weiner S, Addadi L (2011) Crystallization pathways in biomineralization. Annu Rev Mater Res 41:21–40
13. Mandić S (1984) Cephalopoda južnog Jadrana. Stud Mar 15–16:3–79
14. Mačić V (2013) Contribution to the knowledge of Bursatella leachii (de Blainville, 1817) distribution and reproduction in the Boka Kotorska Bay (Montenegro). Stud Mar 26 (1):119–128
15. Doneddu M, Trainito E, Mačić V (2013) First record of *Cabestana cutacea* (Linnaeus, 1767) (Gastropoda; Ranellidae) found on the coast of Montenegro: notes about the range of the species. Biol Serbica 35:76–81
16. Stjepčević J (1967) Makro-Mollusca Bokokotorskog zaliva [Macro-Molluscs of the Boka Kotorska Bay]. Stud Mar 2:3–67 [Serbian]

17. Stjepčević J, Parenzan P (1980) Il Golfo delle Bocche di Cattaro–condizioni generali e biocenosi bentoniche con carta ecologica delle due baie interne: di Kotor (Cattaro) e di Risan (Risano). [Boka kotorska Bay general characteristics and composition of the benthic biocenosis with ecological map of Kotor's and Risan's Bay]. Stud Mar 9–10:3–145 [Italian]
18. Joksimović D, Tomić I, Stanković RA et al (2011) Trace metal concentrations in Mediterranean blue mussel and surface sediments and evaluation of the mussels quality and possible risks of high human consumption. Food Chem 127:632–637
19. Vukanić D (1971) Kopepodi Bokokotorskog zaliva. Stud Mar 5:21–62
20. Marković O, Gokoglu M, Petović S et al (2014) First record of the Northern brown shrimp, Farfantepenaeus aztecus (Ives, 1891) (Crustacea: Decapoda: Penaeidae) in the South Adriatic Sea, Montenegro. Medit Mar Sci 15(1):165–167
21. Stjepčević J, Gašić MJ, Kljajić Z et al (1986) Prilog proučavanja faune Anthozoa unutrašnjeg dijela Bokokotorskog zaliva. Stud Mar 21:17–18
22. Benović A, Lučić D, Onofri V (2000) Does change in an Adriatic hydromedusan fauna indicate an early phase of marine ecosystem destruction? Mar Ecol 21:221–231
23. Lučić D, Pestorić B, Malej A et al (2012) Mass occurrence of the ctenophore *Bolinopsis vitrea* (L. Agassiz, 1860) in the nearshore southern Adriatic Sea (Kotor Bay, Montenegro). Environ Monit Assess 184:4777–4785
24. Pestorić B, Krpo-Ćetković J, Gangai B et al (2012) Pelagic cnidarians in the Boka kotorska Bay (Montenegro, South Adriatic). Acta Adriat 53(2):289–300
25. Wilt FH (2005) Developmental biology meets materials science: morphogenesis of biomineralized structures. Dev Biol 280(1):15–25
26. Matranga V, Bonaventura R, Costa C et al (2011) Echinoderms as blueprints for biocalcification: regulation of skeletogenic genes and matrices. Prog Mol Subcell Biol 52:225–248
27. Politi Y, Arad T, Klein E et al (2004) Sea urchin spine calcite forms via a transient amorphous calcium carbonate phase. Science 306(5699):1161–1164. doi:10.1126/science.1102289
28. Killian CE, Wilt FH (2008) Molecular aspects of biomineralization of the Echinoderm endoskeleton. Chem Rev 108(11):4463–4474
29. Milojević S (1986) Fauna Asteroidea (Echinodermata) u otvorenom litoralnom području južnog Jadrana. Stud Mar 17–18:199–213
30. Kašćelan S, Mandić S, Radović I et al (2009) An annotated checklist of Echinodermata of Montenegro (the south Adriatic Sea). Zootaxa 2275:21–40
31. Petović S, Krpo-Ćetković J (2014) Additions to the echinoderm (Echinodermata) fauna of Montenegro (Adriatic Sea). Stud Mar 27(1):9–18
32. Bruno C (1972) Echinodermi di Boka Kotorska. Thalassia Salentina 6:37–46
33. Ehrlich H (2011) Silica biomineralization in sponges. In: Reitner J, Thiel V (eds) Encyclopedia of geobiology. Springer, Netherlands, pp 796–808
34. Aizenberg J, Weaver JC, Thanawala MS et al (2005) Skeleton of *Euplectella* sp.: structural hierarchy from the nanoscale to the macroscale. Science 309:275–278
35. Weaver JC, Aizenberg J, Fanther GE et al (2007) Hierarchical assembly of the siliceous skeletal lattice of the hexactinellid sponge *Euplectella aspergillum*. J Struct Biol 158:93–106
36. Fratzl P (2007) Biomimetic materials research: what can we really learn from nature's structural materials? J R Soc Interface 4:637–642
37. Meyers MA, Chen P-Y, Lin AY-M et al (2008) Biological materials: structure and mechanical properties. Prog Mater Sci 53:1–206
38. Rai A, Perry CC (2010) Facile fabrication of uniform silica films with tunable physical properties using silicatein protein from sponges. Langmuir 26:4152–4159
39. Macic V, Petovic S, Backovic S (2015) Contribution to the knowledge of protected Axinella species along the Montenegrin coast. Stud Mar 28(1):9–20
40. Schmidt O (1862) Die Spongien des adriatischen Meeres. Verlag von Wilhelm Engelmann, Leipzig, 88 pp

41. Schmidt O (1864) Supplement der Spongien des adriatischen Meeres (Enthaltend die Histiologie und systematische Ergänzungen). Verlag von Wilhelm Engelmann, Leipzig, 48 pp
42. Buccich G (1886) Alcune spugne dell'Adriatico sonosciute e nuove. Bollettino della Società Adriatica di Scienze Naturali in Trieste 9:222–225
43. Babić K (1922) Monactinellida und Tetractinellida des Adriatischen Meeres. Zoologische Jahrbücher, Abteilung für Systematik, Geographie und Biologie der Tiere 46(2):217–302
44. Voltz P (1939) Die Borschwämme (Clioniden) der Adria. Thalassia 2(3):1–64
45. Bakran-Petricioli T, Radolovic M, Petricioli D (2012) How diverse is sponge fauna in the Adriatic Sea? Zootaxa 3172:20–38
46. Sipkema D, Franssen CR, Osinga R et al (2005) Marine sponges as pharmacy. Mar Biotechnol 7:142–162
47. Müller WEG, Diehl-Seifert B, Sobel C et al (1986) Sponge secondary metabolites: biochemical and ultrastructural localization of the antimitotic agent avarol in *Dysidea avara*. J Histochem Cytochem 34:1687–1690
48. Müller WEG, Schatton WFH, Gudrum M (1991) Verwendung von Avarol oder dessen Derivaten zur Bekämpfung von entzündlichen systemischen und dermatologischen Erkrankungen. International Patent Application DE 1991-4,137,093
49. Müller WEG, Böhm M, Batel R et al (2000) Application of cell culture for the production of bioactive compounds from sponges: synthesis of avarol by primmorphs from *Dysidea avara*. J Nat Prod 63:1077–1081
50. Andjus RK, Mitrasinovic O, Zivadinovic D et al (1992) Suppression of uncoupled oxidations in brain synaptosomes by derivatives of a bioactive compound from Adriatic demospongia *Dysidea avara*. Arch Biol Sci 44:7–14
51. Božić T, Novaković I, Gašić MJ et al (2010) Synthesis and biological activity of derivatives of the marine quinone avarone. Eur J Med Chem 45:923–929
52. Cerrano C, Calcinai B, Di Camillo CG et al (2007) How and why do sponges incorporate foreign material? Strategies in Porifera. Porifera Res Biodivers, Innov Sustain 20:239–246
53. Schatton WFH, Schatton M, Mueller-Zahn I et al (2000) Züchtung von Schwämmen in Aquakultur, Verfahren zur umweltschonenden und ökonomisch effizienten Züchtung von Schwämmen, Korallen und anderen Invertebraten im Biozyklus. German Patent DE 19,834,949 A
54. Cimino G, De Rosa S, De Stefano S et al (1983) The bromocompounds of the true sponge *Verongia aerophoba*. Tetrahedron Lett 24:3029–3032
55. Teeyapant R, Proksch P (1993) Biotransformation of brominated compounds in the marine sponge *Verongia aerophoba*: evidence for an induced chemical defense? Naturwissenschaften 80:369–370
56. Teeyapant R, Woerdenbag HJ, Kreis P et al (1993) Antibiotic and cytotoxic activity of brominated compounds from the marine sponge *Verongia aerophoba*. Z Naturforsch C 48:939–945
57. Weiss B, Ebel R, Elbraechter M et al (1996) Defense metabolites from the marine sponge Verongia aerophoba. Biochem Syst Ecol 24:1–12
58. Ciminiello P, Fattorusso E, Forino M et al (1997) Chemistry of Verongida sponges, VIII – Bromocompounds from the Mediterranean sponges *Aplysina aerophoba* and *Aplysina cavernicola*. Tetrahedron 53:6565–6572
59. Turon X, Becerro MA, Uriz MJ (2000) Distribution of brominated compounds within the sponge *Aplysina aerophoba*: coupling of X-ray microanalysis with cryofixation techniques. Cell Tissue Res 301:311–322
60. Thoms C, Wolff M, Padmakumar K et al (2004) Chemical defense of Mediterranean sponges *Aplysina cavernicola* and *Aplysina aerophoba*. Z Naturforsch C 59c:113–122
61. Klöppel A, Brümmer F (2006) *Aplysina aerophoba* and *Aplysina cavernicola*: phenotypic variability or two different species. In: Custodio MR, Lobo-Hajdu G, Hajdu E, Muricy G (eds) 7th international sponge symposium. Museu Nacional, Buzios, Rio de Janeiro, p 290

62. Fattorusso E, Minale L, Sodano G (1970) Aeroplysinin-1, a new bromo-compound from *Aplysina aerophoba*. Chem Commun 12:751–752
63. Fattorusso E, Minale L, Sodano G (1972) Aeroplysinin-1, an antibacterial bromo-compound from the sponge *Verongia aerophoba*. J Chem Soc Perk Trans 1(1):16–18
64. Kreuter MH, Bernd A, Holzmann H et al (1989) Cytostatic activity of Aeroplysnin-1 against lymphoma and epithelioma cells. Z Naturforsch C 44:680–688
65. Kreuter MH, Leake RE, Rinaldi F et al (1990) Inhibition of intrinsic protein tyrosine kinase activity of Egf-receptor kinase complex from human breast cancer cells by the marine sponge metabolite (+)-Aeroplysinin-1. Comput Biochem Phys B 97:151–158
66. Kreuter MH, Robitzki A, Chang S et al (1992) Production of the cytostatic agent aeroplysinin by the sponge *Verongia aerophoba in vitro* culture. Comput Biochem Physiol C 101:183–187
67. Koulman A, Proksch P, Ebel R et al (1996) Cytotoxicity and mode of action of Aeroplysinin-1 and a related dienone from the sponge *Aplysina aerophoba*. J Nat Prod 59:591–594
68. Ebel R, Brenzinger M, Kunze A et al (1997) Wound activation of protoxins in marine sponge *Aplysina aerophoba*. J Chem Ecol 23:1451–1462
69. Hentschel U, Schmid M, Wagner M et al (2001) Isolation and phylogenetic analysis of bacteria with antimicrobial activities from the Mediterranean sponges *Aplysina aerophoba* and *Aplysina cavernicola*. FEMS Microbiol Ecol 35:305–312
70. Friedrich AB, Fischer I, Proksch P et al (2001) Temporal variation of the microbial community associated with the Mediterranean sponge *Aplysina aerophoba*. FEMS Microbiol Ecol 38:105–113
71. Wehrl M, Steinert M, Hentschel U (2007) Bacterial uptake by the marine sponge *Aplysina aerophoba*. Microb Ecol 53:355–365
72. Thompson JE, Barrow KD, Faulkner JD (1983) Localization of two brominated metabolites, aerothionin and homoaerothionin, in spherulous cells of the marine sponge *Aplysina fistularis* (=*Verongia thiona*). Acta Zool (Stockh) 44:199–210
73. Hausmann R, Vitello M, Leitermann F et al (2006) Advances in the production of sponge biomass *Aplysina aerophoba* - a model sponge for ex situ sponge biomass production. J Biotechnol 124:117–127
74. Klöppel A, Pfannkuchen M, Putz A et al (2008) *Ex situ* cultivation of *Aplysina* spp. close to in situ conditions: ecological, biochemical and histological aspects. Mar Ecol 29:259–272
75. Verdenal B, Vacelet J (1990) Sponge culture on vertical ropes in the northwestern Mediterranean Sea. In: Rützler K (ed) New perspectives in sponge biology. Smithsonian Institute Press, Washington, pp 416–424
76. Pronzato R, Bavestrello G, Cerrano C et al (1999) Sponge farming in the Mediterranean Sea: new perspectives. Mem Qld Mus 44:485–491
77. Ehrlich H, Maldonado M, Spindler K-D et al (2007) First evidence of chitin as a component of the skeletal fibers of marine sponges. Part I. Verongidae (Demospongia: Porifera). J Exp Zool (Mol Dev Evol) 308B:347–356
78. Ehrlich H, Ilan M, Maldonado M et al (2010) Three-dimensional chitin-based scaffolds from Verongida sponges (Demospongiae: Porifera). Part I. Isolation and identification of chitin. Int J Biol Macromol 47:132–140
79. Ehrlich H, Brunner E, Richter W et al (2011) Two or three-dimensional cleaned chitin skeleton of dictyoceratid sponges. Method for the production and use thereof WO 2011/023531 A2
80. Ehrlich H, Steck E, Ilan M et al (2010) Three-dimensional chitin-based scaffolds from Verongida sponges (Demospongiae: Porifera). Part II. biomimetic potential and applications. Int J Biol Macromol 47:141–145
81. Brunner E, Ehrlich H, Schupp P et al (2009) Chitin-based scaffolds are an integral part of the skeleton of the marine demosponge *Ianthella basta*. J Struct Biol 168:539–547
82. Noishiki Y, Takami H, Nishiyama Y et al (2003) Alkali-induced conversion of b-chitin to a-chitin. Biomacromolecules 4:869–899

83. Maldonado M (2009) Embryonic development of verongid demosponges supports the independent acquisition of sponging skeletons as an alternative to the siliceous skeleton of sponges. Biol J Linn Soc 97:427–447
84. Green D, Howard D, Yang X et al (2004) Natural marine sponge fiber skeleton: a biomimetic scaffold for human osteoprogenitor cell attachment, growth, and differentiation. Tissue Eng 9 (6):1159–1166
85. Norman M, Bartczak P, Zdarta J et al (2015) Adsorption of C. I. Natural Red 4 onto spongin skeleton of marine demosponge. Materials 8:96–116
86. Szatkowski T, Wysokowski M, Lota G et al (2015) Novel nanostructured hematite-spongin composite developed using extreme biomimetic approach. RSC Adv 5:79031–79040
87. Arndt W (1928) Haltung und Aufzucht von Meeresschwämmen. In: Abderhalden E (ed) Handbuch der biologischen Arbeitsmethoden, vol Abt. IX; Teil 5. pp 443–464
88. Pronzato R (1999) Sponge-fishing, disease and farming in the Mediterranean Sea. Aquat Conserv 9:485–493
89. Pronzato R, Bavestrello G, Cerrano C et al (2000) The millennial history of commercial sponges: from harvesting to farming and integrated aquaculture. Biol Mar Medit 7:1–12
90. Nickel M, Brümmer F (2003) *In vitro* sponge fragment culture of *Chondrosia reniformis* (Nardo, 1843). J Biotech 100:147–159
91. Duckworth A, Battershill C (2003) Sponge aquaculture for the production of biologically active metabolites: the influence of farming protocols and environment. Aquaculture 221:311–329
92. Baldacconi R, Cardone F, Nonnis Marzano C et al (2006) Riproduzione sessuale in una popolazione naturale e in frammenti reimpiantati di *Spongia officinalis var. adriatica* (Porifera, Demospongiae). Biol Mar Medit 13:797–800
93. Ehrlich H, Rigby JK, Botting J et al (2013) Discovery of 505-million-year old chitin in the basal demosponge *Vauxia gracilenta*. Sci Rep 3:3497
94. Ehrlich H (2013) Biomimetic potential of chitin-based composite biomaterials of poriferan origin. In: Ruys AJ (ed) Biomimetic biomaterials: structure and applications. Woodhead Publishing Limited, Cambridge, pp 47–67
95. Ehrlich H, Simon P, Motylenko M et al (2013) Extreme biomimetics: formation of zirconium dioxide nanophase using chitinous scaffolds under hydrothermal conditions. J Mater Chem B 1:5092–5099
96. Wysokowski M, Motylenko M, Bazhenov VV et al (2013) Poriferan chitin as a template for hydrothermal zirconia deposition. Front Mater Sci 7(3):248–260
97. Wysokowski M, Behm T, Born R et al (2013) Preparation of chitin-silica composites by *in vitro* silicification of two-dimensional *Ianthella basta* demosponge chitinous scaffolds under modified Stöber conditions. Mater Sci Eng C 33:3935–3941
98. Wysokowski M, Motylenko M, Walter J et al (2014) Synthesis of nanostructured chitin-hematite composites under extreme biomimetic conditions. RSC Adv 4:61743–61752
99. Wysokowski M, Materna K, Walter J et al (2015) Solvothermal synthesis of chitin-polyhedral oligomeric silsesquioxane (POSS) nanocomposites with hydrophobic properties. Int J Biol Macromol 78:224–229
100. Wysokowski M, Petrenko I, Stelling AL et al (2015) Poriferan chitin as a versatile template for extreme biomimetics. Polymers 7:235–265
101. Wysokowski M, Motylenko M, Beyer J et al (2015) Extreme biomimetic approach for development of novel chitin-GeO_2 nanocomposites with photoluminescent properties. Nano Res 8(7):2288–2301
102. Stepniak I, Galinski M, Nowacki K et al (2016) A novel chitosan/sponge chitin origin material as a membrane for supercapacitors – preparation and characterization. RSC Adv 6:4007–4013
103. Schleuter D, Günther A, Paasch S et al (2013) Chitin-based renewable materials from marine sponges for uranium adsorption. Carbohydr Polym 92(1):712–718

104. Rogulska OY, Mutsenko VV, Revenko EB et al (2013) Culture and differentiation of human adipose tissue mesenchymal stromal cells within carriers based on sea sponge chitin skeletons. Probl Cryobiol Cryomed 23:267–270
105. Rogulska OY, Revenko OB, Petrenko YO et al (2013) Prospects for the application of Aplysinidae family marine sponge skeletons and mesenchymal stromal cells in tissue engineering. Biotechnol Acta 6(5):115–121

The History of Fishery in Boka Kotorska Bay and Traditional Types of Fishery

Ana Pešić, Mirko Đurović, Aleksandar Joksimović, and Slobodan Regner

Abstract Among oldest occupations that the local population in the Boka Kotorska Bay has been engaged in, since the ancient times, is sea fishing, but despite the fact that it has centuries' old tradition in this region, there are very few written records on the history and tradition of fishery in the Boka Bay. This paper provides an overview of the basic fishery types in the Bay over the past centuries, describes the boats and fishing gears used in those times, but also today, as well as the manner of use of certain fishing gear types. It gives also an overview of historical development and changes in some fishing gears over the time as well as changes in socio-economic and social relations in fishery. Apart from its economic significance, the fishing with traditional gear in the Boka Kotorska Bay also has a strong culturological and sociological importance for the local population and as such, it should be preserved and protected at the times of industrialization and development of the coastal area. Activities aimed to preserve the traditional fishery types in the Boka Kotorska Bay should also be implemented in order to diversify further the tourist offer of Montenegro since, in addition to provision of fresh, wholesome food from the sea the use of traditional gear is also a tourist attraction.

Keywords Boats, Boka Kotorska Bay, Fishing gear, Net, Traditional fishery

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Contents

1 Introduction

One of the oldest occupations in the Boka Kotorska Bay is fishery, which is also the case with other parts of the world where the population living on the shores of the rivers, lake and sea has from the ancient times been engaged in fishing. Fishery is mentioned as early as fourteenth century in the Statute of the Town of Kotor, proving that it was quite developed at the time and that, along with agriculture and seafaring, it was one of the main occupations.

Regardless of the importance of fishery in the Boka Kotorska Bay, there are very few written records on this activity. Written documentation was left by priest Savo Nakićenović in the book under the title *Boka* [1], there is a paper of Darinka Žečević *Toward a Study on Fishing in Muo, fishermen's settlement in the Kotor Bay* [2], as well as the capital work *Maritime and Fishery History of Montenegro by 1918* by captain Dinko Franetović [3]. The paper *Fishermen's Posts in the Bays of Kotor and Risan* by Vladimir Uljarević and Antun Tomić [4] gives an overview of the sites on the shore where fishermen take out their nets in traditional fishing using beach seine nets. The most comprehensive study on fishery and its history in the Boka is given by Dragana Radojičić in the papers *Fishing in the Bay of Kotor from the 19th Century to the present day* [5] and *Museological Valorisation of Traditional Fishing Gear in the Boka Kotorska* [6].

In the course of eighteenth century, majority of families in the Boka Kotorska lived on fishery, particularly in settlements Muo and Baošići. Today, a far smaller number of families are engaged in professional fishery. In the course of nineteenth century, particularly after the World War II (1945), seafaring, tourism and industry developed rapidly, resulting in closing down of fishermen's cooperatives, as people began engaging in occupations that secured monetary income, which is not the case with fishery. There is a well-known saying that seafarers' life is bread with seven crusts, and that the fishermen's bread is the one with nine crusts. This is highly demanding occupation, without working hours, guaranteed catch or income. Fishermen depend, first of all, on weather conditions, then on availability of fish as well as on the current market demand for fish.

2 Boat and Fishing Gear Types

Fishing requires a boat, nets or other gear and other accompanying tools. The boats used in the Boka Kotorska Bay were the same as those used in Dalmatia – *leut, gaeta, guc* and *svjećarica* (lamplight fishing boat) – all similar, differing only in size. Even today, wooden boats close to or even more than 100 years old can be found in the mole-enclosed berths in the Boka (the boat of the Krašovec family from Orahovac of 1929, *guc* of the Pasković family from Muo of 1930, etc.).

Leut is our largest boat, 8–12 m in length and 1 m above the sea level in height. It is propelled by six oars. Keel and flooring were made of oak, ribs usually of mulberry wood and the rest of the boat from pine and fir wood. The fore and aft third of the boat are covered by the deck; the aft deck is used to keep the nets and other gear. Below the deck, fishermen kept their personal items and sought shelter from bad weather or for rest (Fig. 1).

Gaeta was most commonly used and in terms of construction it is very similar to *leut*, only somewhat smaller, 7–9 m, propelled by 4–6 oars (Fig. 2). It is made of pine wood and oak beams. The fore third of the boat is covered by the deck and the stern had a small part roofed over, up to 80 cm. The *gaetas* were used for various nets. As *svjećarice*, *gaetas* of different lengths were used with a lamp holder fitted on the prow [7].

Fig. 1 Leut [7]

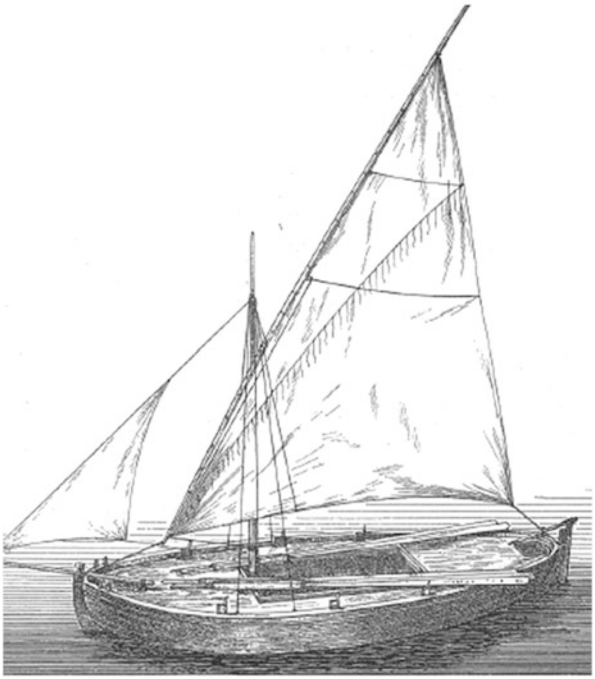
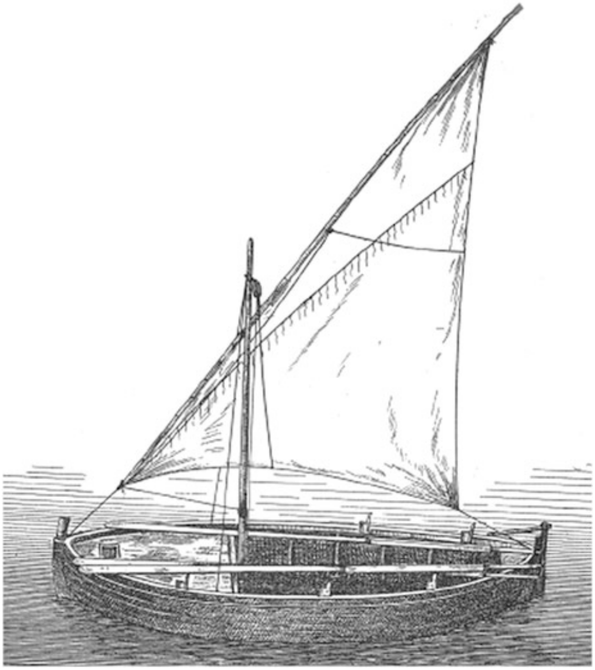


Fig. 2 Gaeta [7]



Guc is a light boat of 4.8–9.5 m in length, very suitable as a secondary boat in major fishing activities as its shape makes it very fast. It is 1.4–1.6 m wide in the central part, narrowing towards the prow and the stern (Fig. 3). The keel is usually made of pine wood and the rest of the boat from mulberry and pine wood. *Guc* is usually completely open, except for roofing of 50–60 cm on the prow and on the stern [7].

The boats were propelled by rows made usually from oak, beech and maple wood. Rowing is strenuous and one oar was held by one oarsman. Even today, when all boats are engine propelled, oars are a mandatory part of the gear and are used when sailing out, landing or in other cases. Local craftsmen rarely built boats, as they were usually bought in Dalmatia, on the islands of Korčula and Gruž. The local craftsmen usually repaired the boats by *kalafatavanje*, i.e., they were caulking the crevices between the boards using tar, pitch and oakum [5]. The most beautiful fishermen's boats originated from the island of Korčula [7].

Renowned craftsmen for *kalafatavanje* and boat repairs in the Boka in early twentieth century were Blago Dabović from Baošići, Ante Pilastro from Prčanj, Viktorijo Panjoko from Muo and others [5].

As already stated, oak wood was most frequently used for building boats, then pine wood, mulberry, beech and fir wood. Due to its compactness, oak wood was used for the keel, main and foundation beams and lateral ribs to the sea level. Pine wood was used for *madijere* (boards that make the boarding/sides of the boat) as well as for the deck beams and in some cases also for the deck itself. Beech wood

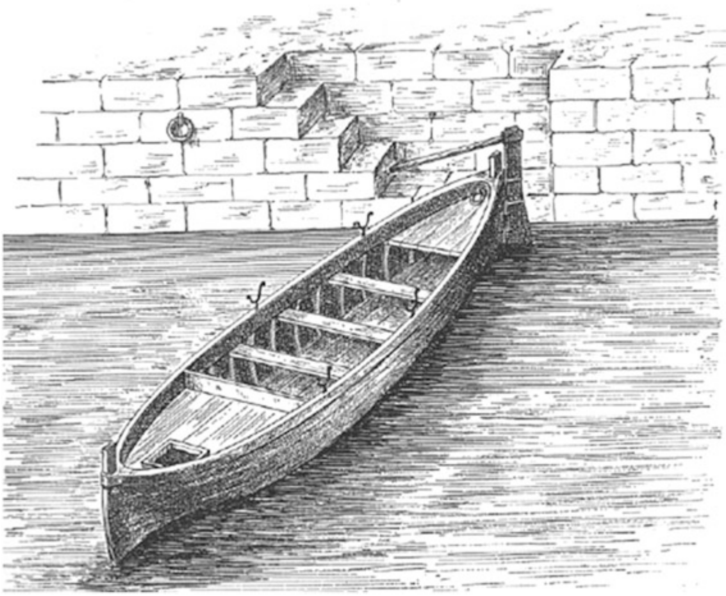


Fig. 3 Guc [7]

was used less frequently as it cracks easily and when used, parts of the boat that are outside the sea were made of it. Mulberry wood was often used for side ribs and deck beams as nails in it are well protected from corrosion, and sometimes wild olive wood was used instead of mulberry. Fir wood was never used for boat parts below the sea level because of its softness; instead, it was used for the deck only.

In order to last longer, the boat needed to be maintained well. Upon arrival from the fishing, the inside and the outside parts of the boat were rinsed by seawater that afterwards needed to be *isekati* – taken out by *palj* (a wooden shovel made for taking the water out of the boat). The boats were *katramavani* by fishermen in order to last longer – all interior sides of the boat were coated by hot tar – the more frequent, the better – only the upper part of the deck was not coated by anything.

Nets, longlines, spears and traps were used as fishing gear in the Boka. According to their construction and the manner of fishing, the nets are divided into gillnets, beech seines, encircling purse seines and trawl nets. The type of the net used depended on the season, so there is a difference between nets for winter and those for summer fishing. Nets used to be bought in Dalmatia in Zadar, Split, rarely they were made by fishermen or their wives. After the World War I, nets were supplied through barter with Italians.

The material used for making fishing gear changed over the times, depending on availability of the raw material. Nets used to be made of cotton thread, while today they are made from various synthetic materials. Materials for net used to be supplied mainly in Dalmatia and were bought in bulk, in kilograms [6]. The net needed was then tailored from the material supplied. In the making process, the net

Fig. 4 *Stirilo* – device used for net drying (photo from private collection of fisherman Anđelko Ivović)

was tailored with some tolerance in order to achieve the elasticity needed, i.e., in order to make a “belly” when towing in order to prevent the fish from escaping the net. In order to be able to use the nets for many years, they needed to be kept and maintained properly. Otherwise, the nets made of cotton thread would soon deteriorate and rot away.

Immediately after fishing, the net needed to be cleaned of fish parts, scales and other dirt, then washed in the sea and if possible, rinsed by fresh water. After that, the net needed to be dried and only a well-dried net could have been stored in the basement. *Stiralo*, devices made of several poles 4–5 m in height, connected by movable beams were used for net drying (Fig. 4). The net is spread over the movable beams that were then used to raise the net to the top of the poles and thus it would be left to dry. Nets could not have been left in the glaring sun and in hot weather. During the winter months and when a specific net was not used for fishing for some time, they were usually kept in basements of houses, but occasionally, they needed to be taken out and shaken in order to prevent mould and rotting as a result of humidity.

As nets were made of white cotton thread, they needed to be dyed so they would not scare the fish away. Today, the nets are made of very thin synthetic threads that are invisible to fish in water. At the same time, dyeing or oiling of the net extended its durability and lifespan. Fishermen used pine bark for dyeing. In Bigova, dyeing was done by a dye produced from the crushed myrtle (*Myrtus communis)* leaves. The net was dyed once in 22 days [6].

Pine bark was collected, dried well and then packed into sacks. Our fishermen used to buy pine bark, usually in Korčula and other parts of Dalmatia where it was sold in shops, both in pieces and in powder [7]. To a lesser extent, it was supplied also in the Boka, from the Vrmac hill. Pine bark was then being crushed to a very fine powder – *krka*. Two days prior to net dyeing, the powder was dissolved in water (in large containers of 200–250 L), and on the day of dyeing it was cooked for 3–4 h. Once the dye cools and when the sediment falls onto the bottom of the container, the liquid was to be sieved and then the net was immersed into the dye and left for several hours. After dyeing, if not used for fishing immediately, the net was immersed into the sea, dried and placed in the cellar. When dying by myrtle, which was used in Bigova, the net was left immersed in the dye for several days [6]. In order to last and be used for longer, the nets needed to be mended and patched, which was done by fishermen themselves, or, rarely, their wives. Needles made of bone, wood or reed were used for mending the nets; later on, iron needles and nowadays, needles made of plastic are used.

Nets used in the Boka were beach seines, purse seines and trawl nets.

Beach seine nets are nets that are towed out to the shore or boat by hands; winch was rarely used for towing. These nets were of different sizes, with smaller or larger mesh size, depending on the target species. The net most frequently used in the Boka was beach seine net *srdelara* with the use of light – candle – intended for pilchard fishing (*Sardina pilchardus*). In addition to pilchard, the catch included anchovy (*Engraulis encrasicolus*), mackerel (*Scomber scombrus*), chub mackerel (*Scomber japonicus*), horse mackerel (*Trachurus* spp.), etc. This net consists of long wings to which two ropes are attached and of the cod-end – *sak*. Wings are 40–43 m in length, cod-end about 6 m, so the total net length is 85.5–93.7 m. In the cod-end part, the drop of *srdelara* is about 18 m and at the end of the wings 8–9 m. Mesh size is 8–10 mm, while towards the center it can be lower by 2 mm (6–8 mm) [7].

Among other beach seine nets that were used in the Boka, it is worth mentioning *geričara, geravica, šabakun, migavica, lokardara*, etc. *Geričara* is a small net used for fishing of sand smelt, *Atherina* spp. It consists of two wings of 8 m long, and of the cod-end – *sak*, which is quite dense and with mesh size barely 5 mm [7]. The total net length is 28–30 m, and its drop is 2.5 m in the middle and up to 1.5 m at the end of the wing, with wooden spear shafts. This net had been used within the bays, ports and breakwaters, where sand smelt would aggregate in dense shoals. *Geravica* is somewhat higher and longer than the previously mentioned net, used for fishing picarel (*Spicara* spp.). Its construction is the same as that of other seine nets – two wings and a cod-end, with 76 m in length and a drop of 7 m in the cod-end and 2.5 m at the end of the wings. This is a dense net, with mesh size usually 9–10 mm, 8 mm in cod-end and it was used at nights. The net has wooden spear shafts at the end of the wings and ropes of up to 80 m in length, for towing. Fishing is performed so that one end of the net is towed from the fishermen's post on the shore, forming a semi-circle and towing back towards the shore. Once the net falls onto the bottom, the fishermen on the shore – six of them – tow the net and pull it out onto the post (Fig. 5). This net was used in winter, from November to March, when sand smelt is on the very bottom. In spring, when sand smelt aggregate into the shoals and move further up from the bottom, the net is not used any more [7].

Fig. 5 Pulling of seine nets to a fishermen's post on the shore (photo by Aleksandar Joksimović)

Migavica is a net that was at first used only around Dubrovnik and then its use spread further throughout the eastern coast [7]. The primary use of this net is for fishing sand smelt in daylight, although it can be used for fishing other species, regardless of the species and size. Wing length in *migavica* is up to 70 m each, with funnel and cod-end length of about 10 m. Mesh size in *migavica* is up to 55 mm in the wings, 12–15 mm in the cod-end [8]. What differs *migavica* from other seine nets is the manner of setting the net – netting wall – as in it, the netting wall is set transversally; while in other seine nets meshes always stay open, in *migavica* the meshes are opening and closing, i.e., the net is "blinking" and that is how it got its name (*miganje* means blinking, winking). Šabakun is a net very similar to migavica, both by construction and by the manner of use, only larger and intended for fishing tuna and other related fish species. This net is rarely used today. Its length is 300–500 m and mesh size 28 mm and above [8].

Encircling purse seine nets are nets intended for pelagic fish. These nets are modification of the seine nets, in order to prevent fishermen being dependent on the shore, sea depth and bottom type, which is characteristic of seine nets. Larger fish quantities can be found mainly in sites that are beyond the area accessible by seine nets, i.e., locations where their use is impossible as a result of large depth and/or inconvenient bottom. Fishing is done usually by three boats, two lamplight boats and one parent boat that can be equipped also with a lamp. Fish aggregation into compact shoals using lights of both boats can last for several hours. After shoals aggregate, nets are thrown. All fish aggregated is placed under the light of one of the lamplight boats that the net is encircling. The parent boat sets the mooring line and one end of the net onto the other lamplight boat and starts throwing the net and

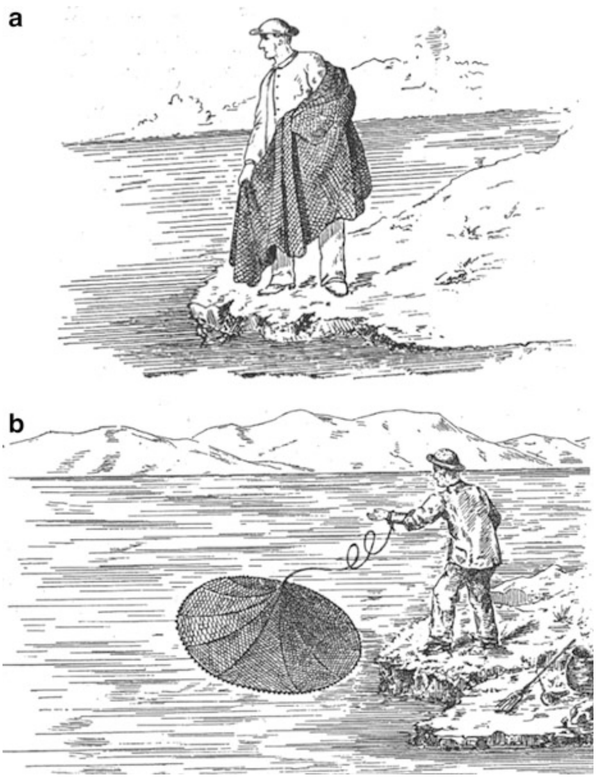


Fig. 6 (**a**) Fisherman preparing to throw the net *ričak*; (**b**) Fisherman throwing the net *ričak* [7]

encircling the shoal by sailing round the first lamplight boat. Once it makes a circle and encircles the entire shoal it is attached to the other lamplight boat and starts closing the net with the purse line. The net is pulled out onto the parent boat until reaching the cod-end containing the fish, which stays between the parent boat and the lamplight boat and is pulled onto the parent boat using the scoop nets [8].

Trawls nets are nets towed along the bottom of the sea and catching all the flora and fauna on its way. The use of these nets in the Boka Kotorska Bay is now prohibited. Even the Austrian authorities prohibited the use of these nets in 1867 due to its negative impact on all marine organisms, but this prohibition was lifted some time later [9].

A small net called *ričak* (cast or throw net) had been used in the Boka, shaped as a circle of around 3 m in diameter (Fig. 6). It is operated from the shore; when thrown out of the hand *ričak* spreads up in a bell shape and falls onto the fish, covering it from above. This net is used for fishing coastal fish species, usually salema (*Sarpa salpa*) and mullets (*Mugilidae*). Lead weights are distributed along the edge of the net so that it sinks and falls onto the bottom quickly and the fisherman then pulls the handline that is surrounding the edge of the net and through the wooden or metal circle in the central part of the net, the edge closes down and the fish stays as if in a pouch [7].

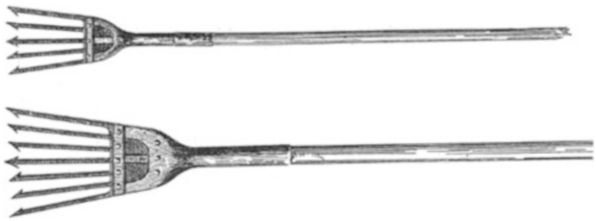


Fig. 7 Spear (harpoon) [7]

Longlines were used to complement the net fishing. The longline consists of a thin but strong line, usually made of well wound hemp, with *pramule* (snoods) with hooks tied at the distance of 4 m. Hook size depends on the target fish species, which usually was quality demersal fish (common pandora – *Pagellus* sp., dentex – *Dentex* sp., gurnard – *Triglidae*), reef fish (grouper – *Epinephelus* sp., conger eel – *Conger conger*, Mediterranean moray – *Muraena helena*), as well as Elasmobranchs (dog fish – *Squalus* sp., rays – *Raja*, *sp* and *Myliobatis* sp.). Longlines are usually set in the vicinity of reefs and submerged rocks as such sites are usually rich in fish. Fishermen would keep such sites secret, particularly if the catch was good. Longlines were placed into oval-shaped wicker baskets, the edge of which was fitted with cork that hooks were pinned into (*kofijer*) [5]. The site where the longline is set is marked with a buoy or a cork piece (*senjal*) that a bell is sometimes attached to in order to enable fishermen to find the longline more easily at nights. Usually, longlines were used for fishing before dawn and the most frequent bait (*njeska*) was pilchard.

Spear (harpoon) is a fork-like iron device with 5–11 prongs, central of which has two lateral barbs, while other prongs have one barb each (Fig. 7). These barbs prevent the fish from sliding back from the spear once the fisherman stabs it. The spear is attached to a wooden pole of up to 5 m in length with a rope at the end of it in order to prevent the spear from being lost in the sea. Spear size depends on the target fish species. Spears are used in the coastal area, in calm weather, when the water is transparent. Fisherman is on lookout from the boat and once he sees the fish, he throws the spear at it and pulls it out of the sea.

Trap is a cylinder-shape fishing gear initially made of wicker or reed, and later on from the metal wire (stainless), and these are used even today (Fig. 8). A trap has one or two funnel-shaped openings that fish can easily enter through, but cannot get out through the same opening so it stays trapped. The traps are made from denser or looser netting (broader or narrower) depending on the target species; the loosest/broadest are spiny lobster (*Palinurus elephas*) traps.

Karola or fishing line is a thread made of wound hemp, flax, cotton or horse hair with a hook attached at the end (Fig. 9). The line is wound onto a *kačak* (a piece of board made of cork or wood that the line is wound on and the hook is pinned into the board). The line can be thicker or thinner, depending on the target fish species, and hook size varies accordingly. One hook can be attached to the end of the line in case of fishing sea bass or sea bream, or several hooks (2–4) when fishing other species. Bait is put on the hook and lead or iron sinker that pulls *karola* to the bottom is put

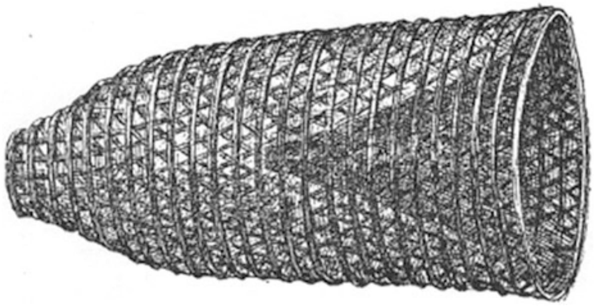


Fig. 8 Trap [7]

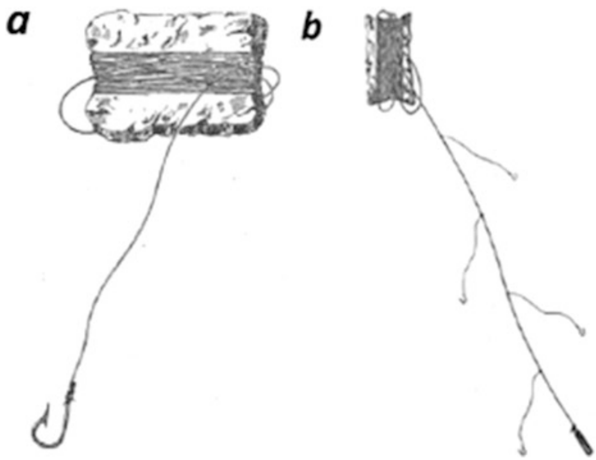


Fig. 9 *Karola* for Sea bass (*Dicentrarchus labrax*) and Sea bream (*Sparus aurata*) (**a**), or other species (**b**) [7]

below the hook. Hook sizes range from 1 to 24, with 1 being the largest. *Karola* is used for fishing small quantities of fish so it is used more by amateurs than by professional fishermen, operating it from the shore or from the boat.

Pendulanje is fishing using *karola* from the boat so that the fisherman tows the line by even repetitive movements while the boat is moving slowly. For fishing squid and cuttlefish *pušća* was used; it was made by fishermen by fitting a small metal pipe to the end of the line to which bait (fish) is attached, at the end of which rounded pins or hooks are placed (Fig. 10). In spring, when cuttlefish spawn, *sipac* was used as well. It is a piece of wood shaped like cuttlefish, lowered to the depth of 1 m (Fig. 11). Once cuttlefish sees it, it jumps and hangs on to it. Fisherman then hooks the cuttlefish by *brankarela* (a pole of 1.5–2 meters in length with several hooks fitted by either rope or wire, used for pulling the catch onto the boat once *karola* or longline are pulled out), or by scoop net and then landed on the boat or the shore.

In the area surrounding settlement Krtole, in Tivat Saline, where waters are very shallow, villagers used to catch fish by making wicker partitions. Once fish enters the encircled area in high tide, that part is closed by wicker gate and fish is then collected in low tide.

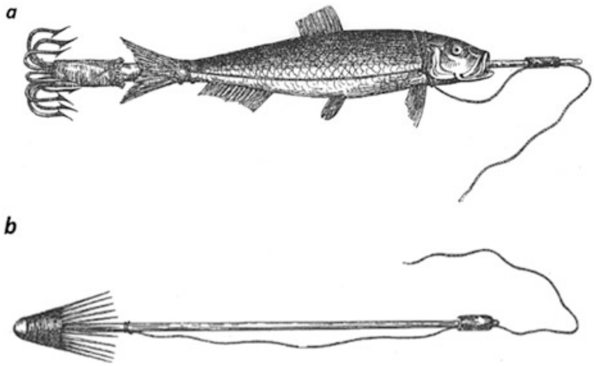


Fig. 10 *Pušća* with hooks (**a**) and rounded pins (**b**) [7]

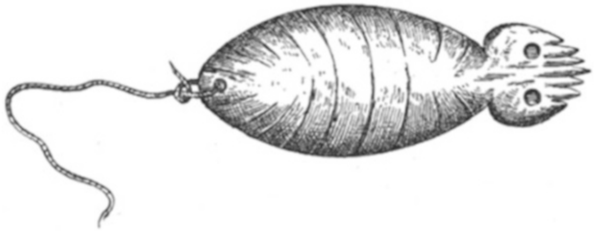


Fig. 11 *Sipac* – bait for *Sepia* spp. [7]

3 Nighttime Fishing Under the Candle Using Seine Nets

Pilchard fishing using lights deserves a special place and a detailed description. As early as during the first rule of the Republic of Venice, pilchard fishing was the most important fishing activity on the eastern coast of the Adriatic. Its significance has only grown over the time, so the Venetian *providur* (ruler) in Dalmatia, Dandolo, in his renowned rulebook of 1809, laid down the principle that pilchard fishing is so important that all other fishing activities are to give way to it, so that it would not be hindered. According to this rulebook, pilchard fishing starts on May 4, the fourth night after the full moon, lasts for 20 consecutive nights, until four nights before full moon. Pilchard fishing would cease for four nights before full moon and four nights after the full moon and then it was resumed for 20 consecutive nights, and so on until the end of August [7]. As stated, the pilchard fishing was allowed on those nights when the moon is either not showing or is showing just in one part of the night. Those moonless nights were known under the name *škuro*-dark. The main dark lasted from May till the end of August. During April and October darks, the Rulebook allowed fishing only of mackerel (*Scomber scombrus*), chub mackerel (*Scomber japonicus*) and horse mackerel (*Trachurus* spp.). The said Rulebook laid down that one seine net may have one light, *gradele* (grid) where wood is set to fire: "*Uno sola cratela sporadi cui si accende il lume"* [5]. This was the only fishery type prudently managed in the eastern part of the Adriatic as it was governed by specific rules issued by the administrative region. These rules applied to Dalmatia and the

Boka, while in Istria pilchard fishing was free as any other fishery type, so fishing was done both in daytime and at nights, in full moon and in the dark. The Rulebook on Fishing, issued later on by the Maritime Government in Trieste in 1906, allowed winter fishing of anchovy, tuna and Atlantic bonito under the lamp in all inland waters to the Verige Strait [10].

Success in fishing using seine nets with light depends on the skills and knowhow of the fisherman, while in all other fishery types it is a matter of fortune. Fishing is done first by one lamplight boat, where earlier, when fatwood was used, crew consisted of two fishermen – one *svjećar* (lamplighter) who fires the fatwood and the other who rows quietly where the lamplighter tells him to. Later on, when other lamp types were used, one fisherman was enough. The lamplighter was maintaining the fire with fatwood for hours and aggregate the fish shoals. Whether fish gathered under the light and how big the shoal is, the fisherman could tell based on the bubbles surfacing, jumping of fish, visual noting of fish and their shimmering. The lamplighter was setting off several hours earlier, while other fishermen were sleeping and then gathering at the call of *patrun*, i.e., the owner of the boat and the net. Other fishermen were met at the fishermen's post and the lamplighter was moving the boat with the light and the aggregated fish slowly towards the fishermen's post. This was done very quietly, the rows had to be in the water all the time in order to prevent scaring the fish away, since, as fishermen say "so many *drača* (bones) in a pilchard, that many minds in it". Once the lamplight boat approaches the fishermen's post, shoal encircling was began. One end of the net was kept by fishermen on the post and the other boat was placing the net into the water, forming a semi-circle around the lamplight boat until the other end of the net comes to the post where the other group of fishermen takes it over. The fishermen on the post were towing both ends of the net evenly and the lamplight boat with the fish enclosed in the central part of the net was approaching the fishermen's post. Once the fishermen towed the net almost until the end, the lamplight boat was rapidly taken over the cod-end beyond the net, and all the fish, following the light, ended up in the cod-end.

Over the years, lighting means have changed. The wood rich in resin and burning easily – fatwood – was used since ancient times. Pine – *Pinus* spp., then fir – *Abies* spp. and juniper – *Juniperus* wood were commonly used as fatwood. This lighting method was used in fishery for the longest period, until the end of nineteenth century, and that is one of reasons why forest lands in Dalmatia and on the islands are denuded. Namely, a single seine net required 100–120 m^3 of wood for a single summer. In Krašići, *fraška* was used instead of fatwood; it is a bundle of strawberry tree *Arbutus unedo* branches, growing in the area. Lamplight boats had metal *gradele* (grid) fitted onto the bow, where wood was put on fire [6]. The lamplighter would prepare and take as much wood as he would need for one night, set off to the site rich in fish – according to his experience – and then light a fire that he would maintain for the following several hours.

The next step in lighting development was the use of oil lamps. Thus, in 1853, a Danish society conducted a number of trials with oil use on this coast [5]. There were numerous oil lamp manufacturers and models (Heinz from Költing in

Denmark, Lepante, Sautter and Lemonnier from Paris, etc.). However, large quantities of oil were used, which was financially demanding and at the same time, it created large quantities of smoke and soot, so both fishermen, the boat and the gear were completely sooty and dirty after fishing, so this lighting method was not used for long.

With the invention of acetylene lamps, the lamplighters' work became much easier. Acetylene was used worldwide for various purposes, and its use in fishery began as of 1898. That year, Mr. Ivan Dellaitti from Senjska Rijeka designed a lamp using acetylene gas, which was fitted to the fore part of the boat, instead of old lamps [7]. Acetylene lamps were further developed and improved, and in this region, the best known was Verka, designed by Ivan Pastrović in 1911. The common name for these lamps in the Boka was *garbitača*. Each *garbitača* had 15–20 *bakuči* or *rubineti*, valves that released the gas into the lamp and the light intensity depended on the number of *bakuči*. While lighting, the lamplighter has been opening or closing as much *bakuči*, to obtain the intensity of light that he needed [5].

Further step in lighting development was design of lamps burning compressed gas, where oil is not burning directly through a wick, but the gas generated by air pressure. The first of such lamps appeared on this coast in the beginning of twentieth century, supplied under German reparations, *Petromax* brand. The Fishing Rulebook for the Boka Kotorska of 1906 lays down that in fishing with seine nets only one lamp of no more than 400 candles may be used [5].

These were followed by gas lamps, which were in use for long, and are used even today. The last stage in lighting development is used of electric lamps supplied with power from a power generator.

As already stated above, seine nets were pulled out at the fishermen's post – a part of the sea and the shore where fishermen place their nets in the water and tow them out (Fig. 12). In those places, the bottom of the sea has to be clean, to prevent the net from tearing or hook up for something – the so-called domesticated posts. The names of the posts date back to long ago, and usually they wore the name of a site on the shore or some other landmark. These are the names of some of the posts: *Pod Anetu, Pod Milinovića, Planika, Veliki Jamac, Mali Jamac, Pod Vodu, Dražin Vrt, Bajova Kula*, etc. Regardless of the fact that by the World War II some parts of the shore, including the sites where the posts were located, were private property, fishermen were entitled to fishing freely and take out their nets in each of the posts [4]. The order in which the posts were used was determined by the Port Master's Office by drawing lots – *brušketa*. If needed, port authorities would clean the posts once a year. When drawing lots, only the so-called domesticated posts were taken into account, while for "wild" posts no lots were drawn and they could be used by all. Each fisherman with a fishing permit received a *kartelon* specifying from which post he would fish during one *škuro*-dark. The fisherman would have to occupy the post until 9 p.m. by anchoring his boat or by leaving the nets or fish crates. In the village of Muo, fishermen agreed among themselves on the use of posts for tuna fishing by drawing lots and port authorities did not intervene. The authorities would

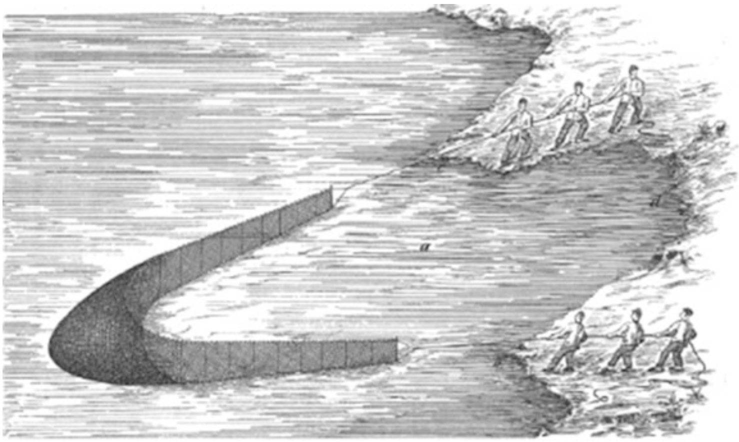


Fig. 12 Pulling of beach seine net to fisherman's post [7]

intervene only when pilchard would be caught outside the fishing season, and in those cases fishing had to stop [4].

Over the past century, particularly over the past decades, due to intensive construction and tourism development, a large number of fishermen's posts have been destroyed. All the remaining fishermen's posts – 107 in the entire Bay – are now protected, recognized by the Law and properly marked [11].

On the territory of the Boka Kotorska Bay there used to be a fishery guard, hired by the Port Master's Office in Kotor. The guard wore uniform and was paid from the funds collected from issuing of fishing permits. At the beginning of the fishing season, the guard would notify the *patruni* that he would come to inspect the nets and mesh sizes. Mesh size on the cod-end could not be less than 9 mm and if a fisherman breached some of the regulations in force, the guard would set and collect the fine on the spot. In 1930s, the fine could be up to 120 dinars (at that time, one kilogram of pilchard was 3–4 dinars, of high quality fish 15–18 dinars), and this was a relatively mild sanction compared to the suspension of the fishing permit for the upcoming period [5].

4 Relations in Fishery

Fishermen engaged in fishing either individually or grouped in crews. A fishermen crew consisted of a *patrun* and several fishermen; one crew was formed by 6–20 fishermen. Usually, the crew consisted of members of the broader family of the *patrun* and other fishermen from that town. Fishermen's sons, preparing to become fishermen were going together with them, as this profession was passed from father to son, from one generation to another. *Patruni* were owners of the boat, fishing gear and holders of the fishing permit and only wealthy fishermen could become *patruni*. They went to fishing together with the rest of the crew and in nighttime fishing with seine nets they usually were the lamplighters. In cases when a *patrun* would be prevented from going fishing, he would usually be replaced by the next of kin, or some other person designated by him. Each fisherman in the crew had his own duties and the work of the entire crew was quite synchronized. Income was divided among fishermen on the basis of their duties in the crew.

Income used to be divided immediately after catch, particularly if fishermen worked for a share of the catch, and sometimes only at the end of the *škuro*-dark. One half of the catch, or income, always belonged to the *patrun*, and the other half was divided among other fishermen in the crew and *patrun* would again had a share in it. The distribution was not equal, it depended on duties the fisherman had during fishing. Due to demanding work, the lamplighter would get one share and a half, meaning the income for "one and a half mate", while boys preparing to become fishermen, as well as fishermen not performing well, received one quarter, or "one quarter of a mate". In some parts of the Boka, in Bijela, for example, *patrun* would take up to 70 % of the catch of income, by taking first a half of the income as the owner of the boat and nets, and then took a share in the other half just like other fishermen, and then again take a share for the boat and the nets. As a result of such attitude of *patruni*, a fishermen mutiny was organized in Bijela in early twentieth century, which resulted in the same method of distribution of catch and income that was used in other parts of the Boka. *Patrun* was the one who set the price at which the fish would be sold, who would sell it and where it would be sold, and the income would be shared. Fish was sold directly from the boat that was sailing slowly along the shore and fishermen would call buyers by yelling "fish, fish". Another way of sale was in *peškarija* (fish market) in Kotor, Risan and Herceg Novi. At the *peškarija,* every fisherman had his own selling point. Fish sold in *peškarija* had to be classified by species and put in boxes and used to be controlled by the municipal doctor.

Each town in the Boka used to have *patruni* and crews (Fig. 13). The crew of Božo Jančić from Njivice was interesting, as its crew included also female family members. This crew used the fishermen's post called *Pećina* (Cave, which exists even today) and as that post is remote and used only by members of this crew, they did not take part in lot drawing or had any *kartelon*. This is one of very few cases where women took part in fishing as their work usually included fish salting, nets mending and making. Women from Bigova had the task of selling fish that they carried to the *peškarija* in Kotor on their backs or on donkeys.

In early twentieth century, fishermen began forming cooperatives (Fig. 14); thus in 1906, the cooperative in Baošići was formed, which had 44 members. In the village of Muo, fishermen cooperative of 27 members was formed the same year, while in the village of Prčanj a cooperative of 37 members was formed in 1925. In Bigova, 14 fishermen formed the cooperative in 1928, and in Strp, a cooperative of 10 fishermen in 1933. After the World War II, all the cooperatives joined the Association of Fishermen Cooperatives, based in Herceg Novi. Today, the only operational cooperative in the Boka Kotorska Bay is the one in Baošići, under the name *Kiril Cvjetković*.

Fig. 13 Crew of fisherman after fishery (photo from private collection of fisherman Anđelko Ivović)

Fig. 14 Fishery of small pelagic fishes (photo from private collection of fisherman Anđelko Ivović)

5 Current State of Affairs in Fishery in the Boka Kotorska Bay

Today, marine fishery is governed by the Law on Marine Fishery and Mariculture (Official Gazette 56/2009, 47/2015) and related Rulebooks. All professional fishermen have to be registered as businessmen in the Central Register of the Business Court of Montenegro, and pay withholdings, contributions and insurance.

With a view to protecting the fish stocks and biocoenoses in the Boka Kotorska Bay, the law prohibits use of certain types of fishing gear within the Bay; thereby the Bay was to a certain extent proclaimed a fisheries restricted areas. In the area of the Boka Kotorska Bay fishing with the bottom trawls, pelagic trawls and encircling purse seine nets of large-scale fishery is prohibited [12]. Only fishing by encircling purse seine nets with a drop of up to 70 m and up to 400 m in length is permitted at the entrance of Boka Kotorska Bay from the village Rose to the Cape Arza along the entire eastern shore at the distance of up to 1000 m as well as in the area around the Island Lastavica – Mamula [13]. In this way, only the small commercial fishing gear may be used within the Bay, such as set nets, seine nets, longlines, traps, spears and harpoons. Minimum mesh sizes are set for specific nets in order to prevent catch of juveniles, as well as the maximum length of the net that may be cast into the sea. Length of a single set net in the Bay may not exceed 160 m and a fisherman may have two or five nets, depending on whether he is engaged in small-scale or large-scale commercial fishing [14]. For all these gear types, the law lays down also the period in which their use is allowed or prohibited in order to protect the species in spawning periods. The law and related Rulebooks lay down that additional measures or protection such as full prohibition of fishing in certain areas or in specific parts of the year, full prohibition of use of certain gear and other management measures may be introduced at proposal of a scientific institution and based on scientific research, with a view to protecting fish stocks. Fishery resources management in Montenegro is based on the principles of sustainable fishery in order to prevent overfishing of certain species and hence distortion in the entire ecosystem community.

As a country in the process of accession to the European Union, Montenegro is bound to accept, incorporate into its legislation and implement all the regulations and rules of the Common Fishery Policy. Some types of fishing gear that have been in use in Montenegro for centuries, which are used mainly in the Boka Kotorska Bay, are not fully harmonized with the EU legislation. This particularly refers to the use of seine nets for pilchard and anchovy. As stated in previous chapters, this fishing gear has centuries' long tradition in this area, a strong sociological and culturological significance for the population of the Boka Kotorska Bay. At the same time, fishing with seine nets has major significance for tourism as well, primarily because it provides fresh, healthy food from the sea, rich in Omega 3 fat acids, and it is at the same time a tourist attraction, since this fishing method, involving a large number of people, is quite attractive to tourists. Significance of fishing by seine nets is recognized by the Fishery Development Strategy of

Montenegro [15], which states that efforts would be made to preserve this traditional fishing manner on the principle of sustainable development through drawing up of a management plan for use of seine nets. The management plan will set the maximum number of seine nets to be used in the Bay and continuous supervision and control of the catch would be provided, as well as monitoring of other biocoenoses as regards use of seine nets, particularly as regards biocoenoses of marine flowering plants (*Posidonia oceanica*).

The number of fishermen using traditional fishing gears today has been decreasing. Intensive tourism development and construction of tourist facilities on the coast has resulted in reduction in number of fishermen's posts, while cruising tourism development resulted in increase of noise and water turbidity, which affects fish stocks. Just around 20 fishermen in the entire Bay use seine nets, a few of them use *ričak* nets, etc. In order to enable use of this traditional fishing gears in the future it is necessary to ensure protection of fish stocks; otherwise, if there is no fish, there will be no fishermen and seine nets and this fishery type would just live in the memories of older fishermen of this region.

Impact of fishery on marine environment cannot be neglected in any part of the world, as well as in Boka Kotorska Bay. According to marine scientists main reasons for decreased biomass of fish stocks are climate changes, pollution and fishery. Boka Kotorska Bay is already protected from use of fishing gears that has most negative effect on marine environment, which are bottom trawl nets [12]. Most numerous fishing gears used inside the Bay are set nets (trammel nets and gillnets) which are very selective and have minimal negative effects on marine environment. Those nets are set to certain bottom, they are fixed and do not influence on other organisms or biocoenoses of marine flowering plants (*Posidonia oceanica*), except on target species of fishery resources (fish, crustaceans and cephalopods). Mesh sizes on those nets are determined by legislation and they depend on target species and period of year [14] and they are already fully harmonized with the EU legislation. Other types of nets used in Boka Kotorska Bay that can have more significant impact on the marine environment are beach seine nets. Those nets are pulled to the fishermen's post on the shore, during these fishing operations biocoenoses of marine flowering plants (*Posidonia oceanica*) can be endangered, which is the main reason why EU regulations prohibit the use of those nets in the areas inside 3 nautical miles from the cost (except in certain cases) [16]. In the Boka Kotorska Bay beach seines are used for centuries and pulled always on the same places, fishermen's post, which are strictly localized and accurately defined dimensions. In this way impact on the marine environment and *Posidonia oceanica* is reduced to a minimum. As stated in previous chapters, maximal number of licences for this type of fishery is determined and management plan will be developed in order to monitor impact of this type of fishery on fishery stocks and marine environment, and to prevent any possible negative effects [15]. Considering all mentioned in this chapter it can be concluded that fishery in the Boka Kotorska Bay has no significant impact on the environment, since most of the fishing gears used are very selective and influence only on target species of fishery resources.

The inland part of the Boka Kotorska Bay, the Risan–Kotor Bay, was proclaimed the world natural and cultural heritage site by the UNESCO Charter. On the basis of this decision, our society has a major duty to protect the centuries' old culture of living in this area. Traditional fishery, as the style of living in the Boka, obliges us to make this activity a postcard of history kept for the generations to come.

References

1. Nakićenović S (1913) Boka. Belgrade: CE3B
2. Zečević D (1954) Prilog proučavanju ribolova u Mulu, ribarskom naselju u Kotorskom zalivu. Glasnik Etnografskog Instituta SANU, Beograd, vols II–III
3. Franetović D-B (1960) Historija pomorstva i ribarstva Crne Gore do 1918 godine. Istorijski Institut Republike Crne Gore, Titograd
4. Uljarević V, Tomić A (1973) Ribarske pošte u Kotorskom i Risanskom zalivu. Godišnjak Pomorskog Muzeja, vol XXI
5. Radojičić D (1983) Fishing in the Bay of Kotor from the 19th century to the present day. BOKA 15–16:193–235
6. Radojičić D (1986) Muzeološka valorizacija tradicionalne ribarske opreme u Boki Kotorskoj. BOKA 18:85–92
7. Lorini P (1902) Ribanje i ribarske sprave pri istočnim obalama Jadranskoga mora. Naklada Školskih Knjiga, Beč
8. Cetinić P, Swiniarski J (1985) Alati i tehnike ribolova. Logos, Split
9. Belamarić V (1909) Priručnik za ribare, ljubitelje ribarstva i ribarskog obrta, Šibenik
10. Pravilnik za ribolov u Boki Kotorskoj (1906) Izdala c.kr. Pomorska Vlada u Trstu s odlukom 11. ožujka
11. Pravilnik o načinu korišćenja, održavanja, zaštite, označavanja, kao i dužini obale, nazivu i mjestu ribarske poste. Official Gazzete of Montenegro, 8/2011, 45/2015
12. Law on marine fisheries and mariculture. Official Gazette of Montenegro, 56/2009
13. Rulebook on terms, restrictions and order in fishing operations in specific fishing areas. Official Gazette of Montenegro, 8/2011
14. Rulebook on basic construction-technical characteristics, methods of use, time, purpose, quantity and type of fishing tools and gear that is permitted for use in large and small-scale commercial fishing. Official Gazette of Montenegro, 8/2011
15. M. o. A. a. R. Development (2015) Fisheries strategy of Montenegro 2015-2020. Podgorica
16. EC (2006) COUNCIL REGULATION (EC) No 1967/2006 concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea. Off J Eur Union 409:11–85

Occurrence and Distribution of Crustacean Decapoda in Boka Kotorska Bay

Olivera Marković, Slavica Petović, Zdravko Ikica, and Aleksandar Joksimović

Abstract An annotated species of crustacean Decapoda list is provided for the area of Boka Kotorska Bay, based on the available literature. Review of the relevant literature showed that the number of the species known in this area is 62. Two of these species are recognized as Atlanto-tropical immigrants. All species were collected using trawl, dredge, grab bottom sampler, gillnets, as well as scuba-diving techniques. Description of each species gives the valid scientific name and vernacular, common names, literature, distribution and findings in Boka Kotorska Bay, Adriatic distribution, and some remarks as well as their potential commercial interest for fishery. Most of these species have a wide distribution range, including the whole Mediterranean Sea.

Keywords Annotated list, Boka Kotorska Bay, Crustacean Decapoda

Contents

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1 Introduction

1.1 Study Area

The Boka Kotorska Bay is situated in the southern part of the eastern Adriatic, and according to Lepetić [1] it represents the most sinuous part of the Adriatic coast. The geographical position of this bay is determined as follows: 42°31′00″N, 42°23′32″S, 18°46′32″E, and 18°30′29″W.

This bay is subdivided into four smaller bays, namely, the Kotor Bay, the Risan Bay, the Tivat Bay, and the Herceg Novi Bay (Fig. 1). The bays of Herceg Novi and Tivat are connected by the Kumbor Strait, and the Kotor and Tivat Bays are joined by the Verige Strait (width 340 m, length 2,300 m). The Bay of Tivat is the most extensive part of Boka Kotorska reaching the depth of 48 m in its southern part but considerably shallower in its eastern part. It is connected with the Herceg Novi Bay (depth 47 m) by the Kumbor Strait (depth 43 m, the minimum width 730 m) [2]. The entrance to the Boka Kotorska, also called the Strait of Oštra, is closed by Cape Oštra from the west and by Cape Mirište from the east. The innermost part of the bay, near Kotor, is at 15 nautical miles from its entrance. Given its depth, the whole Kotor Bay belongs to coastal or littoral system.

It is hypothesized that the Boka Kotorska Bay, having a coastline 105.7 km long, covering an area of 87.3 km^2, containing a volume of 2.4×10^6 km^3 of water, and having a maximum depth of 60 m, was formed by fluvial erosion [3]. In each bay

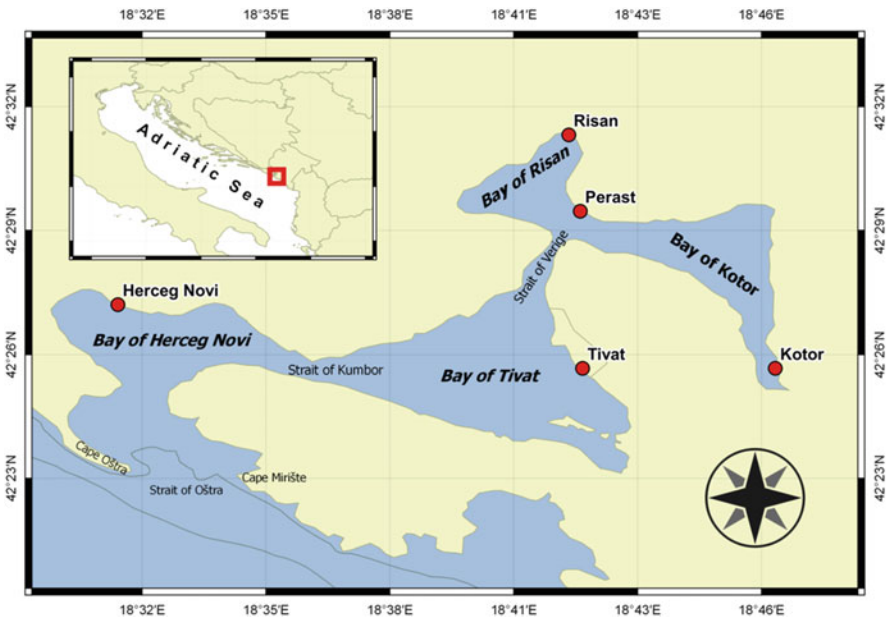

Fig. 1 Map of the Boka Kotorska Bay

the depth increases toward the central part, except in the Kotor Bay where the maximum depth is near the northern coast (Perast). According the latest data, the average depth of the Boka Kotorska Bay is 27.6 m, and its maximum is 64 m (Kotor Bay) [4].

It is well known that Boka Kotorska Bay has a specific position in the Adriatic Sea. This specificity is the result of not only its geographical position but also biotic and abiotic environmental factors. Therefore, life conditions in this bay differ considerably from those of the open sea part of the Adriatic [5]. The hydrographical measurements (temperature, salinity, transparency of the sea, and mechanical composition of the sea bottom) may have considerable and different significance in distribution of zoobenthos in the Boka Kotorska Bay.

The features of the submarine relief may be grouped in two main categories: the first is the continental shelf and the second is the deeper part of the bay [5]. Karaman and Gamulin-Brida [6] during their investigations found that the structure of Boka Kotorska Bay littoral shelf bottom is of terrigenous and mineral origin. The central parts of the Boka Kotorska Bay are covered by soft terrigenous mud with more or less detrital elements. The inshore zone of the Kotor, Risan, and Herceg Novi Bays are of sandy mud. The eastern part of the Kotor Bay bottom is rich in *Zostera*, and the northeast inshore parts of the Herceg Novi Bay and Igalo with the inlet Njivice showed significant concentration of *Cymodocea nodosa*, *Posidonia oceanica*, and *Zostera marina* [5].

Research of benthic biocoenosis in the Boka Kotorska Bay was done in 1970 by Karaman and Gamulin-Brida [6]. They found the following:

- The biocoenosis of the coastal terrigenous ooze as well as elements of other biocoenosis on the solid and mobile substrata
- Elements of the coralligenous biocoenosis
- Elements of the biocoenosis of beds of *Posidonia* (Fig. 2)
- Elements of the biocoenosis of beds of *Zostera*
- Elements of the biocoenosis of beds of *Cymodocea* (Fig. 3)
- Elements of the biocoenosis of photophilic algae (Fig. 4)

1.2 Historic Review

Adriatic decapod crustaceans (Crustacea: Decapoda) have been the subject of numerous investigations [7]. The first documented insights into the Adriatic decapod fauna were presented at the beginning of the sixteenth century by Giovio (syn.: Jovius), whose first documented observations were made in 1524 [8]. According to Merker-Poček [9], the first papers on decapod crustaceans and their records in the Adriatic date back to 1792 [10] and 1863 [11]. Later, Pesta [12] gives a monograph on decapod crustaceans of the Adriatic "Die Decapodenfauna der Adria" citing also their records. They made considerable contribution to knowledge not only with regard to the decapod Crustacea in the Adriatic Sea and the Mediterranean but also

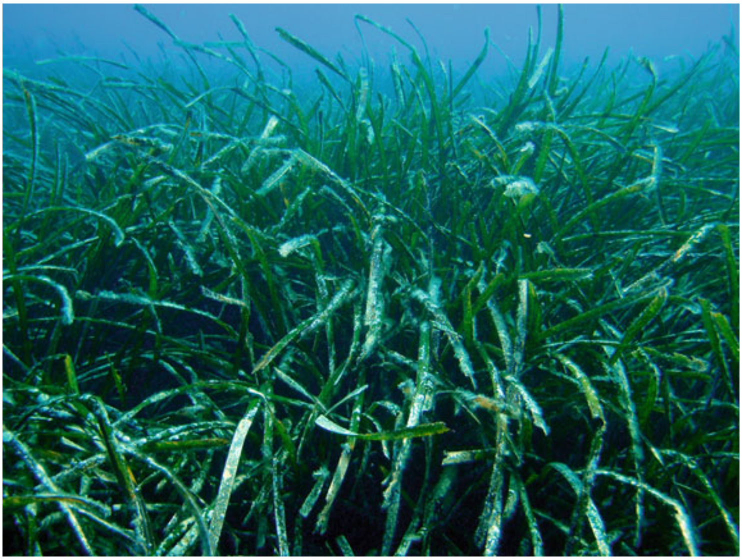

Fig. 2 *Posidonia* beds in the Boka Kotorska Bay

Fig. 3 *Cymodocea* beds with fun mussel, *Pinna nobilis* in the Boka Kotorska Bay

in general [13]. From then on, the intensive research of Adriatic decapods begins (Karlovac [14–17], Lutze [18]; Kurian [19]; Holthuis [20]; Karaman [21]; Riedl [22]; Števčić [23]; Števčić and Forstner [24]; Jukić [25]; Merker-Poček [26–28]; Froglia [29]).

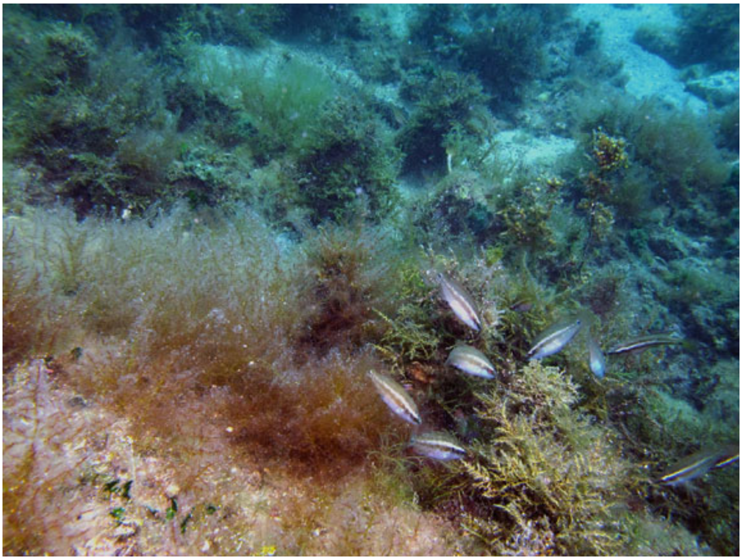

Fig. 4 Beds of photophilic algae

After the publication of the first list of the Adriatic decapod fauna by Števčić [30], several publications increased the number of decapods species known in this area to 203, representing 62.08% of the Mediterranean fauna [31]. The last complete checklist of the Adriatic decapod species was published in 1990 [13] and has thereafter been update twice (Števčić [32, 33]). So far, 241 decapod species have been noted for the Adriatic Sea [34].

Although there is plenty of information on the decapod crustaceans in the Adriatic Sea, there are very few reference works regarding the Boka Kotorska Bay. Only a few papers have addressed this topic.

The existing information on decapod crustaceans in the Boka Kotorska Bay is very limited. The first records of the marine decapods in the Boka Kotorska Bay were published by Karaman and Gamulin-Brida [6]. They recorded 18 species from 12 families. Merker-Poček [9, 35] gives quantitative and qualitative analysis of crustacea Decapoda in biocoenosis in the area of Boka Kotorska Bay. This author registered 39 species from 18 families. After that, Stjepčević and Parenzan [36] reported 33 species for Kotor and Risan bays, of which seven have been already reported in the Kotor Bay and the Risan Bay, while 15 have not been previously reported for the Boka Kotorska Bay.

The main objective of this chapter is to put together all previously published information in an attempt to develop an updated checklist of the decapods occurring in Boka Kotorska Bay.

2 Material and Methods

According to the available bibliographic information, the decapod material has been collected by trawl, dredge, and Petersen grab bottom sampler covering an area of 0.50 m^2 as well as scuba-diving techniques. Karaman and Gamulin-Brida [6] as well as Merker-Poček [9, 35] give the data about decapod species which were collected during the first research survey in the Boka Kotorska Bay. That survey was carried out in 1964/1965 with the research vessel "Atlant." Its trawling speed was 2.5 knots, while the dredge was towed for only 10 min at the same speed. To improve accuracy, when the grab was less than one-half full of collected material, the sampling was repeated. In stations 3K, 4K, 7K, and 8K, the hauls were 50 min long, due to the rocky bottom. Material was collected four times a year. During the research surveys, decapod samples were collected from nine stations. Sampling stations named 1K and 2K were located in the Kotor Bay, 3K in the Risan Bay, 4K in the Verige Strait, 5K and 6K in the Tivat Bay, and 7K, 8K, and 9K in the Herceg Novi Bay. The decapod sampling stations, as reported in the literature, are shown in Fig. 5. Bottom dredging haul stations were the same as for bottom trawling. Material collected from the dredge and Petersen grab bottom sampler was rinsed through the fine sieve and preserved in 5% formalin solution. Material collected by trawl was separated by groups, and decapod crustaceans were preserved in 75% ethyl alcohol.

Stjepčević and Parenzan [36] used dredge to collect decapod species only in the Kotor and Risan Bays. The dredging haul numbers carried out in each bay are presented in Fig. 6.

Two recent alien species were caught by different types of gillnet in the Tivat Bay (Fig. 7). The specimens were brought to the Laboratory of Ichthyology and Marine Fishery in the Institute of Marine Biology. After identification, the specimens were deposited in the Ichthyological Collection of the institute.

3 Results

The Boka Kotorska Bay decapod fauna shows a high diversity. The current information regarding families and their pertaining numbers of genera and species is presented in Table 1.

The following information is given for each species: valid name, common names, literature in which these species were mentioned, distribution in each bay, Adriatic distribution according to Števčić [13], remarks, and for some of them interest to fishery.

In this checklist the families are classified according to WoRMS [37]. Within the families, genera and species are listed alphabetically.

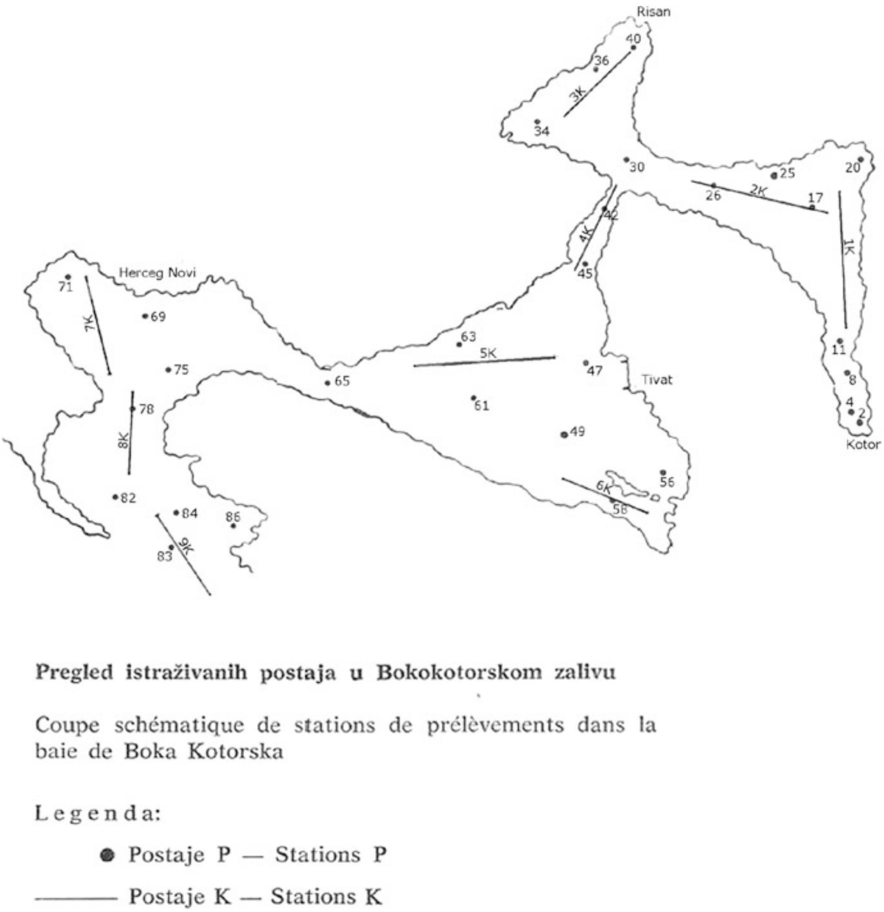

Fig. 5 Decapod sampling stations (collected by bottom trawl and bottom dredge) in the Boka Kotorska Bay according to literature of Karaman and Gamulin-Brida [6]

3.1 List of Species

Order Decapoda Latreille, 1803

Suborder Dendrobranchiata Spence Bate, 1888

Superfamily PENAEOIDEA Rafinesque, 1815

Family Penaeidae Rafinesque, 1815

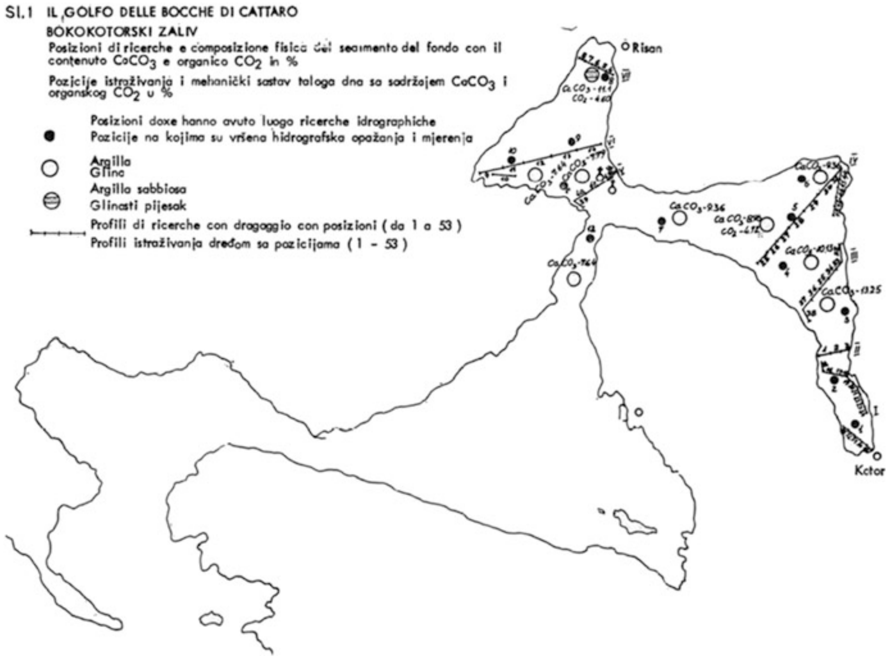

Fig. 6 Decapod sampling stations (collected by dredge) in Kotor Bay and Risan Bay according to literature of Stjepčević and Parenzan [36]

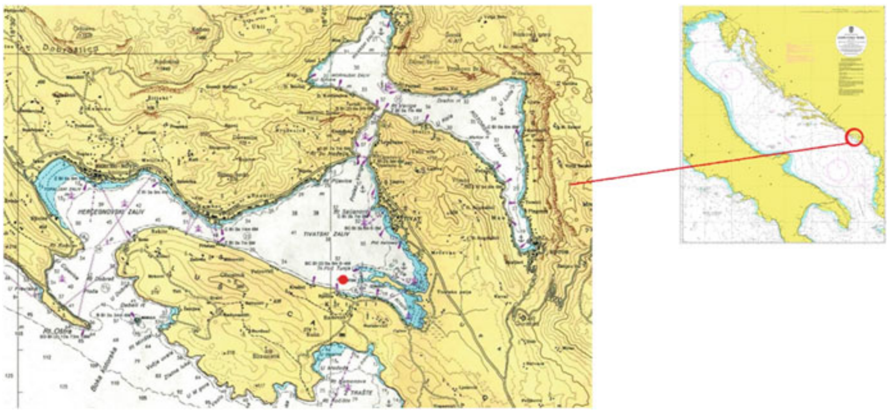

Fig. 7 Map of the Boka Kotorska Bay showing the site (*full red circle*) where the alien species (*Farfantepenaeus aztecus* and *Callinectes sapidus*) have been collected

Table 1 Decapod fauna from the Boka Kotorska Bay: number of genera and species

	Families	No. of genera	No. of species
Suborder Dendrobranchiata	Penaeidae	2	3
	Sicyoniidae	1	1
Suborder Pleocyemata			
Infraorder Achelata	Palinuridae	1	1
Infraorder Anomura	Galatheidae	1	4
	Munididae	1	1
	Porcellanidae	1	3
	Diogenidae	3	3
	Paguridae	2	5
Infraorder Axiidea	Callianassidae	1	1
Infraorder Brachyura	Calappidae	1	1
	Dorippidae	1	1
	Ethusidae	1	1
	Eriphiidae	1	1
	Goneplacidae	1	1
	Leucosiidae	2	3
	Epialtidae	2	3
	Inachidae	2	5
	Majidae	2	3
	Parthenopidae	1	1
	Pilumnidae	1	1
	Polybiidae	1	4
	Portunidae	2	2
	Xanthidae	1	1
	Pinnotheridae	1	1
	Dromiidae	1	1
	Homolidae	1	1
Infraorder Caridea	Alpheidae	1	2
	Palaemonidae	2	3
	Processidae	1	1
Infraorder Gebiidea	Upogebiidae	1	3
	Total	40	62

Parapenaeus longirostris (Lucas, 1846)

Common names:	Kozica (Mne), deep-water pink shrimp (E), Gambero rosa (I), Crevette rose du large (F)
Literature:	Merker-Poček [9]
Distribution:	Sampled by trawl haul only in Herceg Novi Bay on 60 m of depth in very small quantities (Fig. 8)
Adriatic:	This shrimp is reported from the entire area except the northern part [13] and, according to Kasalica [38], occurred in large quantities on continental shelf of South Adriatic (Montenegrin

Fig. 8 Deep-water pink shrimp, *Parapenaeus longirostris* (Lucas, 1846)

	territorial waters) between 20 and 200 m on mud and sandy mud bottoms.
Remarks:	This species occurs in bathyal communities "*Nephrops norvegicus–Thenea muricata*" at depths ranging from 60 to 750 m [13].
Interest to fishery:	Commercially very important species in trawl fishery of Montenegro.

Penaeus aztecus Ives, 1891 = *Farfantepenaeus aztecus* Ives, 1891

Common names:	Astečka kozica (Mne), northern brown shrimp (E), mazzancolla tropicale (I), crevette royale grise (F)
Literature:	Marković et al [39]
Distribution:	Sampled by gillnet called "bukvara," which has a 22 mm mesh size, only in Tivat Bay at a depth between 20 and 25 m (Fig. 9).
Adriatic:	So far, this is the only record of this alien species in the Adriatic.
Remarks:	This species occurs around east side of Mexico and the USA.
Interest to fishery:	In areas where it is commercially caught, it is very important. Marketed mostly frozen and fresh; a small fraction of the catch is canned; juvenile and subadult shrimp are mainly sold as bait. This species has been farm raised on a small scale [40].

Fig. 9 Alien species, northern brown shrimp, *Penaeus aztecus* Ives, 1891 from the Tivat Bay

Penaeus kerathurus (Forskål, 1775) = *Penaeus trisulcatus* Leach

Common names:	Tigrasti gambor (Mne), Caramote prawn (E), mazzancolla (I), Caramote (F)
Literature:	Karaman and Gamulin-Brida [6], Merker-Poček [9, 41]
Distribution:	Karaman and Gamulin-Brida [6] as well as Merker-Poček [41] sampled this species by trawl in all bays, except in Kotor Bay, at depth of around 40 m on stations 3K, 6K, and 8K.
Adriatic:	According to Števčić [13], this species is known from the entire area but more frequent in the southern part, especially near Neretva river mouth. Merker-Poček [41] found this species off the mouth of the Bojana river and in Boka Kotorska Bay.
Remarks:	Prefer brackish waters. According to the Article 18, item 3 of the Law on Marine Fisheries and Mariculture of Montenegro, the Ministry of Agriculture, Forestry, and Water Management has issued the order on prohibition of catch and trade in fish juveniles, undersized fish, and other marine organisms (OG of Montenegro No. 8/11). As the order specifies, it is forbidden to catch and place on market Caramote prawn individuals with total lengths of less than 10 cm.
Interest to fishery:	Commercially very important species (Fig. 10)

Fig. 10 Caramote prawn, *Penaeus kerathurus* (Forskål, 1775)

Family Sicyoniidae Ortmann, 1898

Sicyonia carinata (Brünnich, 1768)

Common names:	Kamena kozica (Mne), Mediterranean rock shrimp (E), Sicionia (I), Boucot méditerranéen (F)
Literature:	Stjepčević and Parenzan [36]
Distribution:	Reported at depth between 3 and 4 m on coarse sand bottoms and between many algae in Kotor Bay (from Dobrota to Prčanj).
Adriatic:	According to Števčić [13], this species is reported from the entire area.
Remarks:	This was the first record of this species in the Boka Kotorska Bay.

Suborder Pleocyemata Burkenroad, 1963

Infraorder Achelata Scholtz & Richter, 1995

Family Palinuridae Latreille, 1802

Palinurus elephas (Fabricius, 1787)

Common names:	Jastog (Mne), common spiny lobster (E), Aragosta (I), Langouste rouge (F)
Literature:	Merker-Poček [9]
Distribution:	This species was found on rocky bottoms near coast in Herceg Novi Bay and in Kotor Bay, in Orahovac despite low and changeable salinity (Fig. 11).
Adriatic:	Reported in the middle and southern areas.
Remarks:	According to Merker-Poček [9], this species is endemic for the Mediterranean.
Interest to fishery:	It is of high commercial value. Because of high prices on the market, spiny lobster was intensively fished and became a very vulnerable species.

Fig. 11 Common spiny lobster, *Palinurus elephas* (Fabricius, 1787)

Infraorder Anomura Mac Leay, 1838

Superfamily Galatheoidea Samouelle, 1819

Family Galatheidae Samouelle, 1819

Galathea dispersa Bate, 1859

Common names:	Strigljač (Mne), squat lobster (E)
Literature:	Stjepčević and Parenzan [36]
Distribution:	Recorded in Kotor Bay, near Prčanj, at a depth of 32 m, on clay mud bottom rich with Ophiuroidea.
Adriatic:	Recorded on few localities throughout the entire area.
Remarks:	Stjepčević and Parenzan [36] were of the opinion that *Galathea nexa* which was found by Karaman and Gamulin-Brida [6] has been confused with *Galathea dispersa*.

Galathea intermedia Lilljeborg, 1851

Common names:	Hlapić (Mne), squat lobster (E)
Literature:	Karaman and Gamulin-Brida [6], Merker-Poček [9, 35], Stjepčević and Parenzan [36]
Distribution:	This species was found on Verige Strait and in Tivat Bay, at depths ranging from 4 to 30 m on oysters and on clay bottoms [6, 9]. Stjepčević and Parenzan [36] recorded this species in Risan Bay at depth from 10 to 18 m on various types of bottoms (detritic, sandy, with *Vidalia volubilis*) (bottom dredging haul number 4, 8, and 14)

Adriatic: Recorded throughout the entire area.
Remarks: Frequent.

Galathea nexa Embleton, 1834

Common names: Smeđi strigljač (Mne), squat lobster (E)
Literature: Karaman and Gamulin-Brida [6], Merker-Poček [9, 35]
Distribution: Karaman and Gamulin-Brida [6] found this species in Kotor Bay and Tivat Bay, and Merker-Poček [9] recorded this species in the muddy-sandy bottoms in all bays, except Herceg Novi Bay, at a depth of about 30 m.
Adriatic: Recorded throughout the entire area.
Remarks: This species is one of the most frequent species in Boka Kotorska Bay [35] and mainly found between sea grass meadows (*Posidonia*, *Zostera*).

Galathea squamifera Leach, 1814

Common names: Strigljač (Mne), squat lobster (E)
Literature: Karaman and Gamulin-Brida [6], Merker-Poček [9, 35], Stjepčević and Parenzan [36]
Distribution: Recorded from trawl and dredge haul samples in Kotor Bay and Tivat Bay by Karaman and Gamulin-Brida [6], while Merker-Poček [9] collected this species in all bays except Herceg Novi Bay. Stjepčević and Parenzan [36] found this species in front of Orahovac, at a depth of 10–12 m on stony bottom with algae.
Adriatic: Reported from many localities throughout the entire area.
Remarks: It inhabits the biocoenosis of the coastal terrigenous ooze with elements of coralligenous biocoenosis, mainly at depths between 5 and 20 m. Locally frequent.

Family Munididae Ahyong, Baba, Macpherson, Poore, 2010

Munida rugosa (Fabricius, 1775)

Common names: Hrapavi hlapić (Mne), rugose squat lobster (E)
Literature: Merker-Poček [9, 35]
Distribution: Recorded in Tivat Bay and Herceg Novi Bay on bottoms with elements of the coralligenous biocoenosis.
Adriatic: Recorded only from the middle and southern parts of the area.

Remarks:	Specimen was found by divers; in trawl and dredge catches were not present.
Interest to fishery:	Edible, but not used for food in the area [13].

Family Porcellanidae Haworth, 1825

Pisidia bluteli (Risso, 1816)

Common names:	Crveni porculanski račić (Mne), granchio pisello (I)
Literature:	Stjepčević and Parenzan [36], Števčić [13]
Distribution:	Recorded in Kotor Bay, in front of Orahovac at a depth of 10–12 m on rocky bottom.
Adriatic:	Found on a few localities: Piran, Rovinj, Jadranovo, Boka Kotorska, Bari.
Remarks:	This was the first record of this species in Boka Kotorska Bay.

Pisidia longicornis (Linnaeus, 1767) = *Porcellana longicornis* Pennant, 1777

Common names:	Porculanski račić (Mne), long-clawed porcelain crab (E)
Literature:	Karaman and Gamulin-Brida [6], Merker-Poček [9]
Distribution:	One individual was found in Tivat Bay from trawl haul 5K [6]. Merker-Poček [9] found this species at the same location on sandy clay bottom.
Adriatic:	Listed from many localities throughout the entire area.
Remarks:	It occurs in littoral zone between 0 and 40 m and does not require specific type of bottom.

Pisidia longimana (Risso, 1816)

Common names:	Mrki porculanski račić (Mne)
Literature:	Stjepčević and Parenzan [36] Števčić [13]
Distribution:	Found in Kotor Bay at a depth of 3–4 m on coarse sand rich with algae.
Adriatic:	Recorded from many localities including the Boka Kotorska Bay.
Remarks:	According to Stjepčević and Parenzan [36], this species has previously been identified as *Porcellana longicornis*.

Superfamily Paguroidea Latreille, 1802

Family Diogenidae Ortmann, 1892

Dardanus arrosor (Herbst, 1796)

Common names:	Rak samac (Mne), striated hermit crab (E)
Literature:	Merker-Poček [9, 35]
Distribution:	Recorded in Herceg Novi Bay and Kotor Bay on muddy-sandy bottoms at depths of about 30 m (Fig. 12)
Adriatic:	Known from a few localities from the middle and southern part of the area.
Remarks:	This species was found in shells of *Tonna galea* (= *Dolium galea*), *Galeodea echinophora* (= *Cassidaria echinophora*), and *Bolinus brandaris* (= *Murex brandaris*).

Diogenes pugilator (Roux, 1829)

Common names:	Diogenov samac (Mne), small hermit crab (E), Paguro Diogene (I)
Literature:	Stjepčević and Parenzan [36]
Distribution:	This species is found in Kotor Bay, along the coast of Dobrota, at depths of 2–3 m, on bottoms with Zoosteracea sea grass.
Adriatic:	Listed from many localities throughout the entire area.
Remarks:	Very common species.

Fig. 12 Striated hermit crab, *Dardanus arrosor* (Herbst, 1796)

Paguristes eremita (Linnaeus, 1767) = *Paguristes oculatus* (Fabricius, 1775)

Common names:	Okati rak samac (Mne), eye-spot hermit crab (E), Scardobola (I)
Literature:	Stjepčević and Parenzan [36]
Distribution:	This species is recorded in Kotor Bay and Risan Bay at a depth of 3–20 m, on detritic bottoms and coarse clean sand.
Adriatic:	Frequently reported over the entire area.
Remarks:	Very common species.

Family Paguridae Latreille, 1802

Anapagurus bicorniger A. Milne Edwards & Bouvier, 1892

Common names:	Dvorogi rak samac (Mne)
Literature:	Stjepčević and Parenzan [36], Števčić [13]
Distribution:	Several specimens were collected in Risan Bay at a depth of 18–20 m and in Kotor Bay, in front of Orahovac at a depth of 12–15 m on muddy bottoms.
Adriatic:	Recorded in Piran, Kvarner, Split, Boka Kotorska.
Remarks:	Rare species.

Anapagurus breviaculeatus Fenizia, 1937

Common names:	Bodljikavi rak samac (Mne)
Literature:	Stjepčević and Parenzan [36], Števčić [13]
Distribution:	Several specimens were collected in Risan Bay and Kotor Bay on various types of bottom (detritic mud, rock covered with algae) between 7 and 15 m.
Adriatic:	Recorded in Rovinj, Makarska, and Boka Kotorska.
Remarks:	Very rare species. This was the new record for the Adriatic as well as for the Boka Kotorska Bay.

Pagurus cuanensis Bell, 1846

Common names:	Rak samac (Mne), hairy hermit crab (E)
Literature:	Stjepčević and Parenzan [36]
Distribution:	This species was found in Kotor Bay and Risan Bay on detritic bottom as well as on coarse sand with stone at a depth of 5–10 m.
Adriatic:	Known from the northern side of the area.
Remarks:	This was the new record for the Boka Kotorska Bay.

Pagurus excavatus (Herbst, 1791) = *Pagurus alatus* Fabricius, 1775

Common names:	Rak samac (Mne), hermit crab (E)
Literature:	Stjepčević and Parenzan [36]
Distribution:	This species was found in Kotor Bay on detritic bottoms at a depth of 10 m.
Adriatic:	Known throughout the entire area.
Remarks:	This was the new record for the Boka Kotorska Bay

Pagurus prideaux Leach, 1815 = *Pagurus prideauxi* Leach, 1815

Common names:	Rak samac (Mne), Prideaux's hermit crab (E)
Literature:	Merker Poček [9, 35]
Distribution:	Recorded in all bays on shallow muddy and sandy bottoms at a depth of max 20 m.
Adriatic:	Recorded from the entire area.
Remarks:	Very common and frequent. It is usually associated with sea anemone *Adamsia palliata*.

Infraorder Axiidea de Saint Laurent, 1979

Family Callianassidae Dana, 1852

Gourretia denticulata (Lutze, 1937) = *Callianassa subterranea* minor Gourret, 1807

Common names:	Nazubčani medo (Mne)
Literature:	Stjepčević and Parenzan [36]
Distribution:	This species is found in the Kotor Bay on depths between 20 and 25 m on muddy bottoms north of the Institute of Marine Biology (bottom dredging haul number 2).
Adriatic:	It has been taken sporadically over the entire area.
Remarks:	This was the first record of this species in the Boka Kotorska Bay.

Infraorder Brachyura Linnaeus, 1758

Section Eubrachyura de Saint Laurent, 1980

Subsection Heterotremata Guinot, 1977

Superfamily Callapoidea De Haan, 1833

Fig. 13 Shamefaced crab, *Calappa granulata* (Linnaeus, 1758)

Family Calappidae De Haan, 1833

Calappa granulata (Linnaeus, 1758)

Common names:	Crvenopjegava rakovica (Mne), shamefaced crab (E), granchio melograno (I), crabe honteux (F)
Literature:	Merker-Poček [9, 35]
Distribution:	Recorded in Kotor Bay as well as in Herceg Novi Bay, on shallow muddy bottoms with parts of submarine reefs (Fig. 13).
Adriatic:	This species is very rare and has only been found in areas of the southern and middle Adriatic [13]. Recently, this species was found in northern Adriatic [42].
Interest to fishery:	Edible.

Superfamily Dorippoidea MacLeay, 1838

Family Dorippidae MacLeay, 1838

Medorippe lanata (Linnaeus, 1767) = *Dorippe lanata* (Linnaeus, 1767)

Common names:	Vuneni kratkorepac (Cro), facchino (I)
Literature:	Karaman and Gamulin-Brida [6], Merker-Poček [9, 35]
Distribution:	According to all authors, a single specimen was found in the middle part of the Tivat Bay in dredge haul (5K) in the biocoenosis of the coastal terrigenous ooze.

Adriatic: Entire area. According to Merker-Poček [9], this species was very abundant in the mouth of river Bojana (south Adriatic) at depths between 10 and 25 m.
Remarks: This species is extremely rare in the Boka Kotorska Bay [6, 35].

Family Ethusidae Guinot, 1977

Ethusa mascarone (Herbst, 1785)

Common names: Granchio facchino (I)
Literature: Karaman and Gamulin-Brida [6], Merker-Poček [9, 35]
Distribution: Sampled by trawl activity in Kotor Bay
Remarks: According to Merker-Poček [9, 35], this species is typical for the biocoenosis of the coastal terrigenous ooze as well as the biocoenosis of beds of *Zostera,* where this species occurs at depths between 10 and 30 m.

Superfamily Eriphioidea Mac Leay, 1838

Family Eriphiidae Mac Leay, 1838

Eriphia verrucosa (Forskål, 1775)

Common names: Grmelj, rak pontaš (Mne), warty crab (E), crabe verruqueux (Fr), granchio favollo (I)
Literature: Merker-Poček [9, 35]
Distribution: Recorded in all bays, mainly in rocky areas near the tide line, especially in Kotor Bay where it occurs in shallow water along rocky coastlines. It lives in the tidal zone, usually inhabiting the underwater rocks near the pier and sea cliffs and among the algae at a depth of 0–6 m (Fig. 14).
Adriatic: Recorded throughout the entire area along both sides.
Remarks: Very common and in Boka Kotorska Bay is called "rak pontaš."
Interest to fishery: Edible and of certain economic value [13].

Fig. 14 Warty crab, *Eriphia verrucosa* (Forskål, 1775)

Superfamily Goneplacoidaea Mac Leay, 1838

Family Goneplacidae Mac Leay, 1838

Goneplax rhomboides (Linnaeus, 1758) = *Gonoplax angulata* (Pennant, 1777)

Common names:	Uglasti račić (Mne), angular crab (E)
Literature:	Karaman and Gamulin-Brida [6], Merker-Poček [9, 35]
Distribution:	This burrowing crab was recorded only in Herceg Novi Bay, station 8K, (all authors) on sandy clay bottom mainly with *Penaeus kerathurus* and *Upogebia pusilla*.
Adriatic:	Listed from many localities throughout the entire area.
Remarks:	Merker-Poček [9] reported this species also as important part of diet of *Trigla lyra*.

Superfamily Leucosioidea Samouelle, 1819

Family Leucosiidae Samouelle, 1819

Ebalia edwardsii O. G. Costa, 1838

Common names:	Edwarsijeva ebalia (Mne)
Literature:	Merker-Poček [9]
Distribution:	Sampled by trawl activity in Herceg Novi Bay
Remarks:	This species is very rare in Boka Kotorska Bay [9].

Ebalia granulosa H. Milne Edwards, 1837

Common names:	Not available.
Literature:	Karaman and Gamulin-Brida [6], Merker-Poček [9, 35], Stjepčević and Parenzan [36]
Distribution:	All authors found this species only in Kotor Bay. Stjepčević and Parenzan [36] recorded this species at a depth of 20 m in front of Orahovac.
Adriatic:	Reported mainly from the eastern side.
Remarks:	Like the previous species, it is very rare in Boka Kotorska Bay [9].

Ilia nucleus (Linnaeus, 1758)

Common names:	Mrtvačka glava (Mne), pebble crab (E), testa di morto (I)
Literature:	Stjepčević and Parenzan [36]
Distribution:	Recorded in Kotor Bay, in front of Orahovac at depths ranging between 10 and 12 m
Adriatic:	Sampled in the entire area.
Remarks:	This was the first record of this species in Boka Kotorska Bay

Superfamily Majoidea Samouelle, 1819

Family Epialtidae MacLeay, 1838

Lissa chiragra (Fabricius, 1775)

Common names:	Kvrgava rakovica (Mne)
Literature:	Merker-Poček [9, 35]
Distribution:	Recorded in Kotor Bay on detritic mud bottom at a depth of 35 m.
Adriatic:	Reported from the entire area.

Pisa armata (Latreille, 1803)

Common names:	Kosteljašica (Mne), Gibb's sea spider (E), Araignée à rostre pointu (F)
Literature:	Merker-Poček [9]
Distribution:	This species recorded in Kotor Bay on clay bottoms at a depth of 35 m.
Adriatic:	Listed from many localities in particular from northeastern and eastern coasts.

Remarks:	According to Merker-Poček [9], this species is almost always camouflaged by algae, while Števčić [13] reported that is often camouflaged with various sessile organisms, especially sponges.

Pisa tetraodon (Pennant, 1777)

Common names:	Mala kosteljašica (Mne)
Literature:	Merker-Poček [9, 35]
Distribution:	Several individuals were sampled in trawl catches in Risan and Tivat Bays on 35 m depth but it is usually occurred at depth of 20 m.
Adriatic:	Reported from many localities throughout the area.
Remarks:	According to Merker-Poček [9], this species is often camouflaged with sponges and serpulids, while Števčić [13] reported that it is usually camouflaged by algae.

Family Inachidae MacLeay, 1838

Inachus dorsettensis (Pennant, 1777)

Common names:	Morski pauk (Mne)
Literature:	Karaman and Gamulin-Brida [6], Merker-Poček [9, 35], Stjepčević and Parenzan [36]
Distribution:	This species was recorded only in Kotor Bay, mainly on depths between 15 and 32 m.
Adriatic:	Reported in the entire area.
Remarks:	Mainly found between algae and often associated with sponges.

Inachus leptocheirus Leach, 1817

Common names:	Morski pauk (Mne)
Literature:	Karaman and Gamulin-Brida [6], Merker-Poček [9]
Distribution:	Like the previous species, it is found only in the middle part of the Kotor Bay
Adriatic:	Recorded from many localities along the eastern coast, in particular from southern part.
Remarks:	Rare.

Inachus thoracicus Roux, 1830

Common names:	Morski pauk (Mne)
Literature:	Karaman and Gamulin-Brida [6], Merker-Poček [9, 35]
Distribution:	Few individuals were collected in Kotor Bay and Risan Bay on sandy clay bottoms.
Adriatic:	Reported throughout the entire area
Remarks:	Fairly scarce.

Macropodia longirostris (Fabricius, 1775)

Common names:	Rakovica (Mne)
Literature:	Karaman and Gamulin-Brida [6], Merker-Poček [9, 35]
Distribution:	Sampled in the middle part of the Kotor Bay on clear clay bottom and in Risan Bay on sandy clay bottom [9].
Adriatic:	Reported throughout the area.

Macropodia rostrata (Linnaeus, 1761)

Common names:	Kljunasta rakovica (Mne)
Literature:	Karaman and Gamulin-Brida [6], Merker-Poček [9, 35], Stjepčević and Parenzan [36]
Distribution:	Occurred in Tivat Bay as well as in Kotor Bay where Stjepčević and Parenzan [36] found it in front of Orahovac at depth of 20 m.
Adriatic:	Reported throughout the area.

Family Majidae Samouelle, 1819

Eurynome aspera (Pennant, 1777)

Common names:	Hrapava rakovica (Mne)
Literature:	Stjepčević and Parenzan [36]
Distribution:	Recorded in Risan Bay at a depth of 15 m and in Kotor Bay at a depths ranging between 10 and 32 m.
Adriatic:	Reported from a great number of localities throughout the entire area.
Remarks:	No earlier reported for the Boka Kotorska Bay.

Fig. 15 Lesser spider crab, *Maja crispata* Risso, 1827

Maja crispata Risso, 1827 = *Maja verrucosa* H. Milne Edwards

Common names:	Mala rakovica (Mne), lesser spider crab (E), granceola piccola (I), araignée naine (F)
Literature:	Merker-Poček [9, 35]
Distribution:	Reported in Kotor Bay on bottom between sea grass meadows.
Adriatic:	Reported throughout the entire area [13]
Remarks:	Usually found in the biocoenosis of the coastal terrigenous ooze, facies of sessile forms, at depths of about 40 m (Fig. 15).
Interest to fishery:	Edible but of no commercial importance.

Maja squinado (Herbst, 1788)

Common names:	Granceola (Mne), spinous spider crab (E), granzeola (I), araignée européene (F)
Literature:	Karaman and Gamulin-Brida [6], Merker-Poček [9, 35]
Distribution:	Several individuals reported in Kotor Bay and Risan Bay (Fig. 16).
Adriatic:	Reported throughout the entire area, in particular on the western Istrian coast.
Remarks:	In Boka Kotorska Bay, it lives on bottoms ranging between 20 and 50 m. According to the Article 18, item 3 of the Law on Marine Fisheries and Mariculture, the Ministry of Agriculture, Forestry, and Water Management has issued the order on prohibition of catch and trade in fish juveniles, undersized fish, and other marine organisms (OG of Montenegro No. 8/11). As the order specifies, it is forbidden to catch and place on market spinous spider crab individuals with total lengths of less than 10 cm. All caught specimens shorter than 10 cm and females with eggs, regardless

Fig. 16 Spinous spider crab, *Maja squinado* (Herbst, 1788)

	of their length, must be returned to the sea. According to Merker-Poček [9], this species is endemic to the Mediterranean Sea.
Interest to fishery:	Edible, commercially important.

Superfamily Parthenopoidea MacLeay, 1838

Family Parthenopidae, MacLeay, 1838

Parthenopoides massena (Roux, 1830) = *Parthenope massena* (Roux, 1830)

Common names:	Not available.
Literature:	Stjepčević and Parenzan [36]
Distribution:	Found in Kotor Bay, along the coast of Dobrota, at a depth of 3–4 m, on coarse sand with many algae.
Remarks:	This was the first record of this species in Boka Kotorska Bay.

Superfamily Pilumnoidea Samouelle, 1819

Family Pilumnidae Samouelle, 1819

Pilumnus hirtellus (Linnaeus, 1761)

Common names:	Runjavac (Mne)
Literature:	Karaman and Gamulin-Brida [6], Merker-Poček [9, 35], Stjepčević and Parenzan [36], Števčić [13]

Distribution:	Karaman and Gamulin-Brida [6] found this species in all bays, except in Herceg Novi Bay. According to Merker-Poček [9], this species is present in all bays, mainly at depths between 5 and 40 m. Stjepčević and Parenzan [36] collected this hairy crab from rocky bottoms with sea urchin *Sphaerechinus*, in Orahovac at a depth of 8–10 m.
Adriatic:	Listed from many localities throughout the area.
Remarks:	This is the most widespread species in percentages [9, 35] in Boka Kotorska Bay. It was even found among oysters as well as on wood remains. Števčić [13] claimed that this species is recorded with certainty in Boka Kotorska Bay.

Superfamily Portunoidea Rafinesque, 1815

Family Polybiidae Ortmann, 1893

Liocarcinus corrugatus Pennant, 1777 = *Macropipus corrugatus* Pennant, 1777

Common names:	Rak veslač (Mne), wrinkled swimcrab (E), Etrille ballante (F)
Literature:	Merker-Poček [9, 35]
Distribution:	This species was found only in coastal parts of Herceg Novi Bay (station 7K) where the elements of coralligenous biocenosis are present.
Adriatic:	Recorded throughout the entire area.

Liocarcinus depurator (Linneaus, 1758) = *Macropipus depurator* (Linnaeus, 1758)

Common names:	Rakovica lopatašica (Mne), Blue-leg swimcrab (E), Etrille pattes bleues (F), Granchio di strascico (I)
Literature:	Merker-Poček [9]
Distribution:	Like the previous species, this species was also found only in Herceg Novi Bay, in its middle part, on sandy clay bottoms (Fig. 17).
Adriatic:	Recorded from many localities throughout the entire area.
Remarks:	Edible but rarely used as human food.

Liocarcinus navigator (Herbst, 1794) = *Liocarcinus arcuatus* (Leach, 1814) = *Macropipus arcuatus* Leach, 1814

Common names:	Rak veslač (Mne), arched swimming crab (E), Étrille arquée (F)
Literature:	Merker-Poček [9], Stjepčević and Parenzan [36]

Fig. 17 Blue-leg swimming crab, *Liocarcinus depurator* (Linneaus, 1758) (damaged specimen)

Distribution:	Merker-Poček [9] recorded this species in Risan Bay in shallow waters on sandy clay at depths ranging between 5 and 20 m. Stjepčević and Parenzan [36] reported this species for Kotor Bay on various types of bottoms (coarse sand, detritic muddy, and sandy bottoms) at depths between 3 and 20 m and in Risan Bay on muddy sand in front of Morinj at depth of 2.5 m.
Adriatic:	Known from the entire area.

Liocarcinus pusillus (Leach, 1816) = *Macropipus pusillus* (Leach, 1816)

Common names:	Rak veslač (Mne)
Literature:	Karaman and Gamulin-Brida [6], Merker-Poček [9, 35], Stjepčević and Parenzan [36]
Distribution:	Recorded in Risan Bay and in Tivat Bay by Karaman and Gamulin-Brida [6]. Merker-Poček [9] found this species only in Risan Bay (station 3K). According to Stjepčević and Parenzan [13], this species was the most frequent species in Kotor and Risan bays, found at depths ranging between 15 and 20 m.
Remarks:	Števčić [13] reported that this species has been confused with *Liocarcinus maculatus*.

Family Portunidae Rafinesque, 1815

Callinectes sapidus Rathbun, 1896

Common names:	Plavi rak (Mne), blue crab (E), granchio blu (I), crabe bleu (F)
Literature:	Marković and Đurović [43]

Fig. 18 Alien species, blue crab, *Callinectes sapidus* Rathbun, 1896 from the Tivat Bay

Distribution:	Sampled by gillnet called “polandara,” with 45 mm mesh size at a depth of 15 m in Tivat Bay (Fig. 18).
Adriatic:	The reports of the blue crab occurrence in the Adriatic are mainly limited to the southern part of the Adriatic Sea. Only few reports are dealing with the finding of this species in the northern Adriatic, reporting sites such as Grado, the Venetian Lagoon, and the waters of Ravenna [44].
Remarks:	This is the first record of the occurrence of this alien species in the Boka Kotorska Bay.
Interest to fishery:	Commercially important.

Carcinus aestuarii Nardo, 1847 = *Carcinus mediterraneus* Czerniavsky, 1884

Common names:	Mediterranean shore crab (E), granchio ripario (I), crabe vert de la Méditerranée (F)
Literature:	Stjepčević and Parenzan [36]
Distribution:	Recorded in Risan Bay at a depth of 15 m and in Kotor Bay at a depths ranging between 10 and 32 m (Fig. 19).
Adriatic:	Reported from a great number of localities throughout the entire area.
Remarks:	No earlier reported for the Boka Kotorska Bay.

Fig. 19 Mediterranean shore crab, *Carcinus aestuarii* Nardo, 1847

Superfamily Xanthoidea MacLeay, 1838

Family Xanthidae MacLeay, 1838

Xantho poressa (Olivi, 1792)

Common names:	Jaguar round crab (E), granchio di luna (I), Crabe de pierre méditerranéen (F)
Literature:	Merker-Poček [9, 35], Stjepčević and Parenzan [36]
Distribution:	Merker-Poček [9] recorded this crab in Herceg Novi Bay and Tivat Bay at a depths between 10 and 50 m, while Stjepčević and Parenzan [36] found it in Kotor Bay (bottom dredging haul 15 and 16), between Muo and the Institute of Marine Biology, on sandy detritic bottoms at a depth of 2–3 m.
Adriatic:	Listed from the entire area.
Interest to fishery:	Edible.

Section Eubrachyura de Saint Laurent, 1980

Subsection Thoracotremata Guinot, 1977

Superfamily Pinnotheroidea De Haan, 1833

Family Pinnotheridae De Haan, 1833

Pinnotheres pisum (Linnaeus, 1767)

Common names:	Čuvarkuća (Mne), pea crab (E), granchio pisello (I)
Literature:	Merker-Poček [9]
Distribution:	Reported in all bays on clay, sand, and rocky bottoms mainly where bivalves live such as *Mytilus*, *Cardium*, and *Ostrea*.

Fig. 20 Sleepy crab, *Dromia personata* (Linnaeus, 1758)

Adriatic:	Known from the entire area.
Remarks:	Bivalves are the most common host of this species.

Section Podotremata Guinot, 1777

Superfamily Dromioidea De Haan, 1833

Family Dromiidae De Haan, 1833

Dromia personata (Linnaeus, 1758)

Common names:	Kosmač (Mne), sleepy crab (E), crabe dormeur (Fr), granchio dormiglione (I)
Literature:	Merker-Poček [9]
Distribution:	Recorded in Tivat Bay and Herceg Novi Bay at depths from 10 to 30 m (Fig. 20).
Adriatic:	Known over the entire area.
Remarks:	It is usually camouflaged by sponge species.

Superfamily Homolodromioidea Alcock, 1899

Family Homolidae De Haan, 1839

Homola barbata (Fabricius, 1793)

Common names:	Kratkorepac (Mne), homole crab (E), homole (F)
Literature:	Merker-Poček [9, 35]
Distribution:	Recorded in Risan Bay and Tivat Bay on sandy and sandy-muddy bottoms at depth of 40 m.
Remarks:	Very rare in all bays.

Infraorder Caridea Dana, 1852

Superfamily Alpheoidea Rafinesque, 1815

Family Alpheidae Rafinesque, 1815

Alpheus dentipes Guérin, 1832

Common names:	Pucketavi rak (Mne), snapping shrimp (En)
Literature:	Stjepčević and Parenzan [36]
Distribution:	This species was found in Risan Bay, at a depth of 15 m on bottom rich with *Vidalia volubilis* (bottom dredging haul number 4) and on sandy bottoms rich with detritus at depth of 10 m (bottom dredging haul number 8).
Adriatic:	It is known from many localities throughout the area.

Alpheus glaber (Olivi, 1792)

Common names:	Crveni pucketavi rak (Mne), red snapping shrimp (En), gamberetto alfeo (I), cardon rouge (F)
Literature:	Stjepčević and Parenzan [36]
Distribution:	This species was found in Risan Bay (bottom dredging haul number 14), in a depth of 18 m.
Adriatic:	Reported from many localities throughout the entire area.
Remarks:	This species had not been reported before for the Boka Kotorska Bay.

Superfamily Palaemonoidea Rafinesque, 1815

Family Palaemonidae Rafinesque, 1815

Palaemon adspersus Rathke, 1837

Common names:	Mala kozica (Mne), Baltic prawn (En), gamberetto (I), Bouquet balte (F)
Literature:	Stjepčević and Parenzan [36]
Distribution:	Stjepčević and Parenzan [36] recorded this species in the Kotor Bay on depths between 2 and 5 m on detritus bottoms and bottoms with *Ulva lactuca* (location Muo, bottom dredging haul number 15 and 16) and at depth of 20 m on bottom rich with *Gracilaria* (bottom dredging haul number 17).
Adriatic:	Known throughout the entire area.
Remarks:	This was the first record of this species in the Boka Kotorska Bay.
Interest to fishery:	Edible.

Fig. 21 Common prawn, *Palaemon serratus* (Pannant, 1777)

Palaemon serratus (Pannant, 1777)

Common names:	Mala kozica (Mne), common prawn (En), gamberetto maggiore (I), Bouquet commun (F)
Literature:	Merker-Poček [9, 35], Stjepčević and Parenzan [36]
Distribution:	Merker-Poček [9] found this species in the Kotor Bay in large quantities (haul 1K) in coastal littoral zone near the mouths of two springs (Fig. 21) where beside the elements of the biocoenosis of the coastal terrigenous ooze, photophilic algae can also be found. Stjepčević and Parenzan [36] found this species in the same bay at depth of 3 m along the coast of Dobrota on bottom covered with *Zostera* meadows.
Adriatic:	This shrimp was reported from many localities over the entire area.
Remarks:	This species is one of the most frequent species in Boka Kotorska Bay [9].
Interest to fishery:	Common prawn is valued for human consumption and may also be used as bait.

Typton spongicola O.G. Costa, 1844

Common names:	Spužvar (Mne)
Literature:	Merker Poček [9, 35]
Distribution:	Recorded in all bays, at depths between 20 and 50 m.
Adriatic:	Recorded from the entire area.
Remarks:	*Typton* lives in some sponges.

Superfamily Processoidea Ortmann, 1896

Family Processidae Ortmann, 1896

Processa canaliculata Leach, 1815

Common names:	Žljebasta kozica (Mne), *Processa* shrimp (En), Processa di fondale (I), Guernade processe (F)
Literature:	Stjepčević and Parenzan [36]
Distribution:	This species was found in Kotor Bay (along the coast of Prčanj and north of the Institute of Marine Biology) on muddy clay bottoms at depths ranging between 20 and 32 m.
Adriatic:	Recorded in the middle and southern parts.
Remarks:	This was the first record of this species in the Boka Kotorska Bay.

Infraorder Gebiidea de Saint Laurent, 1979

Family Upogebiidae Borradaile, 1903

Upogebia deltaura (Leach, 1815)

Common names:	Kanjoč (Mne)
Literature:	Stjepčević and Parenzan [36]
Distribution:	Found on coarse sand bottom with fine gravel and stone at depths between 8 and 10 m, in bottom dredging haul number 31, near the settlement Orahovac in Kotor Bay.
Adriatic:	Reported from the entire area with exception for the northern part (Gulf of Venice).

Upogebia pusilla (Petagna, 1792) = *Upogebia litoralis* (Risso, 1816)

Common names:	Kanjoč (Mne), Mediterranean mud shrimp (En), Corbola (I), Crevette fouisseuse (F)
Literature:	Karaman and Gamulin-Brida [6], Merker-Poček [9, 35], Stjepčević and Parenzan [36]
Distribution:	Reported in all sampled stations in Boka Kotorska Bay on various types of muddy and sandy bottom (clayey silt, detritic, clayey sand) (Fig. 22) where lives in burrows, except in station situated in the entrance of the bay [6, 9]. It has been found in trawl haul as well as in dredge haul. Stjepčević and Parenzan [36] collected this species in Risan Bay on coarse sand and gravelly sand at depths of 6–7 m (bottom dredging haul number 10).
Adriatic:	Reported from the entire area.
Remarks:	This is the most represented species in the Boka Kotorska Bay [9].

Fig. 22 Mediterranean mud shrimp, *Upogebia pusilla* (Petagna, 1792)

Upogebia tipica (Nardo, 1869) = *Upogebia typica* (Nardo, 1847)

Common names:	Zvjezdasti karlić (Mne)
Literature:	Stjepčević and Parenzan [36], Števčić [13]
Distribution:	Recorded in the Kotor bay on depth of 10 m on muddy bottoms close to coast of St. Matija (bottom dredging haul number 1).
Adriatic:	According to Števčić [13], it has been found only in Boka Kotorska Bay and in north Adriatic.
Remarks:	This was the first record of this species in the Boka Kotorska Bay.

Because of permanent revision, species names have to be changed and adjusted to the current state of nomenclature of decapod Crustacea [34]. Accordingly, the names of some decapod species listed in this checklist are updated and replaced by the valid names given in Table 2.

4 Discussion

After a review of the available literature, the decapod fauna of the Boka Kotorska Bay consists of 62 species (four Dendrobranchiata, 58 Pleocyemata of which 1 is Achelata, 16 are Anomura, 1 is Axiidea, 31 are Brachyura, 6 are Caridea, and 3 are Gebiidea), which constitute approximately 26% of the total Adriatic recorded Decapoda species. The smallest number of species, 17, was recorded in the Herceg Novi Bay, 21 in the Tivat Bay, 25 in the Risan Bay, and 45 in the Kotor Bay. Among them, four species (*Goneplax rhomboides*, *Ebalia edwardsii*, *Liocarcinus corrugatus*, *Liocarcinus depurator*) were only found in the Herceg Novi Bay. In the Tivat Bay, among four species which were collected only in that bay, two were

Table 2 Updated names of the Decapoda species from the Boka Kotorska Bay

Previously used name	References	Current name (according to WoRMS, 2015)
Farfantepenaeus aztecus Ives, 1891	Marković et al. [39]	*Penaeus aztecus* Ives, 1891
Penaeus trisulcatus Leach	Karaman and Gamulin-Brida [6], Stjepčević and Parenzan [36]	*Penaeus kerathurus* (Forskål, 1775)
Porcellana longicornis Pennant, 1777	Karaman and Gamulin-Brida [6], Merker-Poček [9]	*Pisidia longicornis* (Linnaeus, 1767)
Paguristes oculatus (Fabricius, 1775)	Stjepčević and Parenzan [36]	*Paguristes eremita* (Linnaeus, 1767)
Pagurus alatus Fabricius	Stjepčević and Parenzan [36]	*Pagurus excavatus* (Herbst, 1791)
Pagurus prideauxi Leach, 1815	Merker-Poček [9, 35]	*Pagurus prideaux* Leach, 1815
Callianassa minor Gourret	Stjepčević and Parenzan [36]	*Gourretia denticulata* (Lutze, 1937)
Dorippe lanata (Lin-naeus, 1767)	Karaman and Gamulin-Brida [6], Merker-Poček [9, 35]	*Medorippe lanata* (Linnaeus, 1767)
Gonoplax angulata (Pennant, 1777)	Karaman and Gamulin-Brida [6]	*Goneplax rhomboides* (Linnaeus, 1758)
Maja verrucosa H. Milne Edwards	Merker-Poček [9, 35]	*Maja crispata* Risso, 1827
Parthenope massena (Roux, 1830)	Stjepčević and Parenzan [36]	*Parthenopoides massena* (Roux, 1830)
Macropipus corrugatus Pennant, 1777	Merker-Poček [9, 35]	*Liocarcinus corrugatus* Pennant, 1777
Macropipus depurator (Linnaeus, 1758)	Merker-Poček [9]	*Liocarcinus depurator* (Linneaus, 1758)
Macropipus arcuatus Leach, 1814	Merker-Poček [9], Stjepčević and Parenzan [36]	*Liocarcinus navigator* (Herbst, 1794)
Macropipus pusillus (Leach, 1816)	Karaman and Gamulin-Brida [6], Merker-Poček [9, 35], Stjepčević and Parenzan [36]	*Liocarcinus pusillus* (Leach, 1816)
Carcinus mediterraneus Czerniavsky, 1884	Stjepčević and Parenzan [36]	*Carcinus aestuarii* Nardo, 1847
Upogebia litoralis (Risso, 1816)	Karaman and Gamulin-Brida [6]	*Upogebia pussila* (Petagna, 1792)
Upogebia typica (Nardo, 1847)	Stjepčević and Parenzan [36]	*Upogebia tipica* (Nardo, 1869)

recognized as alien species (*Pisidia longicornis*, *Medorippe lanata*, *Penaeus aztecus*, and *Callinectes sapidus*). Two species from the Alpheidae family were found only in the Risan Bay. In the Kotor Bay, almost half of the recorded species were found only in that bay (21 species). The most diverse, in terms of species number, were the true crabs (brachyurans) followed by anomurans (hermit crabs, squat lobsters) and caridean shrimps. Dendrobranchiate shrimps and macrurans (lobsters and relatives) contribute to a lesser extent to the decapod species diversity. Most of crustaceans were non-commercial or potentially commercial species. The most abundant species were *Upogebia pusilla* and *Pilumnus hirtellus*, while *Lissa chiraga* and *Medorippe lanata* occurred with very small number of specimen.

During the last 5 years, two species from American waters have been reported. The mode of introduction of these alien, immigrant species is probably by shipping, through ballast waters and hull fouling. This bay offers suitable environmental conditions for the establishment of such immigrants.

Finally, we conclude that the decapod fauna of this beautiful bay is fairly rich. But, the number of references for this small area has not increased from the last research survey. Continuing investigations on the fauna should add additional decapod species to the list. We believe that it would be very important to revise this checklist, as according to the experiences of many fishermen and divers, the number of the decapod crustacea species in this bay is much bigger.

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References

1. Lepetić V (1965) Composition and seasonal dynamics of ichthyobenthos and edible invertebrata in bay of Boka Kotorska and possibilities of their exploitation. Studia Marina 1:1–127
2. Magaš D (2002) Natural-geographic characteristics of the Boka Kotorska area as the basis of development. Geoadria 7(1):51–81
3. Jović M, Stanković A, Slavković-Beskoski L, Tomić I, Degetto S, Stanković S (2011) Mussels as a bio-indicator of the environmental quality of the coastal water of the Boka Kotorska Bay (Montenegro). J Serb Chem Soc 76(6):933–946. doi:10.2298/JSC101007075J
4. RAC/SPA - UNEP/MAP (2014) In: Petovic S, Batakovic M (eds) Marine biodiversity of Boka Kotorska Bay - Pilot project on testing Ecosystem Approach (EcAp) application in Boka Kotorska Bay (Montenegro) - Executive summary. RAC/SPA - MedMPAnet Project, Tunis, pp 1–25
5. Stjepčević J (1967) Macro-Mollusca of Boka Kotorska Bay. Studia Marina 2:1–67
6. Karaman G, Gamulin-Brida H (1970) Contribution aux recherches des biocoenoses benthiques du Golfe de Boka Kotorska. Studia Marina 4:3–24
7. Števčić Z (1993) History of investigations of the Adriatic decapod fauna. Bios 1(1):151–161
8. Müller CHG, Schubart CD (2007) Insights into the Crustacea Decapoda of the Adriatic Sea. Observations from four sampling locations along the Croatian coast. Rostocker Meeresbiologische Beiträge 18:112–130
9. Merker-Poček B (1974) Kvantitativna i kvalitativna analiza dekapodnih rakova u biocenozama na području Boke Kotorske. MSc Dissertation, University Zagreb
10. Olivi G (1792) Zoologia Adriatica, ossia catalogo regionato degli animali del golfo e della lagune di Venezia Bassano, Venecia

11. Heller C (1863) Die Crustaceen des südlichen Europa. Crustacea Podophthalmia. Mit einer Uebersicht über die horizontale Verbreitung sämmtlicher europäischer Arten: ixi, 1–336
12. Pesta O (1918) Die Decapodenfauna der Adria. Versuch einer Monographie, F. Deuticke. Wien-Leipzig
13. Števčić Z (1990) Check list of the Adriatic decapod Crustacea. Acta Adriat 31:183–274
14. Karlovac O (1936) *Parapenaeus longirostris* (H. Lucas) an der Ostküste der Adria. Zool Anz 115:60–62
15. Karlovac O (1948–1949) Le *Parapenaeus longirostris* (H. Lucas) de la Haute Adriatique. Acta Adriat 3(12):1–14
16. Karlovac O (1952) The first finding and occurrence of *Latreillia elegans* Roux in the Adriatic. Acta Adriat 4:395–404
17. Karlovac O (1953) An ecological study of *Nephrops norvegicus* (L.) of high Adriatic. Rep Inst Oceanogr Split 5(2c):1–51
18. Lutze J (1937) Eine neue Callianassa-Art aus der Adria. Note Ist Biol Mar Rovigno 2(1):1–12
19. Kurian CV (1956) Larvae of decapod Crustacea from the Adriatic Sea. Acta Adriat 6(3):1–108
20. Holthuis LB (1961) Report on a collection of Crustacea Decapoda and Stomatopoda from Turkey and the Balkans. Zool Verhand Leiden 47:1–67
21. Karaman M (1922) *Galathea bolivari* Zar. novi dekapod za Jadransko more. Biološki Vestnik 10:69–70
22. Riedl R (1963) Decapoda. In: Fauna und Flora der Adria. P. Parey, Hamburg-Berlin, pp 265–296
23. Števčić Z (1969) Da li su dekapodi Jadrana dobro poznati? Thalassia Jugoslavica 5:345–351
24. Števčić Z, Forstner H (1966) *Sirpus zariquieyi* Gordon, 1953 (Crustacea: Brachyura) – eine für die Adria neue Art. Bull Sci Conseil Acad RSF Yougoslavie Sect A 11(10–11):251
25. Jukić S (1971) Studies on the population and catchabillity of Norway lobster in the central Adriatic. FAO Stud Rev 48:27–52
26. Merker-Poček B (1970) Contribution to the knowledge of autecology of *Plesionika heterocarpus* Costa – a new species for the Adriatic Sea. Studia Marina 4:67–75
27. Merker-Poček B (1970) Situation et distribution bathimatrique de certaines especes de Natantia dans l'Adriatique meridionale. Studia Marina 4:77–84
28. Merker-Poček B (1972) Check-list of decapod Crustácea from the Southern Adriatic Sea caught by a trawl net - a survey of the current investigations. Thalassia Jugosl 8(1):99
29. Froglia C (1972) Segnalazione di alcuni croctacei nuovi o rari per Adriatico. Quad Lab Tecnol Pesca 1:43–52
30. Števčić Z (1969) Lista desetonožnih rakova Jadrana. Biološki Vestnik 17:125–134
31. Koukouras A, Dounas C, Türkay M, Voultsiadou-Koukoura E (1992) Decapod Crustacean Fauna of the Aegean Sea: new information, check list, affinities. Senckenberg Marit 22(3/6): 217–244
32. Števčić Z (1995) Contribution to the faunistic list of Adriatic decapod Crustacea. Natura Croatica 4(2):113–115
33. Števčić Z (2002) New observation on the Adriatic decapod fauna (years 1990–2000). Crustaceana 75(3–4):643–647
34. Kirinčić M, Števčić Z (2008) Fauna of the Adriatic Decapod Crustaceans (Crustacea: Decapoda)-status and outlook. Natura Croatica 17(2):131–139
35. Merker-Poček B (1977) Quelques resultates de la recherché des crustaces decapodes dans le golfe de Boka Kotorska. Rapp Comm Int Mer Medit 24(4):109–110
36. Stjepčević J, Parenzan P (1980) Il Golfo delle Bocche di Cattaro – condizioni generali e biocenosi bentoniche con carta ecologica delle sue due baie interne: di Kotor (Cattaro) e di Risan (Risano). Studia Marina 9–10:3–146
37. WoRMS Editorial Board (2015) World Register of Marine Species. Available from http://www.marinespecies.org at VLIZ. Accessed 2015-12-02
38. Kasalica O (2005) Population dynamics of deep-water pink shrimp *Parapenaeus longirostris* (Lucas, 1846) on the shelf of the Montenegrin coast. M.Sc. Thesis, University of Belgrade

39. Marković O, Gokoglu M, Petović S, Mandić M (2014) First record of the Northern brown shrimp, Farfantepenaeus aztecus (Ives, 1891) (Crustacea: Decapoda: Penaeidae) in the South Adriatic Sea, Montenegro. Mediterr Mar Sci 15/1:165–167. doi:10.12681/mms.673
40. Tavares (2002) Shrimps. In: Carpenter KE (ed) The living marine resources of the western Central Atlantic, vol 1 (FAO Species Identification Guide for Fishery Purposes, FAO, Rome and American Society of Ichthyologists and Herpetologists, Special Publication No. 5). FAO, Rome, pp 251–291
41. Merker-Poček (1970) Situation et distribution bathimatrique de cartaines especes de Natantia dans lAdriatique Maridionale. Studia Marina 4:77–82
42. Dulčić J, Tutman P (2012) Northernmost record of the shamefaced crab *Calappa granulata* (Linnaeus, 1767) (Brachyura, Calappidae) in the Mediterranean area. Crustaceana 85(4/5): 601–606. doi:10.2307/23212683
43. Markovic O, Ðurovic M (2014) First documented record of the American blue crab, *Callinectes sapidus* Rathbun, 1896 in the Boka Kotorska Bay, Southern Adriatic Sea, Montenegro. pp 208–209. In: Kapiris et al., 2014 New Mediterranean marine biodiversity records. Mediterr Mar Sci 15/1:198–212. doi:10.12681/mms.737
44. Dulčić J, Dragičević B, Lipej L (2010) New record of the blue crab, *Callinectes sapidus* Rathbun, 1896, (Decapoda: Brachyura) in the Adriatic sea. Ann Ser Hist Nat 20:23–28

Mariculture in the Boka Kotorska Bay: Tradition, Current State and Perspective

Milica Mandić, Zdravko Ikica, and Slađana Gvozdenović

Abstract This paper presents data on initial scientific research activities conducted in order to explore the possibilities for bivalve farming in the conditions of the Boka Kotorska Bay; the data on experimental project related to technology transfer and protection of farming sites against predators, as well as the methods for defining the mariculture sites and principles that sustainable bivalve and fish farming should be based on. Mariculture development in Montenegro began after the completion of initial explorations on the possibilities of farming edible bivalves on the area of the Boka Kotorska Bay, which were conducted in the 1960s. After this period, the first commercial farming of mussels (*Mytilus galloprovincialis*) began, while the first commercial farming of oysters (*Ostrea edulis*) began in 2009 in the Bay of Kotor. Today, there are around 20 active shell farms as well as two fish farms using the multitrophic aquaculture system. Bivalve farming is done using the traditional method of floating parks system (long-lines), while fish farming is done in floating cages.

Keywords Boka Kotorska Bay, Farming technology, Mariculture, South Adriatic

Contents

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1 Introduction

Aquaculture is a dynamic industry with annual growth rate of around 10.8%, with a high profit rate, particularly in developed countries [1]. World mariculture production (18.3 million tonnes) comprises marine molluscs (75.5%, 13.9 million tonnes), finfishes (18.7%, 3.4 million tonnes), marine crustaceans (3.8%, 3.9 million tonnes) and other aquatic animals (2.1%, 0.33 million tonnes). The share of molluscs (mostly bivalves, e.g. oysters, mussels, clams, cockles, ark-shells and scallops) declined from 84.6% in 1990 to 75.5% in 2010, reflecting the rapid growth in finfish culture in marine water, which grew at an average annual rate of 9.3% from 1990 to 2010 (seven times faster than the rate for molluscs) [1]. World per capita apparent fish consumption increased from an average of 9.9 kg in the 1960s to 19.2 kg in 2012 (preliminary estimate). World food fish aquaculture production expanded at an average annual rate of 6.2% in the period 2000–2012 (9.5% in 1990–2000) from 32.4 million to 66.6 million tonnes [2].

According to Information System for the Promotion of Aquaculture in the Mediterranean (FAO-SIPAM) for 2012, total marine and brackish water aquaculture production in the General Fisheries Commission of Mediterranean (GFCM) areas (excluding aquatic plants, freshwater aquaculture and marine and brackish aquaculture from Atlantic areas) increased from about 540,000 tonnes in 1990 to around 1,400,000 tonnes in 2010 [3]. These data indicates a huge demand for aquaculture products and the high rate of development of this sector.

Taking into account the intensive growth of the human population worldwide and that food availability in many countries is decreasing, it is necessary to intensify the production of healthy food in existing areas and also to identify additional locations. Experiences of many coastal countries in the process of production of healthy food in the sea resulted in the fact that mariculture today is a strategic development industry. Mariculture provides opportunity for producing protein rich food and economic development of the area in which the farming activity is done. Considering that development of this sector in the Boka Kotorska Bay is limited in terms of development of industrial production in mariculture, potential threats to marine and coastal diversity of species are negligible.

Although the Fishery Strategy of Montenegro 2015–2020 provides for an increase in production of autochthonous species, particularly as regards bivalves, the production growth is still limited, considering the natural potential, but long-term prospects are quite good. Over the past few years, the global production in aquaculture has been increased and reached a point above 50% of commercial fish catch in fishery [4]. Farming of fish and other marine organisms in Montenegro is done on the basis of the following: the Law on Marine Fishery and Mariculture [5], the Spatial Plan for Special Purpose Area for the Coastal Zone [6], the Law on Environment [7], the Law on Environmental Impact Assessment [8], the Law on Nature Protection [9] and secondary legislation applicable based on the abovementioned laws.

2 History of Mariculture in Montenegro

Initial exploration on the possibility of mussel (*Mytilus galloprovincialis*) and oyster (*Ostrea edulis*) farming in Boka Kotorska Bay goes back to the early 1960s of the last century. Farming process implied three stages of cultivation for oysters and two phases of mussels farming. Bundles of branch, the so-called fašine, were placed in the sea, and young oysters were caught on them after 6 months. Then oyster fries were extracted from the sea for second phase. Second phase implied processing and beam forming braids with diluted branches. The third phase involved the removal of branches, cementing and interference in the final braids.

Mussel farming was somewhat easier compared to oyster farming, and it implied two stages – collecting young on old ropes, the so-called kadena that were placed horizontally below the surface. Collecting the fries was followed by a second phase – the removal of young mussels from *kadena* and involvement in braids, which have been positioned on the floating park in the space of 35–40 cm. Breeding parks and piers were a steel structure, and these experimental parks were placed in positions with a very shallow depth (5–10 m).

Total time of oysters growing lasted from 28 to 30 months, while mussel reaching market size in 2–3 years, depending on the size of the individual [10].

Farming technology had involved stationary parks for mussels and oysters (Fig. 1), as well as oyster cementing using a methodology similar to that still

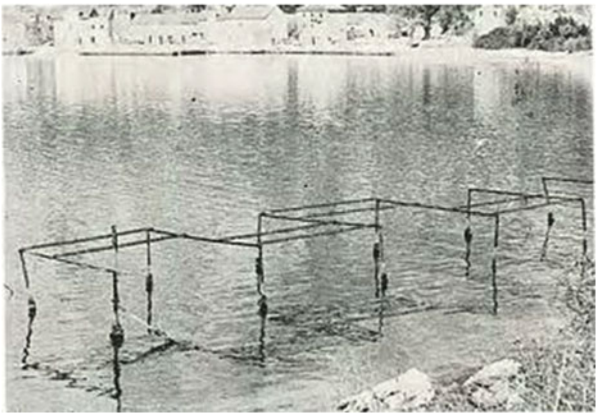

Fig. 1 Former appearance of the experimental stationary park (Orahovac, Montenegro) [10]

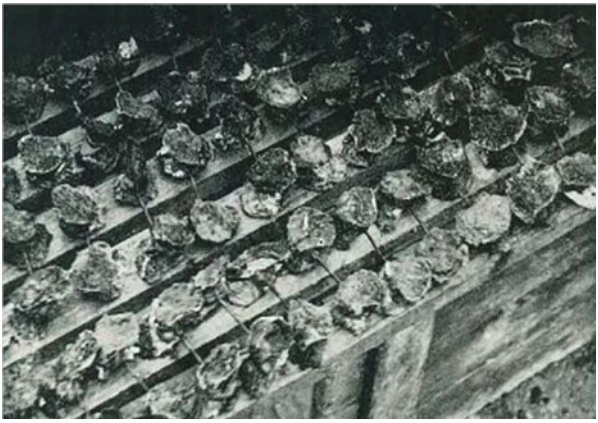

Fig. 2 Oyster cementing method in the first investigations on possibility for farming in the Boka Kotorska Bay [10]

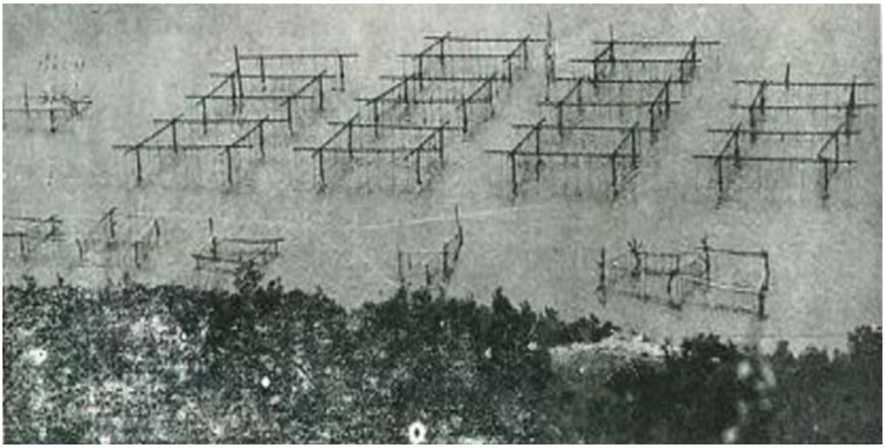

Fig. 3 Former appearance of the stationary park for oyster and mussel farming, the Malostonski Bay, Croatia [10]

used in most of Adriatic and Mediterranean countries (Fig. 2). Former appearance of stationary parks in countries of the region is presented in Figs. 3 and 4.

Several decades after the initial surveys, commercial mussel farming on the area of the Boka Kotorska Bay began to develop in the second half of the 1980s and it implied introduction of the floating parks methodology, used even today, while commercial oyster farming began as late as in 2009. Today, the farming technology of mussels and oysters in the Boka Kotorska Bay uses long-lines system, which proved that it meets all the necessary conditions for safe production [11].

In the period of the first surveys until today, additional research activities and experiments have been made in order to explore the possibilities for the Pacific oyster (*Crassostrea gigas*) and rainbow trout (*Oncorhynchus mykiss*) farming in the

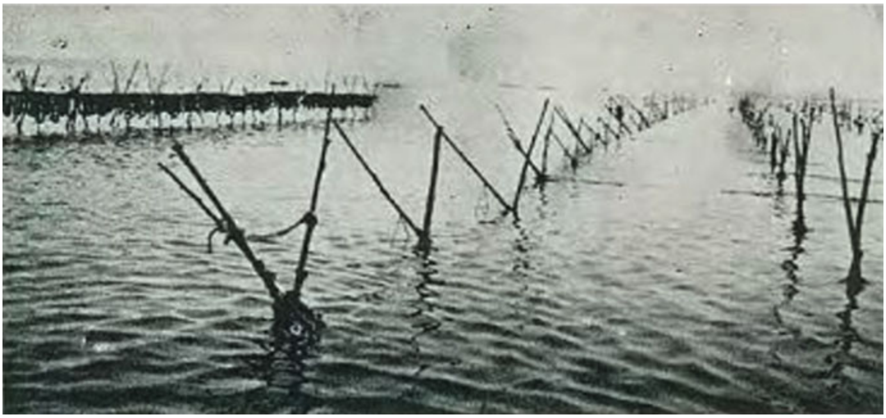

Fig. 4 Former appearance of the stationary park for *M. galloprovincialis* farming, the Taranto Bay, Italy [10]

sea. One of the very important segments of marine aquaculture is technology transfer, and in that regard activities were conducted with colleagues from Spain, Italy, Norway and China. Many plans such as farming of salmon, brine shrimps *Artemia salina*, eel (*Anguilla anguilla*), mullet (Mugil sp.) as well as development of lagoon farming are still in the conceptual phase as a result of lack of funds.

3 Current State of Montenegrin Marine Aquaculture: Species, Technologies and Production

Marine aquaculture in Montenegro includes fish farming (sea bass and sea bream) and farming of two species of bivalves – mussels (*Mytilus galloprovincialis*) and oysters (*Ostrea edulis*) (Fig. 5).

Bivalve farming is at a relatively low level, considering the natural potential available. In 20 farming sites on the territory of the Boka Kotorska Bay, the current annual mussel production is somewhat below 200 tonnes [12] (Fig. 6), while the quantity of oyster farmed is negligibly low, considering that the first farming site was set up in 2009 (Fig. 7). Sale is done mainly through direct supply, while lately retail chains have begun placing this product on the market. One of the major problems in this sector is absence of a centre for dispatch and depuration of live molluscs (absence of sanitary-hygiene conditions necessary for exports) as well as lack of organized market.

White fish farming implies a closed farming cycle in floating cages in the sea. Although it shows a mild growth over the past few years, it is still at a low level, particularly in comparison with countries with relatively small production (Croatia, Albania, Morocco or Tunisia). Two fish farming sites on the territory of the Boka Kotorska Bay have annual production of around 120 tonnes [12]. Production shows

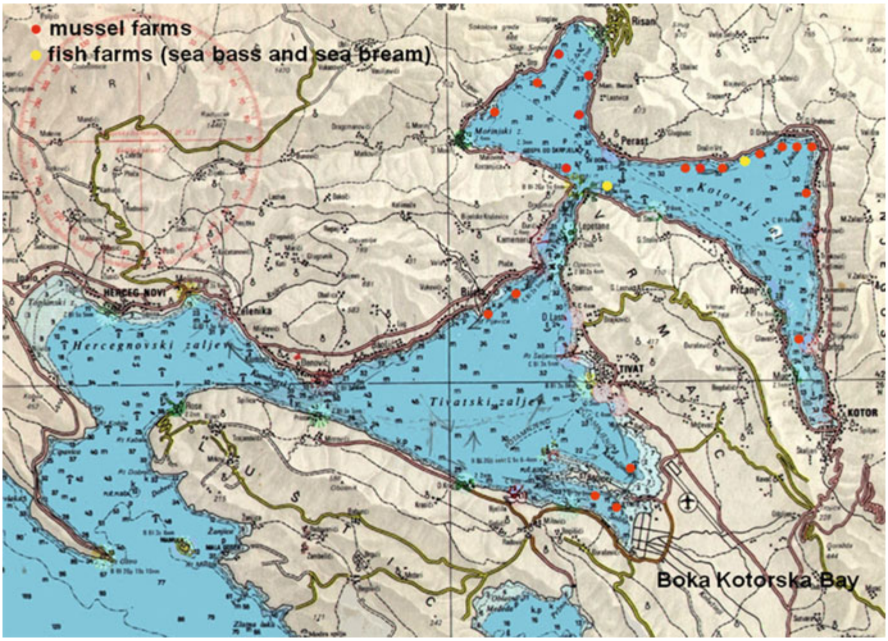

Fig. 5 Map of bivalves and fish farming sites (the Boka Kotorska Bay)

Fig. 6 Technology of mussel farming in Montenegro

Fig. 7 Technology of oyster farming in Montenegro

growth in recent years, thanks to decisive management of one of the two existing farms. However, the development of this sector is stagnant, as there are no defined locations for aquaculture in the open sea of the Montenegrin coast, which should be an integral part of the spatial plan of the coastal zone management and which should constitute security for investors to invest in cage farming. There is a growing interest in recent years by various investors for growing not only sea bass and sea bream, but also for Atlantic bluefin tuna (*Thunnus thynnus*). Poor development of aquaculture in Montenegro contributes to the conflict of this sector with tourism and ecology, and ignorance of the actual situation and the possibility of linking these sectors. Although fish farming can significantly affect the ecological and biological condition of water, proper and sustainable management of production, regular monitoring of the environment and regular control to prevent the risk and disease could make the development of this sector viable and environmentally sound [13].

Fish farming has a negative impact on the environment, it can generate considerable amounts of effluent, such as waste feed, faeces, medicinal substances, heavy metals and persistent organic pollutants, which can pollute the marine environment with a range of negative impacts varying in severity [14–18]. Unlike extensive aquaculture of mussels and oysters, which uses primary production from the marine ecosystem, intensive production of fish within sea-cages is increasingly occupying more coastal space, uses high protein pellets for feeding and introduces a large source of nutrients to coastal areas which can exceed the assimilative capacity of the local marine environment, leading to coastal eutrophication [15, 16]. Development of fish farming in the open sea (semi-off shore and off shore aquaculture), intensive control of the fish stocking density in order to overcome possibility of overcrowded conditions and consequently possible development of diseases, polyculture production systems (IMTA), combining the cage system with an artificial reef [19] are just some of the solutions for overcoming the negative impact of fish farming.

During several years of research activities conducted in cooperation with bivalve farmers, a number of important projects have been implemented of which we would like to highlight the following: (1) technology transfer aimed at increasing the mussel production on the territory of the Boka Kotorska Bay, and (2) protection of farming sites against predatory fish species.

The first project implied introduction of the technology of the so-called shark ropes, intensively used in Spain (Galicia) in raft systems. Juvenile mussel attaching was done by hand on ropes 12 m in length, put in a ‘U’ position on existing long-line systems. In 2 farming sites included in the experiment attaching was done on 3 ropes each, with different juveniles density (400, 500 and 600 g/m). Juveniles were attached using a cotton biodegradable net (Fig. 8). Upon regular monthly monitoring, it was established that mussel growth is extremely good, but that the said technology cannot be used on long-line systems due to the weight that raft system supports relatively easily. Nevertheless, in this experiment it was also

Fig. 8 ‘Shark rope’ prepared with juvenile mussels colony

established that the said ropes are extremely favourable as spat collectors if placed horizontally, at the depth of about 1 m, which is the way in which the farming sites that participated in the experiment are using them currently.

The second project was an attempt to resolve the problem of mussel and oyster predators in farming sites. The predation issue in farming sites is an issue spread throughout the Mediterranean [20–24]. The experiment implied placing of three different types of protective nets in three sites in the Boka Kotorska Bay. The first net type (Fig. 9) was designed in cooperation with farmers. Net mesh size is 50 × 50 mm, they are hand-made nets, made of polyethylene based on experiences of our farmers and in cooperation with the scientific staff of the Institute of Marine Biology. The number of nets placed in all 3 sites was 300 each.

The second net type, the so-called Spanish nets with mesh size 15 × 15 mm, is made of polyethylene and they are extremely strong. The manufacturer is company JJChicolino (Spain) and the nets were reinforced with plastic hoops prior to their placing into the sea (Fig. 10a, b).

The third net type is also made of polyethylene (Fig. 11) with mesh size of 50 × 50 mm, but is far stronger than the first two type nets. The manufacturer is company Sigma Promet from Bečej (Serbia). After preparation and treatment of protective nets, supplied in rolls 1.2 m in width and 25 m in length, the nets were distributed to farming sites.

Upon completion of a thorough analysis and monitoring of the quality, strength and resilience of the nets that lasted for several months, it was concluded that two net types (type 2 and type 3) can be widely used to protect farming sites against

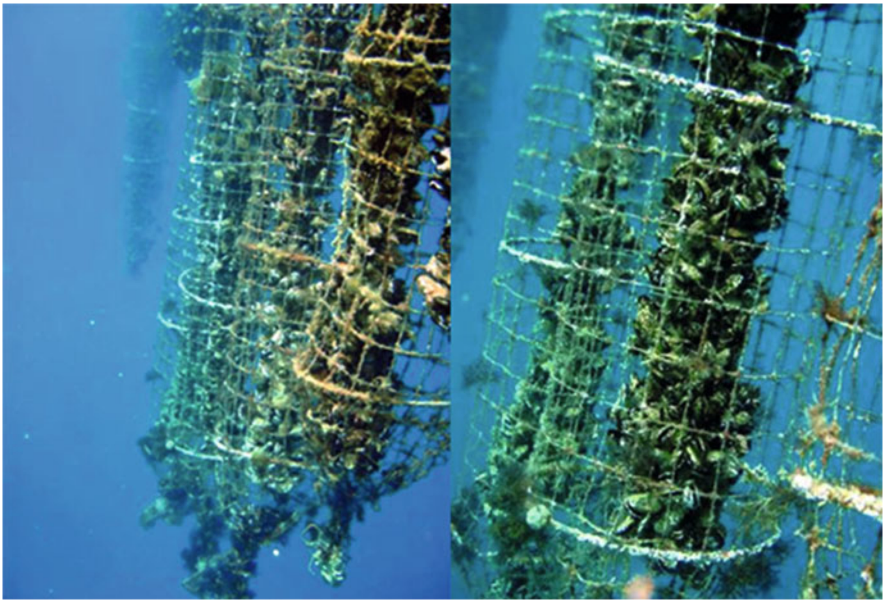

Fig. 9 The first type of protective nets placed on *pergolar* – mesh sleeves

Fig. 10 Spanish net reinforced by plastic hoops (**a**) and difference between type 1 and type 2 nets (**b**)

predator fish species. The first net type was not of a satisfactory quality in terms of resilience and net strength, so we do not recommend it to farmers to protect their farming sites. The net types 2 and 3 were of considerable quality in terms of strength, resilience and protection of the farming site; however, we note that type 2 net has much smaller mesh size so the quantity and intensity of fouling organisms is much higher than in the type 3 net, which causes additional burden to farmers. The results of this project found a direct and wide use among bivalve farmers who are intensively using the recommended net types, while results were officially supported by the Ministry of Agriculture and Rural Development of Montenegro.

Fig. 11 The third type of protective nets

4 Problems and Possible Threats in Mariculture Development

One of the main reasons due to which this sector is not sufficiently developed is absence of new farming sites, particularly in the open sea. Spatial planning plays a major role in resolving this key problem, in the process of site selection not only in order to resolve possible conflicts with other activities in the sea (tourism, transport, navigation and fishing) but also in order to ensure security to investors.

The additional problems are related to fouling organisms, predatory fish species, presence of unregistered farming sites, absence of organized market, absence of dispatch centre and an active depuration centre, as well as unused opportunities for farming other autochthonous bivalve species attractive for the market.

The major threats are possible faecal pollutions and biotoxins that many countries in the region have been facing.

5 Prospects of Mariculture Sector Development in Montenegro

Advancement and technological development of the mariculture sector should be based on security standards and preservation, development and promotion of quality food from the sea, in accordance with contemporary production and market trends, along with preservation of natural values of the area concerned. In future development activities, this sector should be taken into consideration through its multi-functional link with tourism. There are numerous development opportunities for cooperation of the two sectors (gastronomic contribution to the tourist offer, increase in national consumption of healthy food from the sea, reduction of fishing pressure on existing resources and creation of new jobs).

On the basis of previous studies conducted by the Institute of Marine Biology, potential locations for aquaculture in the open part of the Montenegrin coast have been proposed [13].

The sites proposed are stated as potentially suitable for mariculture program, which means that it is necessary to conduct baseline surveys for each site separately. The criteria listed are laid down in accordance with the FAO AZA concept (Allocated Zones for Aquaculture) – a concept based on which locations suitable for mariculture are identified. This concept is proposed by the General Fisheries Commission for the Mediterranean (GFCM) that Montenegro is a member of, and it implies the observance of the ICZM Protocol, the ecosystem approach to aquaculture development, the Blue Growth as well as observance of three fundamental principles, as follows:

1. Aquaculture development and management should take into account the full scope of ecosystem services without jeopardizing their sustainability,
2. Aquaculture development enhances human wellbeing and the principle of equality for all relevant users,
3. Aquaculture development has to be developed in accordance with development of other sectors, policies and objectives,

all that in accordance with the Directive 2014/89/EU. Baseline surveys entail the following analyses:

Basic information:

– Bathymetry analyses (minimum sea depth depends on the species of the organism farmed – bivalves or fish),
– Coastal infrastructure and accessibility of the location,
– Basic infrastructure: availability of roads and communication, availability of electric power and vicinity of ports.

Administrative information:

– Protected areas (natural parks, RAMSAR sites and sites of particular importance),
– Waste disposal sites (landfill),
– Submarine cables,
– Tourist areas (beaches),
– Submarine archaeological areas,
– Traditional fishing zones,
– Fishermen's posts,
– Artificial reefs, and

– Military zones.

Environmental information (biophysical characteristics):

– Climatology (temperature, winds, precipitation and evaporation),
– Site exposure to the open sea,
– Seabed characteristics (sediment structure – granulometry, organic matter, demersal ichthyofauna, phyto- and zoobenthos),
– Water quality (oxygen, salinity, chlorophyll a, temperature, suspended matter, water transparency and nutrients),
– Trophic status (oligotrophic, mesotrophic and eutrophic),
– Organographic conditions (waves – minimum and maximum amplitudes, sea currents – course and direction, hydrodynamics),
– Sanitary quality (microbiology).

With a view to sustainable development of the sector, opportunities for appropriate monitoring of the environment in all phases, introduction of the indicator system [25] and the above-mentioned AZA concept is proposed in order to avoid some impacts of aquaculture by improving the site selection process and, in turn, protecting aquaculture itself from adverse environmental conditions. This would also likely prevent conflicts among stakeholders on the use of the marine resources by enhancing the integration of aquaculture with other activities within the coastal areas [25].

6 Conclusions

Mariculture development in Montenegro is at a relatively low level compared to the opportunities offered by the area of the Boka Kotorska Bay and the open sea of the Montenegrin coast. All the sites where mariculture takes place are located in the area of the Boka Kotorska Bay, while the open sea is still completely unused for mariculture program. Furthermore, introduction of new autochthonous fish and bivalve species, transfer of technologies, experiences and know-how, development of organic farming, insisting on multitrophic aquaculture as well as stronger support to the research and development sectors are doubtlessly the directions in which the sector should be developed further. Not only in Montenegro, but also Mediterranean aquaculture is still at an early stage of development although some productions (molluscs) have already a long tradition. Its sustainable development needs a better integration in the society and to take better into consideration basic principles. At the international/regional level there is a current effort to streamline the sector, its framework and its communication tools (European Federation of Aquaculture Producers, Committee on Aquaculture of the General Fisheries Commission for the Mediterranean). However, as in many other cases, the Mediterranean aquaculture is quite diverse in terms of stage of development and needs for scientific and technological support. The current efforts made by various international entities should be better coordinated and strengthened. However, the efforts are also to be made at the local levels where operational decisions are to be made and the development is to take place [26]. Taking into account that accession to the European Union is Montenegro's strategic objective, it also implies adoption and implementation of ecological and technological standards of the Union. It is beyond doubt that apart from economic development, development of tourism and services, mariculture, along with fisheries, will become one of the most important development sectors, taking into account the fact that global demand for healthy food produced in the sea is at a high level.

References

1. The State of World Fisheries and Aquaculture. Food and Agriculture Organization of the United Nations, Rome, 2012
2. The State of World Fisheries and Aquaculture. Opportunities and challenges. Food and Agriculture Organization of the United Nations, Rome, 2014
3. FAO SIPAM Database 2012
4. World aquaculture. Food and Agriculture Organization of the United Nations. Rome, 2010
5. Official Gazette of Montenegro, No 56/09, and 47/15. Law on Marine Fisheries and Mariculture
6. Official Gazette of Montenegro, No 30/07. Spatial Plan for the Special Purpose for Coastal Zone Management
7. Official Gazette of Montenegro, No 48/08. Law on environment
8. Official Gazette of Montenegro, No 80/05. Law on environmental impact assessment
9. Official Gazette of Montenegro, No 51/08 and 21/09. Law on Environmental Protection
10. Stjepčević J (1974) Ekologija dagnje (*Mytilus galloprovincialis* LAMK) i kamenice (*Ostrea edulis* L.) u gajilištima Bokokotoroskog zaliva. Stud Mar 7:5–164
11. Mandić S (2008) Plantažna proizvodnja i komercijalni uzgoj dagnje (*Mitylus galloprovincialis*) i kamenice (*Ostrea edulis*) u uslovima Bokokotorskog zaliva. Institut za biologiju mora, Kotor
12. FAO SIPAM Database, 2011
13. Mandić M, Drakulović D, Petović S, Huter A, Mandić S (2014) Development perspectives of fish farming in Montenegro. Agric For 60(2):233–243
14. Black KD (2001) Environmental impacts of aquaculture. Sheffield Academic Press, Sheffield, p 214
15. Read P, Fernandes T (2003) Management of environmental impacts of marine aquaculture in Europe. Aquaculture 226:139–163
16. Mendiguchia C, Moreno C, Manuel-Vez MP, Garcia-Vargas M (2006) Preliminary investigation on the enrichment of heavy metals in marine sediments originating from intensive aquaculture effluents. Aquaculture 254:317–325
17. Sather PJ, Ikonomou MG, Haya K (2006) Occurrence of persistent organic pollutants in sediments collected near fish farm sites. Aquaculture 254:234–247
18. Dempster T, Jerez-Sanchez P (2008) Aquaculture and coastal space management in Europe: an ecological perspective. Chapter 3. In: Holmer M et al (eds) Aquaculture in the ecosystem. Springer, Dordrecht, pp 87–116
19. Bugrov L, Antsulevich A, Joksimović A, Keondjian V, Mandić M (2015) Prospect of marine aquaculture in Adriatic Sea-comparison of sheltered and open sea areas within Montenegro coastal zone. Stud Mar 28(1):39–50

20. Hortle ME, Cropp DA (1987) Settlement of the commercial scallop, *Pecten fumatus* (Reeve) 1985, on artificial collectors in Eastern Tasmania. Aquaculture 66:79–95
21. Hayden BJ (1995) Factors affecting recruitment of farmed Greenshell Mussels, *Perna canaliculus* (Gmelin) 1791, the Marlborough Sounds. Ph.D. thesis, University of Otago, p 168
22. Brehmer P, Gerlotto F, Guillard J, Sanguinède F, Guennegan Y, Buestel D (2003) New applications of hydroacoustic methods for monitoring shallow water aquatic ecosystems: the case of mussel culture grounds. Aquat Living Res 16:333–338
23. Peteiro LG, Filgueira R, Labarta U, Fernandez-Reiriz MJ (2007) Settlement and recruitment patterns of *Mytilus galloprovincialis* L. in the Rıa de Ares-Betanzos (NW Spain) in the years 2004/2005. Aquacult Res 38:957–964
24. Šegvić-Bubić T, Grubišić L, Karaman N, Tičina V, Mišlov JK, Katavić I (2011) Damages on mussel farms potentially caused by fish predation—self service on the ropes? Aquaculture 319: 497–504
25. Fezzardi D, Massa F, Àvila Zaragoza P, Rad F, Yücel Gier G, Deniz H, Hadj Ali Salem M, Hamza HA, Ben Salem S (2013) Indicators for sustainable aquaculture in Mediterranean and Black Sea countries. Guide for the use of indicators to monitor sustainable development of aquaculture. Studies and Reviews. General Fisheries Commission for the Mediterranean. No 93. FAO, Rome, p 60
26. Simard F, Ojeda J, Haroun R (2008) The sustainable development of Mediterranean aquaculture: problems and perspectives. Options Méditerr B 62:113–124

Cetaceans in the Boka Kotorska Bay

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Abstract The Boka Kotorska Bay, as a unique geographical area, with specific ecological conditions, was always inhabited by cetaceans. There is very little recorded data on their presence in the bay. This article presents an overview of cetacean species inhabiting the southern Adriatic Sea, with a particular focus on bottlenose dolphin and fin whale, species whose presence has been documented in the Boka Kotorska Bay. A detailed review on the presence of one of the most famous dolphins in the bay, the dolphin Joca, who was a favourite with swimmers and bathers and was awarded a special protection status by the local government of the city of Kotor has been carried out. A history of unfortunate events – accidental and intentional dolphin deaths in the last 20 years – is provided, as recorded by the society for protection of animals 'Fifi' from Kotor. This society of volunteers was involved in the protection of the Boka Kotorska Bay environment since its founding in 1997, and the protection of marine mammals was among its activities. An overview of the first survey of marine mammal populations in the Boka Kotorska Bay area within the frame of the EU IPA NETCET project is also provided. The results of the survey represent the first scientifically collected data on cetaceans in the area. Preservation of these species in the area of the bay requires constant

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involvement, education of the local population and children on the importance of preservation of cetaceans and careful development of all forms of tourism, including the nautical tourism, which is one of the gravest threats to marine mammals in the Boka Kotorska Bay area.

Keywords Boka Kotorska Bay, Bottlenose dolphin, Fin whale, South Adriatic, Stranding

Contents

1 Introduction

The Boka Kotorska Bay is characterised by a specific geomorphological position in the Adriatic Sea. It consists of four embayments – Herceg Novi and Tivat bays forming the outer part and Risan and Kotor bays, forming the inner part. The bay cuts deeply into the shore, so the influence of the open sea is not substantial. In the context of research of cetaceans in the area of the Boka Kotorska Bay, it has to be taken as an inseparable entity of the southern part of the Adriatic Sea. All cetaceans populating the Adriatic Sea today are highly migratory species, distribution areas of which are vast. Data on their presence in the area of the Boka Kotorska Bay are quite scarce; however, the data reveal their continuous presence in the bay.

This chapter provides an overview and biology of all cetacean species identified in the South Adriatic and thus the Boka Kotorska Bay and identified the presence of a number of individual species in the bay based on reference data and research and overview of bottlenose dolphin killings on the territory of the Boka Kotorska Bay.

2 Presence of Cetacean in the South Adriatic Sea

*2.1 The Common Bottlenose Dolphin (***Tursiops truncatus***)*

The common bottlenose dolphin (*Tursiops truncatus*) is found throughout the Mediterranean Sea [1]. It favours regions where neritic waters are important such as the northern Adriatic [2]. They are also found in other habitats, ranging from oceanic waters to lagoons and river deltas (see Bearzi et al. [3] for a review) (Fig. 1).

Since the 1980s long-term research and monitoring of the ecology of common bottlenose dolphins have been ongoing in the Lošinj-Cres archipelago and its adjacent areas [1, 2, 4–7]. The core research tool used in this region is photo-identification. This research has provided the first quantitative information on population dynamics of the local population of common bottlenose dolphins in the Adriatic Sea [4, 8–10]. Other studies of populations of the common bottlenose dolphin were initiated in Slovenia [11, 12], the central Croatia in 2002 [13], south Croatia in 2007 [14–16] and Montenegro in 2012 (authors' data). Additional data has been collected from short and medium term from both Italian and Croatian waters [17–19].

Aerial surveys were carried out in 2010 and 2013 by ISPRA and the Blue World Institute [20–23] to provide a snapshot of the summer distribution and abundance of common bottlenose dolphins throughout the Adriatic Sea Basin. The aerial surveys confirmed that the common bottlenose dolphin is the only cetacean species regularly observed in the Adriatic Sea [1, 2, 7]. It is clear that this species prefers the neritic environment ($<$200 m) more than the oceanic one, especially areas with depths $<$100 m.

The absence of quantitative historical information limits the possibility to infer population trends in the Adriatic Sea. However, local experts believe that the common bottlenose dolphin numbers possibly declined by as much as 50% in the second half of the twentieth century, largely due to deliberate killing, with

Fig. 1 The common bottlenose dolphin (*Tursiops truncatus*). Photo by D. Holcer, Blue World Institute

additional stresses from habitat degradation and overfishing of prey species [1, 24, 25]. A recent study on genetics does not seem supporting this conclusion for such an abrupt and dramatic decline at the basin level [26]. The aerial survey data collected in 2010 and 2013 provide a baseline for quantitative comparison for the entire basin and for its subregions in the future [20, 21].

The Adriatic Sea population structure of common bottlenose dolphins follows the 'meta-population concept', comprising of 'local populations' that are discrete or relatively discrete entities in space, but interact via migration, and hence there is a gene flow [27]. The meta-population concept implies that the processes of 'geographical extinction' and 'recolonisation' may occur 'regularly'. The genetic structure of the common bottlenose dolphin within the Adriatic Sea, based on mitochondrial (mtDNA) and nuclear DNA analysis, was analysed for 63 samples by Gaspari et al. [28] who found that the population cannot be considered as a single 'unit to conserve'. The Adriatic common bottlenose dolphins reveal a fine-scale genetic structure with differentiation between north and central-south subbasins (mtDNA) and between the western and eastern coasts (nuclear DNA). This subdivision reflects the existing physiographic differences along both latitudinal and longitudinal axes of the basin. The genetic structure suggests that females are the principal gene flow mediators. Migration rates indicate a relatively high level of gene flow from the northern Adriatic to adjacent areas, with mtDNA and nuclear DNA analysis revealing diverse levels of differentiation between the Adriatic putative local populations and the Tyrrhenian Sea and the Aegean Sea. This reinforces the MSFD subregion 'Adriatic Sea' as an ecologically meaningful management area for this species. However this requires that additional research be undertaken in the Adriatic Sea for the development of appropriate management and conservation measures. Gaspari et al. [28], despite potential sample size limitations, suggest that the appropriate level for conservation issues is at the 'subregional', if not the 'local', population level, rather than basin-wide. Potential threats should be evaluated accordingly.

Data from photo-identification research also suggests that the common bottlenose dolphins of the Adriatic Sea are structured in putative local populations [9, 11, 12, 16, 29]. Social characteristics play an important role in structuring a meta-population and should be investigated to inform on inter alia average home ranges of populations.

The Mediterranean common bottlenose dolphin subpopulation is listed as 'vulnerable' under IUCN (World Conservation Union) criterion A2dce [25].

2.2 *The Striped Dolphin (*Stenella coeruleoalba*)*

The distribution of the striped dolphin reflects the oceanographic characteristics of the regions' subbasins [2, 20]. They occur in sea depths greater than 600 m, feeding mostly on cephalopods and epipelagic fish [30]. It is only exceptionally found in

Fig. 2 The striped dolphin (*Stenella coeruleoalba*). Photo by G. Pleslić, Blue World Institute

areas less than 200 m [2, 31]. On occasion solitary dolphins and small groups appear in the shallow northern portion of the Adriatic Basin [32–35]. The striped dolphin is a gregarious species found in large herds of several hundred in the South Adriatic Sea [20], in contrast in the northern Adriatic group size which ranges from one to three specimens (Fig. 2) [32–35].

The genetic population structure of the striped dolphin in the Adriatic Sea in unknown. However, a very preliminary study ($n = 15$) suggests that specimens using the Adriatic Sea are not strongly differentiated from those of other parts of the Mediterranean Sea [36].

The Mediterranean subpopulation of the striped dolphin is listed as 'vulnerable' under IUCN (World Conservation Union) criterion A2bcde [37].

*2.3 The Short-Beaked Common Dolphin (***Delphinus delphis***)*

The short-beaked common dolphin has a worldwide distribution (Fig. 3). Historically, it was distributed throughout the Mediterranean Sea and was once considered the most abundant cetacean species in the region. The abundance of this species is in steep decline throughout the Central and Eastern Mediterranean [3]. The only notable population remaining is in the Alboran Sea [38]. The overview of species status and ecology is reviewed in Bearzi et al. [3].

The Mediterranean short-beaked common dolphin is found mainly in pelagic and neritic habitats [39] where they feed mainly on epipelagic and mesopelagic shoaling fish and cephalopods [3].

The short-beaked common dolphin was once widely present in the Adriatic Sea until the mid-nineteenth century. Numerous records noted that the species was the most common in the Adriatic Sea [40–42]. During the late 1970s, there was a sharp decrease in the numbers and group sizes of short-beaked common dolphins in the

Fig. 3 The short-beaked common dolphin (*Delphinus delphis*). Photo by T. Kopcsanyi, Blue World Hungary

Adriatic [43]. Since then the species has disappeared from the northern Adriatic Sea [7, 44–46]. Only solitary individuals or small groups have been documented since the late 1990s [34, 47–50]. Overfishing, organised culling and habitat degradation are suggested as the main reasons for the decline and disappearance of this species from the Adriatic Sea [24]. Due to the lack of information from the central and southern Adriatic, this species was listed as data deficient in the Croatian Red List, although it was indicated that species could be critically endangered [51].

Aerial surveys from 2010 and 2013 of the entire Adriatic Sea [20, 21] and ISPRA and BWI (*unpublished data*) did not provide any sightings of the short-beaked common dolphin, which leads to the conclusion that this species is regionally extinct in the Adriatic Sea.

The short-beaked common dolphin of the Mediterranean is listed as 'endangered' under IUCN (World Conservation Union) criterion A2abc (Bearzi et al. [3]).

*2.4 The Cuvier's Beaked Whale (*Ziphius cavirostris*)*

The Cuvier's beaked whale is a midsized cetacean (Fig. 4). Adults reach between 5.5 and 7 m in length [52]. It is the beaked whale with the widest distribution range, globally, absent only in polar waters [53].

Cuvier's is the only beaked whale species known to regularly occur throughout the entire Mediterranean Sea [54, 55]. Distribution of the Cuvier's beaked whale is often associated with deep slope habitat and a preference for submarine canyons, steep slopes, scarps or submarine mounts [56–58].

Data collected from 1990 to 2010 for habitat modelling of Cuvier's beaked whales in the Mediterranean Sea identified the Alboran Sea, the Central Ligurian Sea, the Hellenic Trench and the South Aegean Sea (north Cretan Sea) as the areas of highest predicted density. The areas of the Tyrrhenian Sea, the southern Adriatic Sea, some areas to the north of the Balearic Islands and south of Sicily had higher

Fig. 4 The Cuvier's beaked whale (*Ziphius cavirostris*). Photo by G. Pleslić, Blue World Institute

predicted densities compared to the rest of the Mediterranean [59]. The modelling exercise did not include all of the records latter collected from the Adriatic Sea, making this area under-evaluated.

Information regarding the distribution and occurrence of this species in the Adriatic Sea is scarce. Historically the species was considered an occasional visitor to the deeper southern basin, where stranded specimens have been regularly found [60–68]. The review paper by Holcer et al. [69] presents a detailed overview on the occurrence of the species in the Adriatic concluding that the southern Adriatic Sea could be an important habitat for Cuvier's beaked whale. In total 11 stranded specimens of Cuvier's beaked whales had been documented in the Adriatic Sea until 2004 [69]. Five of these were recorded along the Italian Apulian coast, one in Albania and another five strandings along the Croatian Adriatic shore. Additionally, in 2008 a newborn was found stranded in Trstenica bay on the Pelješac Peninsula in Croatia [70]. Two stranded animals, previously unreported, were examined by Pino d'Astore et al. [71]. Finally, an additional two stranded animals were recently reported by the Museo Civico in Gallipoli and Department of Pathology, University of Bari, to the Italian stranding database (http://mammiferimarini.unipv.it).

Strandings of Cuvier's beaked whale in the Adriatic show that animals have been found around the entire southern Adriatic Basin. There have been no reports in the northern Adriatic Sea, and the occurrence in the central Adriatic seems marginal. Considering the ecology of the Cuvier's beaked whale as a deep-diving species with preference for deep slope habitats, the lack of occurrence in the rather shallow continental shelf of the northern Adriatic is not surprising.

The analysis of the stomach contents of an individual from the Adriatic Sea revealed similar prey species as found in other stranded specimens in the Mediterranean. This included Histioteuthidae (34.7%), Octopoteuthidae (39.1%, not found in the Adriatic), Chiroteuthidae (17.7%), Cranchiidae (8.2%, not found in the Adriatic) and Sepiolidae (0.2%) [70]. Furthermore, some of the prey species found in the stomach contents were not recorded in the Adriatic Sea indicating either some form of migration between Adriatic and Mediterranean or a broader lack of knowledge of the deep living cephalopods of the Adriatic Sea by researchers.

In addition to strandings, the presence of Cuvier's beaked whales in the Adriatic Sea has been confirmed through two aerial surveys in 2010 and 2013 [20, 21, 72]. In total, five confirmed sightings were made in areas with a water depth between 700 and 1,200 m and steep bathymetry. It is notable that the sightings are grouped along the northern and eastern part of the South Adriatic Basin where there is a steep drop to the depth of 1,000 m. Within the sighting areas, many of the known prey species are found. Sightings included females with juvenile animals indicating that the southern Adriatic could be an important nursery area.

The indication of group size based on five sightings during aerial surveys in the Adriatic is 2,6 (Holcer, Fortuna unpublished data). The analysis of genetic diversity of 87 samples obtained worldwide (ten Mediterranean, two Adriatic) found that mtDNA haplotypes from the Mediterranean Sea were not found elsewhere and were highly distinct from the neighbouring eastern North Atlantic [73]. This could indicate a low level of exchange between the two basins. Of the two haplotypes (T3 and T4) found, only one (T3) was found in the two specimens stranded on the Croatian coast [73].

The Cuvier's beaked whales in the Mediterranean are currently listed as 'data deficient' [74].

2.5 *The Risso's Dolphin (*Grampus griseus*)*

Risso's dolphins are relatively large dolphins measuring up to 4 m in length [75]. The most distinctive feature of this species is the blunt head without a beak and the dark colouration dominated by scars which they accumulate throughout life (Fig. 5). Older animals appear almost white in colour. Risso's dolphins are distributed worldwide in tropical and temperate seas. They prefer deep offshore waters and coastal areas with narrow continental shelves [76].

The Risso's dolphin throughout the Mediterranean Sea is considered a regular inhabitant, although abundance is unknown [39]. Risso's dolphins are encountered in deep pelagic waters, in particular over steep shelf slopes and submarine canyons in the Mediterranean Sea [36, 77, 78]. Gaspari [36] suggests that the distribution of the Risso's dolphin is not a function of depth but habitat; Risso's dolphins prefer areas of greater depth and where the continental slope was deeper and steeper, possibly related to a feeding specialisation. The analysis of the stomach contents of stranded Risso's dolphins indicates that species feeds mostly on cephalopods inhabiting oceanic waters over steep continental slope areas [79, 80]. The analysis of Blanco et al. [81] indicates that Risso's dolphins feed mainly on cephalopods from the middle slope of the continental shelf edge (600–800 m depth). Risso's dolphins are regularly observed and found stranded in most areas of the Mediterranean Sea [82].

Fig. 5 The Risso's dolphin (*Grampus griseus*). Photo by Blue World Institute

Within the Adriatic Sea, Risso's dolphins have been recorded on numerous occasions. First records originate from the nineteenth century [40, 42, 83, 84]. Most records originate from the Italian and Croatian coastlines where stranded animals have been found [41, 63–65, 85–90]. According to the available information, no animals have been observed or found stranded on the coasts of Slovenia, Montenegro or Albania. On several occasions, individuals that are stranded live, while some have died; others have successfully returned to the sea [85]. In most instances, records relate to single animals; only in two cases more animals were observed. Three animals were observed near the Gulf of Trieste [87] and two animals were found stranded on the island of Molat [89]. Most authors conclude that the Risso's dolphin is only occasionally present in the Adriatic Sea [24].

Research carried out in the northern Adriatic Sea between 1988 and 2013 [4, 6, 9, 17, 29] has not recorded any sightings of Risso's dolphin. Additionally, localised surveys in the central Adriatic [14, 16, 91–95] have not recorded any sightings of the Risso's dolphins. It must be considered, however, that all research effort was undertaken in areas which would not normally represent a usual habitat for Risso's dolphins, and thus their absence could be expected.

The two aerial surveys carried out on the basin-wide scale confirm such conclusions [20, 21, 96]. Risso's dolphins were only observed in the southern Adriatic along the steep slope areas with depths between 600 and 900 m. Several additional opportunistic observations have been reported from the ferries traversing the southern Adriatic Sea [97]. Such results are consistent with the known habitat preferences and feeding specialisation of Risso's dolphins [77].

The Risso's dolphin of the Mediterranean is listed as "data deficient" [98].

*2.6 The Fin Whale (*Balaenoptera physalus*)*

Fin whales are most commonly found in the deep waters (400–2,500 m) of the Mediterranean Sea (Fig. 6). However, they can occur in slope and shelf waters,

Fig. 6 The fin whale (*Balaenoptera physalus*). Photo by D. Holcer, Blue World Institute

depending on the distribution of their prey (e.g. Canese et al. [99]). They favour upwelling and frontal zones [100] and coastal areas [99] with high zooplankton concentrations.

Most records in the Adriatic Sea rely on strandings and sightings of stray individuals which are scattered throughout the northern and central Adriatic ([101], BWI *unpublished data*), and some regular sighting in the central Adriatic which suggests distribution is likely related to the seasonal presence of their primary prey [20].

The only genetic information available for a fin whale from the Adriatic Sea is the analysis of a single specimen which showed an allotype typical from the Ligurian Sea [102].

The fin whale is listed as 'vulnerable' in the Mediterranean under IUCN (World Conservation Union) criterion C2a(ii) [103].

2.7 *The Sperm Whale (*Physeter macrocephalus*)*

The sperm whale population of the Mediterranean is genetically distinct [104] (Fig. 7). There is no estimate of population size for the region. Preferred Mediterranean habitats are areas of deep continental slope waters where mesopelagic cephalopods are abundant [77, 105].

The occurrence of sperm whales in the Adriatic Sea includes 36 strandings documented from as early as 1,555 [106]. This is the only cetacean species that had a mass stranding on the Adriatic Sea coast. In December 2009, a pod of seven male sperm whales was stranded on the northern side of Gargano promontory [107]. The last recorded occurrence of a group of sperm whales was in summer of 2014, when seven animals were observed swimming along Croatian coast up to northern Dalmatia. The latter group was stranded near Vasto in Italy. Four animals were refloated, while three died on the beach. Sperm whales are deep-diving cetaceans; as such they have no suitable habitat in the central and northern Adriatic.

Fig. 7 The sperm whale (*Physeter macrocephalus*). Photo by G. Barathieu, CC BY-SA 2.0

The deeper southern Adriatic may host vagrant animals from the Ionian Sea or animals during seasonal migration. Given its physiography and size, it is probably not an area of regular distribution for the Mediterranean sperm whale. This is consistent with the results of the aerial surveys [20, 21] and towed hydrophone surveys which did not produce any sightings or recordings [50].

3 Cetacean Species in the Boka Kotorska Bay

Bottlenose dolphins in the Boka Kotorska Bay have for centuries been dear and appreciated residents of the sea. The people from the Boka Kotorska Bay were always ready to help them when in trouble and take care of their calves. They are considered friends of seafarers in particular, but also of all people in general. By 1980s, dolphin pods used to arrive to the bay. Identification of species and continuous monitoring of dolphin presence in the Boka Kotorska Bay had not been done before 2013. Namely, Montenegro restored its independence in 2006, and it renounced all the legal acts and international agreements that are used to be applicable on its territory during the former State Union of Serbia and Montenegro. Upon restoration of independence, there was a need for re-establishing and signing of numerous international agreements concerning the environmental protection, including the Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS). The ACCOBAMS (Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and Contiguous Atlantic Area) is a cooperative tool for the conservation of marine biodiversity in the Mediterranean and Black Seas. Its purpose is to reduce threats to cetaceans in Mediterranean and Black Sea waters and improve our knowledge of these animals. It requires the states to implement a detailed conservation plan for cetaceans, based first on respect of legislation banning the deliberate capture of cetaceans in fishing zones by their flag vessels or those subject to their jurisdiction, on measures for minimising incidental capture and, finally, on the creation of protected areas. This approach combines both the protection of threatened species and the institution of reinforced geographic protection. Governments are also undertaking to assess and manage the interactions between humans and cetaceans; conducting research and continuous monitoring; developing programmes to inform, train and educate the public; and setting up emergency response measures [108].

At the fifth sitting, held on 25 November 2008, the Parliament of Montenegro ratified the ACCOBAMS [109]. With this agreement, Montenegro, as the ecological state, bound itself to protect dolphins and whales on its territory and observe all the guidelines and proposals as laid down by this convention.

However, this is not the first legal framework for dolphin protection on the territory of Montenegro. Namely, in 1987 a dolphin entered the Boka Kotorska Bay and the population named him Joca. He gained his popularity because he often swam with children and adults and kept fishermen company; he even liked to pose so the majority of tourists in the Boka in those years, in the period 1987–1992, had a photo with the dolphin Joca. He belonged to the species *Tursiops truncatus,* the bottlenose dolphin, known to live in smaller or larger groups. In difference to other members of his species, Joca led a solitary life – he belonged to the group of solitary animals. The existence of solitary animals of this species is known. The reasons dolphins become solitary are common to many mammalian species, but the response of some dolphins to the solitary state, including a redirection of social responses to humans or other species, could be unique to the Delphinidae [110].

Dolphin Joca was the main tourist attraction of the Boka Kotorska Bay at the time. The popularity among local population of the bay induced the local assembly of the municipality of the town of Kotor to adopt on 28 July 1987 the decision on the protection of dolphin Joca on the territory of the aquatorium of the municipality of Kotor. We take this decision of the local assembly of the municipality of the town of Kotor as the first legal act that specifically protects marine mammals in the Montenegrin coastal area. The text of the decision and its articles show the care and affection of the town's management for the dolphin Joca, and we present the text of the decision of the local assembly of the municipality of Kotor in its entirety:

> Pursuant to Articles 151 and 169 of the Statute of the Municipality of Kotor and provisions of Articles 3 and 4 of the Law on Nature Protection (Official Gazette of the Socialist Republic of Montenegro 36 of 19 December 1977), at sittings of the Council of Associated Labour, the Council of Local Communities and the Socio-Political Council of equal authority, held on 28 July 1987, adopt the
>
> DECISION
>
> On placing under special protection Dolphin JOCO, member of the famous Adriatic family of Delphinidae, who has been residing in the beauties of the Kotor Bay for a longer period of time
>
> Article 1
>
> The Dolphin Joco, member of the Delphinidae family, with broad flippers, odd number of dorsal fins and horizontal flukes, the best swimmer of the Bay, about 4 meters long, with shiny skin, highly intelligent, favourite of the youngest and their best companion from the sea shall be placed under special protection.
>
> With his physical appearance, swimming skills, frequent, unselfish and attractive jumps, he wins the hearts of locals and tourists, staying in the photo, verse, lenses. The

Bay gains more attraction with JOCO and the Bride of the Adriatic[1] is now richer by one more rarity of the nature.

Article 2

For the purpose of providing particular protection of the integrity of the Dolphin JOCO, with qualities described in the Article above and in order to ensure conditions for his free residence in the Bay, the following shall be prohibited:

- Move him from his habitat,
- Chase him, hunt him or disturb him,
- Injure or destroy him.

Article 3

A fine ranging from 40,000-60,000 dinars shall be imposed on a natural person for offence referred to in Article 2 of this Decision.

Article 4

The competent authorities of the state shall ensure criminal legal protection and possible prosecution in accordance with the penalty provisions of the Law on Nature Protection.

Article 5

The supervision over the implementation of this Decision shall be done by the Inter-municipal Marine Fisheries Inspector Kotor.

Article 6

This Decision shall enter into force on the 8th day from the day of its publishing in the Official Gazette of the Socialist Republic of Montenegro – Municipal legislation.

Ref. No.: 01-3019/1
Kotor, 28 July 1987
Local Assembly of the Municipality of Kotor
President
Anđelko Kovačević, manu propria
President of the Council of Local Communities
Nikica Franović, s. r.
President of the Council of Associated Labour
Andrija Bilafer, manu propria
President of the Socio-Political Council
Ljubo Mačić, manu propria

There are numerous video footages of the dolphin Joca playing with the residents of the Boka Kotorska Bay [111], but this dolphin became the most famous for his part in the movie *The Dark Side of the Sun* [112], by renowned Montenegrin director Božidar Bota Nikolić, in which one of the main roles is played by Milena Dravić, ex-Yugoslav movie star, and Brad Pitt, currently one of the most famous actors in the world. The scene with dolphin Joca starts in the 38th minute of the movie and lasts for 40 s, with the famous actor Brad Pitt, as a part of his role in this movie, swimming together with dolphin Joca.

Joca disappeared somewhere between 1992 and 1993. It is not clear whether he left forever or may have been killed by people.

After this period, there was no systematic monitoring of dolphins' arrivals to the Boka Kotorska Bay by 2012 and the beginning of implementation of the NETCET project – Network for the Conservation of Cetaceans and Sea Turtles in the Adriatic [6] – which was financed under the IPA programme of Adriatic cross-border

[1] *Bride of the Adriatic* is how Serbian poet, Aleksa Santic, refers to the Boka Kotorska Bay in one of his famous poems.

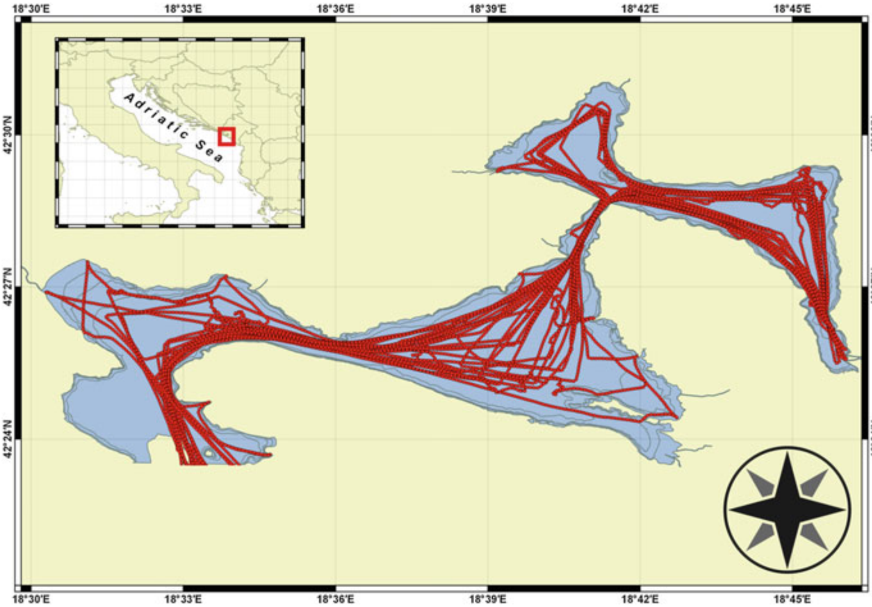

Fig. 8 Navigational tracks for the dolphin photo-ID survey in the Boka Kotorska Bay in 2013/2014

cooperation. Under this project, the Institute for Biology of the University of Montenegro began dolphin monitoring on the territory of the Boka Kotorska Bay in 2013, using the photo-identification method [29]. Scientists conduct a boat-based survey of a certain area of aquatorium and upon sighting dolphins take high-resolution photographs using a telephoto lens. Photographers focus mainly on dolphins' fins and backs, as the nicks, grooves and scars visible there are specific to each animal and can be used as identifying marks, much like a person's fingerprint. Usually, the goal is to photograph each animal in the group from both the left and right side, as the markings can be different on each side of their bodies. After a selection process (it is not unusual for photographers to take several thousand photos during a single day's survey, only a fraction of which will be of high enough quality to be useful for photo-identification), the photos are analysed using standard photo-identification method [29]. Each animal in a given sighting is compared to other animals from the same sighting, until all of them have been successfully identified. Adding the results to a database allows the scientists to see the frequency of sightings for each animal, differentiating between frequent visitors (or permanent residents) and those visiting only occasionally or even just once.

Navigational data from each trip are also analysed, providing the data on location of each sighting, as well as on the length of each field trip, distance covered and any other relevant information collected during the survey.

During the Montenegrin photo-ID survey of 2013–2014 within the frame of NETCET project, the researchers covered the distance of about 540 nm (1,000 km) in the Boka Kotorska Bay (Fig. 8), spending a total time of 55 h at sea at an average

Fig. 9 Bottlenose dolphins from the Kotor Bay. Photo by V. Vuković and M. Đurović

speed of 9.7 knots (18 km/h). Eight individuals were identified on several occasions in the Boka Kotorska Bay (Fig. 9), whether in smaller (two to four individuals) or larger groups (five to eight individuals). Although animals would be absent from the bay for days at a time, reports from the local fishermen confirm their presence in the bay throughout the year, regularly damaging gill nets and trammel nets in their search for food.

Apart from the bottlenose dolphin, the presence of the fin whale *Balaenoptera physalus* was also recorded in the bay. On 17 December 2011, early in the morning, one individual of fin whale was recorded by amateur camera in the most inner part of Boka Kotorska Bay – in the bay of Kotor (42°25′37.67″ N, 18°45′33.84″ E), where the maximum depth is between 5 and 7 m. By detailed analyses of the recorded material by the researchers from the Institute of Marine Biology (Kotor), it was estimated that the specimen was about 10 m long. This is the first occurrence of the fin whale in such shallow waters up to now [113].

One explanation for this unusual appearance in Boka Kotorska Bay may be a heavy storm, accompanied by strong winds on previous night and that morning in the southern Adriatic. It is possible that the whale was seeking a sheltered area from the storm and was most likely to stray into very shallow waters of the most inner part of the Boka Kotorska Bay (Fig. 10).

Another possible explanation may lie in intensive oil and gas exploration in the southern Adriatic. It is well known that these investigations include geophysical surveying with airguns and underwater explosions. Together with bad weather, these factors may have affected the movements of this individual in Boka Kotorska Bay [113].

It is widely known that fin whale sighting is registered primarily in deep waters, far from the shore. Thus, some surveys done in the Mediterranean show that mean depth where these whales were registered ranged from 1,775 m in the Central

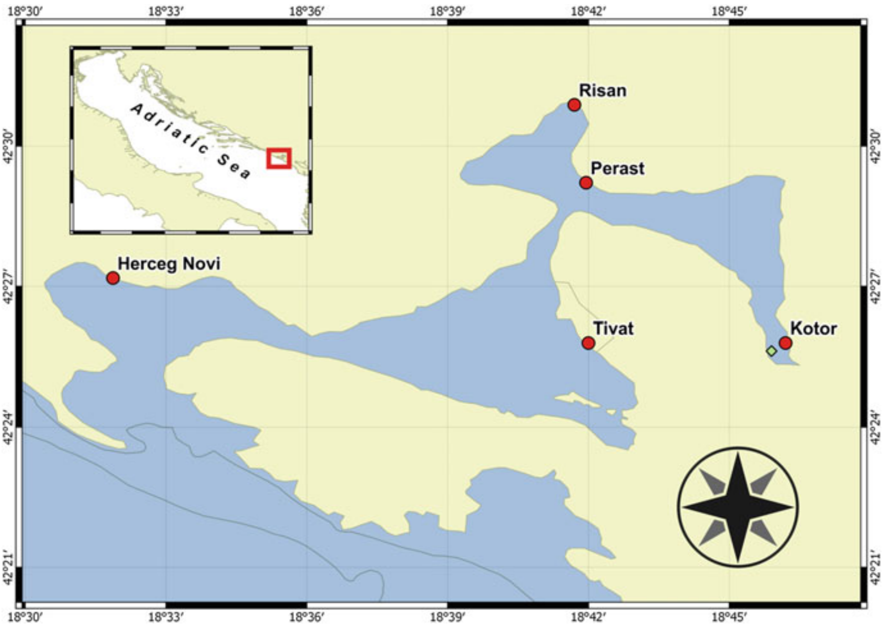

Fig. 10 Geographical position of Boka Kotorska Bay and location where fin whale was sighted (*green diamond*)

Mediterranean [2], above 2,248 in the Ligurian Sea [114], to 2,360 in the Western Mediterranean [115].

These surveys show that the presence of fin whale in the Adriatic Sea is very rare, particularly in the shallow waters of the northern and central part, and observed individuals in the Adriatic are believed to originate from the eastern Mediterranean/Ionian feeding grounds [100]. Other authors [101] agree, but they believe that the appearance of fin whales in shallow waters of the northern Adriatic can be a sign that something new is going on in the northern Adriatic Sea.

Stranding of this specimen in the Boka Kotorska Bay had been expected, but taking into account that its sighting had not been registered in the bay afterwards, we are certain that it left, which shows the ability of this animal to find its way through very narrow and shallow passages of the Boka Kotorska Bay.

4 Stranding of Cetaceans in the Boka Kotorska Bay

It is known that accidental or deliberate killings of marine mammals are happening in the Mediterranean, in the Adriatic and even in the Boka Kotorska Bay. Fisheries pose the great risk to marine mammals, since the number of specimens that get entangled in the fishermen's nets, particularly set nets, is not insignificant. As they are not able to reach the surface, the animals drown.

Due to restricted fishing activities in the Boka Kotorska Bay (fishing with large trawls prohibited and with maximum allowable set net length of 160 m), marine mammals residing in the bay are not under the huge pressure from fishermen. Naturally, the years of long experience in the work with fishermen show that very few of them are happy to see them, mainly because they believe dolphins eat too much fish.

According to historical data, from the end of the nineteenth century until 1990, dolphin killing campaigns were organised along the eastern coast of the Adriatic Sea, including the Boka Kotorska Bay. These campaigns were justified by views that dolphins are pests in the sea that need to be exterminated. Of course, the main objective was to create as much space for fishermen as possible. In order to encourage this activity, monetary awards were given for accidental or deliberate dolphin killings. The first data on monetary awards date back to 1,872, when the port authorities of Trieste and Rijeka paid compensations for every dolphin killing, as an attempt to reduce the conflicts with fishermen by promoting this activity [116]. Furthermore, in the period of the Kingdom of Serbs, Croats and Slovenes, the government had paid two allowance types – one for accidental death and a higher one for deliberate killing. According to the same author [116], a total of 335 dolphins were killed in the period 1933–1935. After the World War II (1945), the dolphin killing campaign was intensified throughout the territory of former Yugoslavia, and it is believed that around 5,000 dolphins were killed on the territory of Slovenia, Croatia, Bosnia and Herzegovina and Montenegro in the period 1950–1960 [117]. During the eradication campaigns, every opportunity was taken to harm dolphins. A number of ideas were proposed to exterminate them, including the use of dedicated boats, special nets, harpoons, guns and other weapons [116]. Although the perception of dolphins as mere competitors and game trophies progressively changed in subsequent years [118], dolphin killings remained legal until 1995.

There are no written records that such dolphin killing campaigns were organised on the territory of the Boka Kotorska Bay, but in talks with older fishermen, we learned that they remember quite well that compensations were paid for a killed dolphin through fishermen's cooperatives, particularly in the period 1950–1965 (Đurović M, personal communication), which corresponds to the data on the eastern Adriatic mentioned above.

Unfortunately, numerous dolphin deaths occurring in the last decade of the twentieth century remained unrecorded on the territory of the Boka Kotorska Bay, and they received no particular attention. After the establishment of the Animal Protection Society Fifi from Kotor in 1997, led by Nevres Đerić, engineer, an intensive campaign aimed at protecting the dolphins on the territory of the bay began. Furthermore, this society is active in protection of other species, such as sea turtles and stray dogs; they also point to the issue of illegal dumping sites on the territory of the entire bay. The society established the eco-patrol Joca, comprising numerous enthusiasts and nature lovers who, on voluntary basis, work on overall

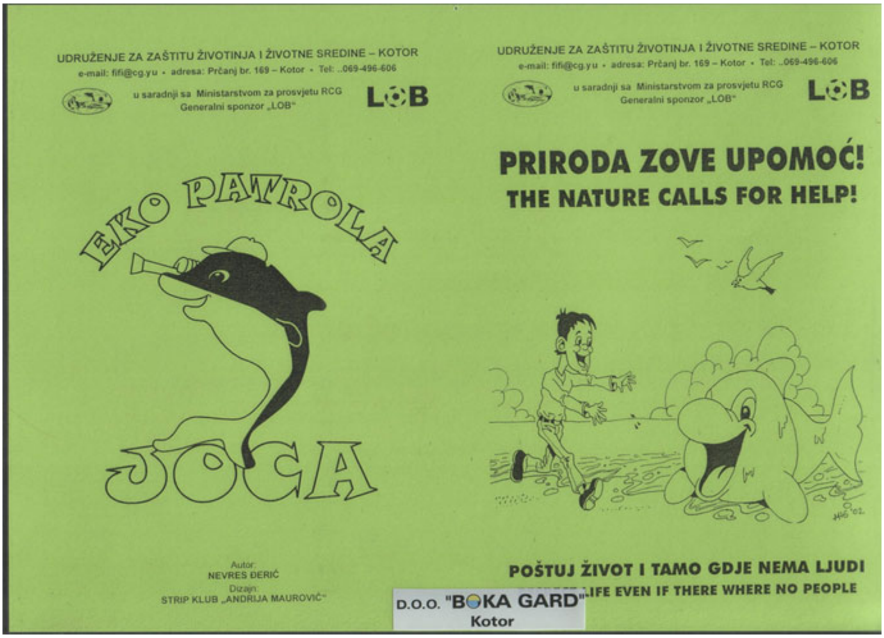

Fig. 11 Eco-patrol Joca, logo of the campaign

protection of the environment of the Boka Kotorska Bay. This society is running a proactive campaign, printing a large number of posters, flyers and brochures (Fig. 11); it is often in local and regional media, pointing to environmental problems or, more specifically, to the importance of preventing the dolphin killings and strict penalising of those accountable for such acts by the competent national authorities.

The Animal Protection Society Fifi tours and controls the Boka Kotorska Bay on daily basis and records any harm to the environment. Thus, the eco-patrol Joca found a dead dolphin on 15 August 1999 in the Kotor Bay (Fig. 12). It was established that it was a bottlenose dolphin female, 335 cm in length, weighing 240 kg. The dolphin was killed by dynamite.

A few days after this event, another dead dolphin was found in the Kotor Bay. This time, the post-mortem examination established death caused by firearms, as multiple perforating wounds were found on the dolphin's body. That year, several dolphin pods were spotted in groups of six and above [119].

Just a few months later, a bottlenose dolphin calf, 1.5 m long, was found in the area of Bigova; death was caused by dynamite [120].

After a calm period that lasted for almost 1 year and a half, a dead dolphin was found in the vicinity of Herceg Novi. Again firearms were used (two perforating gunshot wounds were identified) to deliberately kill a bottlenose dolphin 3 m long [121] (Fig. 13).

Fig. 12 Flyer of the Animal Protection Society Fifi, made after a dolphin was killed using dynamite

Fig. 13 Bottlenose dolphin killed by firearms in Meljine, 2001. Photo by S. Kosić

After just more than a week after this sad incident, another dolphin was found near Bigova, killed by dynamite [122]. No violent deaths of dolphins occurred in the area of the Boka Kotorska Bay several years after this incident, until 2008, when a dead dolphin was washed ashore on the beach of Igalo.

Flukes were cut off this dolphin with a very sharp knife, so it was assumed that one or more persons deliberately killed the animal taking the flukes as a trophy (Đurović M, unpublished data). According to the data available, this is the last case of violent dolphin death on the territory of the Boka Kotorska Bay. However, it should be noted that in the open sea, the use of dynamite continues, and violent death cases occur every year from the area of Ulcinj to the entry into the Boka Kotorska Bay.

The latest data on dead dolphins in the bay date from 2013, when two young bottlenose dolphin animals were found on the beach of Kalardovo near Tivat; death is most probably caused by drowning in the fishing nets (Ikica Z, unpublished data).

5 Conclusion

Based on all the data available, obtained from archive surveys and data from field surveys, we can conclude that the Boka Kotorska Bay is regularly visited only by bottlenose dolphins. The Boka Kotorska Bay is a very specific area, comprising four small embayments (Herceg Novi, Tivat, Risan and Kotor bays), cut deeply into the coast (26 km) with very shallow mean depth (about 40 m) and medium bay volume, so for bottlenose dolphins visiting it, it is just a temporary residence they use only for feeding. The number of animals in groups identified ranged from two to eight per pod. The occurrence of the fin whale in the Boka Kotorska Bay is an unusual event with a happy ending, because we are certain that the whale found its way out and left the bay.

The presence of the solitary dolphin Joca is deeply impressed in the memory and in many footages and photographs of numerous locals and tourists that visited the Boka Kotorska Bay at the time. Also, the decision of the local assembly of the town of Kotor placing the dolphin Joca under protection shows that even back then, many feared this dolphin would suffer bad fate. Joca disappeared somewhere between 1992 and 1993 and his body was never found, but it is assumed he was killed, like many other dolphins. These killings are the result of wrong decisions and assessments made in the past in a number of areas in the Adriatic by port and other authorities. Propaganda that dolphins are 'pests that need to be destroyed' because they harm fishery had lived for decades in the Adriatic, resulting in huge misfortunes and notable reduction in populations of all Cetaceans living in the Adriatic. Such heritage had influenced also some unconscientious residents of the Boka Kotorska Bay, who cold-bloodedly killed dolphins, causing major ecological harm.

Joint activities of citizens and establishing of ecological societies at the end of the twentieth century encouraged the competent national authorities to react more firmly and adopt European and international policies in the area of marine mammal protection. Not a single dolphin killing was recorded since 2008, so we deem that these activities had a positive effect on raising the awareness of the population, but various campaigns and education of schoolchildren on this topic should be continued.

The presence of bottlenose dolphins in particular in the Boka Kotorska Bay has been increasingly recorded by residents, which is understandable, as, nowadays, people have various recording and photographing devices and recordings are distributed quickly via websites and social networks, which was not the case before. The increasing number of cruisers, big yachts and speed boats sailing into the bay poses a major threat to the dolphins' safety, and in that sense we hope that they all would observe speed limits and increase safety of dolphins in the bay.

Acknowledgement We would like to express our gratitude to Mr. Nevres Đerić and all his colleagues from the Animal Protection Society Fifi who have, on voluntary basis, been protecting and warning all residents and tourists of the importance and the need to protect all the natural resources, pointed to the large number of illegal dumping sites and, finally, fought against dolphin killings and for placing all marine mammals in Montenegro under protection.

References

1. Bearzi G, Fortuna CM, Reeves RR (2008) Ecology and conservation of common bottlenose dolphins *Tursiops truncatus* in the Mediterranean Sea. Mamm Rev 39:92–123
2. Notarbartolo Di Sciara GN, Venturino MC, Zanardelli M, Bearzi G, Borsani FJ, Cavalloni B (1993) Cetaceans in the central Mediterranean Sea - distribution and sighting frequencies. Boll Zool 60(1):131–138
3. Bearzi G, Reeves RR, Notarbartolo-Di-Sciara G, Politi E, Canadas ANA, Frantzis A, Mussi B (2003) Ecology, status and conservation of short-beaked common dolphins *Delphinus delphis* in the Mediterranean Sea. Mamm Rev 33(3–4):224–252
4. Bearzi G, Notarbartolo di Sciara G, Politi E (1997) Social ecology of bottlenose dolphins in the Kvarnerić (northern Adriatic Sea). Mar Mamm Sci 13(4):650–668
5. Bearzi G, Politi E, di Sciara GN (1999) Diurnal behavior of free-ranging bottlenose dolphins in the Kvarnerić (northern Adriatic Sea). Mar Mamm Sci 15(4):1065–1097
6. Bearzi G, Costa M, Politi E, Agazzi S, Pierantonio N, Tonini D, Bastianini M (2009) Cetacean records and encounter rates in the northern Adriatic Sea during the years 1988–2007. Ann Ser Hist Nat 19(2):145–150
7. Bearzi G, Notarbartolo di Sciara G (1995) A comparison of the present occurrence of bottlenose dolphins, *Tursiops truncatus*, and common dolphins, *Delphinus delphis*, in the Kvarnerić (northern Adriatic Sea). Ann Ser Hist Nat 7:61–68
8. Fortuna CM, Wilson B, Wiemann A, Riva L, Gaspari S, Matesic M, Oehen S (2000) Pribanic S How many dolphins are we studying and is our study area big enough? In: Evans PGH, Pitt-Aiken R, Rogen E (eds) European research on cetaceans 14. Cork, Ireland, pp 370–373
9. Fortuna CM (2006) Ecology and conservation of bottlenose dolphins (*Tursiops truncatus)* in the North-Eastern Adriatic sea. University of St. Andrews, Andrews
10. Pleslić G, Rako-Gospić N, Mackelworth CP, Wiemann A, Holcer D, Fortuna CM (2014) How many bottlenose dolphins (*Tursiops truncatus*) inhabit the former Cres-Lošinj special marine reserve, Croatia? Euro Res Cetaceans 28, 259pp
11. Genov T, Kotnjek P, Lesjak J, Hace A (2008) Bottlenose dolphins (*Tursiops truncatus*) in Slovenian and adjacent waters (Northern Adriatic Sea). Ann Ser Hist Nat 18(2):227–244
12. Genov T, Wiemann A, Fortuna CM (2009) Towards identification of the bottlenose dolphin (*Tursiops truncatus*) population structure in the north-eastern Adriatic Sea: preliminary results. Varstvo Narave 22:73–80
13. Impetuoso A, Wiemann A, Antollovich W, Holcer D, Mackelworth PC, Fortuna CM (2003) A preliminary study of Cetacean presence and abundance in the archipelago of the Kornati National park (Croatia). In: Besendorfer V, Kopjar N (eds) 8th Croatian biological congress, Croatian Biological Society, Zagreb, Croatia, 27.09 - 2.10.2003

14. Holcer D, Wiemann A, Mackelworth P, Fortuna CM (2008) Preliminary results on the distribution and abundance of Cetaceans in the Croatian southern Adriatic Sea. In: 22nd conference of the European Cetacean Society. European Cetacean Society, Egmond aan Zee, Netherlands, 10-12th March 2008
15. Holcer D, Nimak M, Pleslić G, Jovanović J, Fortuna CM (2009) Survey of bottlenose dolphins (*Tursiops truncatus*) in the area of Lastovo island, Adriatic Sea. In: Besendorfer V, Kopjar N, Vidaković-Cifrek Ž, Tkalec M, Bauer N, Lukša Ž (eds) 10th Croatian biological congress. Croatian Biological Society, Osijek, September 14–20. pp 300–301
16. Holcer D (2012) Ecology of the common bottlenose dolphin, *Tursiops truncatus* (Montagu, 1821) in the Central Adriatic Sea. University of Zagreb, Zagreb
17. Bearzi G, Azzellino A, Politi E, Costa M, Bastianini M (2008) Influence of seasonal forcing on habitat use by bottlenose dolphins *Tursiops truncatus* in the northern Adriatic Sea. Ocean Sci J 43(4):175–182
18. Kammigan IC, Bräger S, Hennig V, Wiemann A, Impetuoso A (2008) Ecology of bottlenose dolphins (*Tursiops truncatus*) in the Kornati National Park, Croatia: Population estimation, group composition and distribution. In: Pierce GJ, Philips E, Lick R (eds) 22nd annual conference of the European Cetacean Society, European Cetacean Society, Egmond aan Zee, The Netherlands, 10–12 March 2008
19. Triossi F, Willis TJ, Pace DS (2013) Occurrence of bottlenose dolphins *Tursiops truncatus* in natural gas fields of the northwestern Adriatic Sea. Mar Ecol 34(3):373–379
20. Fortuna CM, Holcer D, Filidei Jr E, Donovan GP, Tunesi L (2011) The first cetacean aerial survey in the Adriatic Sea: summer 2010. 7th Meeting of the ACCOBAMS Scientific committee
21. Fortuna CM, Mackelworth CP, Holcer D (2014) Toward the identification of EBSAs in the Adriatic Sea: hotspots of megafauna. In: Mediterranean regional workshop to facilitate the description of ecologically or biologically significant marine areas (EBSAs), Convention on Biological Diversity, Málaga, Spain, 7–11 April 2014, p 5
22. Holcer D, Fortuna C, Filidei E, Mackelworth P, Tunesi L (2010) Distribution and abundance of megafauna in the Adriatic Sea: relevance for identification of important marine areas. In: 3rd international workshop on biodiversity in the Adriatic: towards a representative network of MPAs in the Adriatic, Piran, Slovenia, 28-29.10.2010
23. Holcer D, Fortuna CM, Mackelworth CP (2014) Status and conservation of cetaceans in the Adriatic Sea. Draft internal report. In: Mediterranean regional workshop to facilitate the description of ecologically or biologically significant marine areas (EBSAs), UNEP-MAP-RAC/SPA, Tunis, Málaga, Spain, 7–11 April 2014, p 70
24. Bearzi G, Holcer D, Di Sciara GN (2004) The role of historical dolphin takes and habitat degradation in shaping the present status of northern Adriatic cetaceans. Aquat Conserv Mar Freshw Ecosyst 14(4):363–379
25. Bearzi G, Fortuna CM (2012) *Tursiops truncatus* (Mediterranean subpopulation). http://www.iucnredlist.org/. Accessed 26 Feb 2014
26. Gaspari S, Scheinin A, Holcer D, Fortuna C, Natali C, Genov T, Frantzis A, Chelazzi G, Moura A (2015) Drivers of population structure of the bottlenose dolphin (*Tursiops truncatus*) in the Eastern Mediterranean Sea. J Evol Biol 42:177
27. Hanski I, Gaggiotti OE (2004) Metapopulation biology: past, present, and future. In: Hanski I, Gaggiotti OE (eds) Ecology genetics and evolution of metapopulations: standard methods for inventory and monitoring. Academic, Amsterdam, pp 3–22
28. Gaspari S, Holcer D, Mackelworth P, Fortuna C, Frantzis A, Genov T, Vighi M, Natali C, Rako N, Banchi E, Chelazzi G, Ciofi C (2013) Population genetic structure of common bottlenose dolphins (*Tursiops truncatus*) in the Adriatic Sea and contiguous regions: implications for international conservation. Aquat Conserv Mar Freshw Ecosyst n/a-n/a. doi:10.1002/aqc.2415

29. Pleslić G, Rako N, Mackelworth CP, Wiemann A, Holcer D, Fortuna CM (2013) The abundance of common bottlenose dolphins (*Tursiops truncatus*) in the former marine protected area of the Cres-Lošinj archipelago. Croat Aquat Conserv Mar Freshw Ecosyst. doi:10.1002/aqc.2416
30. Aguilar A (2000) Population biology, conservation threats and status of Mediterranean striped dolphins (*Stenella coeruleoalba*). J Cetacean Res Manag 2:17–26
31. Fortuna CM, Canese S, Giusti M, Revelli E, Consoli P, Florio G, Greco S, Romeo T, Andaloro F, Fossi MC, Lauriano G (2007) An insight into the status of the striped dolphins, *Stenella coeruleoalba*, of the southern Tyrrhenian Sea. J Mar Biol Assoc U K 87 (5):1321–1326. doi:10.1017/s002531540705669x
32. Bearzi G, Notarbartolo di Sciara G, Fortuna CM (1998) Unusual sighting of a striped dolphin (*Stenella coeruleoalba*) in the Kvarnerić, Northern Adriatic Sea. Nat Croat 7(3):169–278
33. Francese M, Picciulin M, Tempesta M, Zuppa F, Merson E, Intini A, Mazzatenta A, Genov T (2007) Occurrence of striped dolphins (*Stenella coeruleoalba*) in the gulf of trieste. Ann Ser Hist Nat 17:185–190
34. Rako N, Holcer D, Fortuna CM (2009) Long-term inshore observation of a solitary striped dolphin, *Stenella coeruleoalba,* in the Vinodol channel, Northern Adriatic Sea (Croatia). Nat Croat 18(2):427–436
35. Nimak-Wood M, Pleslić G, Rako N, Mackelworth P, Holcer D, Fortuna CM (2011) Presence of a solitary striped dolphin (*Stenella coeruleoalba*) in Mali Lošinj harbour, northern Adriatic Sea, Croatia. Vie et Milieu 61(2):87–93
36. Gaspari S (2004) Social and population structure of striped and Risso's dolphins in the Mediterranean Sea. University of Durham, Durham
37. Aguilar A, Gaspari S (2012) *Stenella coeruleoalba* (Mediterranean subpopulation). http://www.iucnredlist.org/. Accessed 26 Feb 2014
38. Canadas A, Hammond PS (2008) Abundance and habitat preferences of the short-beaked common dolphin *Delphinus delphis* in the southwestern Mediterranean: implications for conservation. Endanger Species Res 4:309–331
39. Notarbartolo di Sciara G, Birkun A (2010) Conserving whales, dolphins and porpoises in the Mediterranean and Black Seas: an ACCOBAMS status report. ACCOBAMS, Monaco
40. Brusina S (1889) Sisavci Jadranskog mora. Rad JAZU 95:79–177
41. Trois E (1894) Elenco dei cetacei dell'Adriatico. Atti Regio Istituto Veneto di Scienze Lettere e Arti 7(5):1315–1320
42. Faber GL (1883) The fisheries of the Adriatic and the fish thereof. A report of the Austro-Hungarian sea-fisheries, with detailed description of the Adriatic gulf. Bernard Quaritch, London
43. Pilleri G, Gihr M (1977) Some records of cetaceans in the Northern Adriatic Sea. Investig Cetaceans 8:85–88
44. Bearzi G (1989) Contributo alle conoscenze sulla biologia di *Tursiops truncatus* (Montagu, 1821) nel mare Adriatico settentrionale. University of Padova, Padova
45. Bearzi G, Politi E, Fortuna CM, Mel L, Notarbartolo di Sciara G (2000) An overview of cetacean sighting data from the northern Adriatic Sea: 1987–1999. Eur Res Cetaceans 14:356–361
46. Notarbartolo di Sciara G, Bearzi G (1992) Cetaceans in the northern Adriatic Sea: past, present, and future. Rapport Commisione Internationale Mer Méditerranée 33:303
47. Bearzi G (2000) First report of a common dolphin (*Delphinus delphis*) death following penetration of a biopsy dart. J Cetacean Res Manag 2(3):217–221
48. Lazar B, Holcer D, Mackelworth P, Klinčić D, Herceg Romanić S (2012) Organochlorine contaminant levels in tissues of a short-beaked common dolphin, *Delphinus delphis*, from northern Adriatic Sea. Nat Croat 21(2):391–401
49. Genov T, Bearzi G, Bonizzoni S, Tempesta M (2012) Long-distance movement of a lone short-beaked common dolphin *Delphinus delphis* in the central Mediterranean Sea. Mar Biodiversity Rec 5:3. doi:10.1017/S1755267211001163

50. Boisseau O, Lacey C, Lewis T, Moscrop A, Danbolt M, Mclanaghan R (2010) Encounter rates of cetaceans in the Mediterranean Sea and contiguous Atlantic area. J Mar Biol Assoc U K 90(8):1589–1599. doi:10.1017/S0025315410000342
51. Holcer D (2006) Kratkokljuni obični dupin (Short-beaked common dolphin), *Delphinus delphis* Linnaeus, 1758. In: Tvrtković N (ed) Crvena knjiga sisavaca Hrvatske (Red book of mammals of Croatia). Ministarstvo kulture, Državni zavod za zaštitu prirode, Zagreb, p 127
52. MacLeod CD (2006) How big is a beaked whale? A review of body length and sexual size dimorphism in the family Ziphiidae. J Cetacean Res Manag 7(3):301–308
53. Heyning J (1989) Cuvier's beaked whale *Ziphius cavirostris* G. Cuvier, 1823. In: Ridgway SH, Harrison RJ (eds) Handbook of marine mammals, vol 4: river dolphins and the larger toothed whales. Academic, London, pp 289–308
54. Notarbartolo di Sciara G, Demma M (1997) Guida dei mammiferi marini del Mediterraneo, 2nd edn. Franco Muzzio Editore, Padova
55. Notarbartolo di Sciara G (2002) Cetacean species occurring in the Mediterranean and Black Seas. In: Notarbartolo di Sciara G (ed) Cetaceans of the Mediterranean and Black Seas: state of knowledge and conservation strategies. Section 3. A report to the ACCOBAMS Interim Secretariat. ACCOBAMS Interim Secretariat, Monaco, p 17
56. MacLeod CD (2005) Niche partitioning, distribution and competition in North Atlantic beaked whales. University of Aberdeen, Aberdeen
57. D'Amico A, Bergamasco A, Zanasca P, Carniel S, Nacini E, Portunato N, Teloni V, Mori C, Barbanti R (2003) Qualitative correlation of marine mammals with physical and biological parameters in the Ligurian Sea. IEEE J Oceanic Eng 28(1):29–43. doi:10.1109/Joe.2002.808206
58. Gannier A, Epinat J (2008) Cuvier's beaked whale distribution in the Mediterranean Sea: results from small boat surveys 1996–2007. J Mar Biol Assoce U K 88(6):1245–1251. doi:10.1017/s0025315408000428
59. Cañadas A, Fortuna C, Pulcini M, Lauriano G, Bearzi B, Cotte C, Raga JA, Panigada S, Politi E, Rendell L, B-Nagy A, Pastor X, Frantzis A, Mussi B (2011) Accobams collaborative effort to map high-use areas by beaked whales in the Mediterranean. In: 63 Scientific committee meeting of the international whaling commission. International Whaling Commission, Tromso, Norway, June 2011
60. Lamani F, Peja N, Ruka E (1976) Balena me sqep e Kyvierit (*Ziphius cavirostris*) ne bregdetin shqiptar. Buletini i Shkencave te Natyres 1:73–78
61. Cetacei CS (1987) Cetacei spiaggiati lungo le coste Italiane, I. Rendiconto 1986. Atti Soc Ital Sci Nat Mus Civ St Nat Milano 128(3-4):305–313
62. Cetacei CS (1995) Cetacei spiaggiati lungo le coste Italiane. VII. Rendiconto 1992. (Mammalia). Atti Soc Ital Sci Nat Mus Civ St Nat Milano 134(2):285–298
63. Notarbartolo di Sciara G, Holcer D, Bearzi G (1994) Past and present status of cetaceans in the northern and central Adriatic Sea. In: Gomerčić H (ed) Proceeding of abstracts of the 5th congress of biologists of Croatia, Croatian Biological Society, Pula, Croatia, 3–7 October 1994, pp 401–402
64. Storelli MM, Zizzo N, Marcotrigiano GO (1999) Heavy metals and methylmercury in tissues of Risso's dolphin (*Grampus griseus*) and Cuvier's beaked whale (*Ziphius cavirostris*) stranded in Italy (South Adriatic Sea). Bull Environ Contam Toxicol 63(6):703–710
65. Holcer D, Mackelworth P, Fortuna CM (2002) Present state of understanding of the Cetacean fauna of the Croatian Adriatic sea. European research on Cetaceans 16, Poster presentation
66. Holcer D, Notarbartolo di Sciara G, Fortuna CM, Onofri V, Lazar B, Tvrtković N (2003) The occurrence of Cuvier's beaked whale (*Ziphius cavirostris*) in Croatian Adriatic waters. In: Besendorfer V, Kopjar N (eds) Proceeding of abstracts of eight Croatian biological congress, Croatian Biological Society, Zagreb, Croatia, 27.9-2.10.2003, pp 255–256

67. Gomerčić H, Đuras Gomerčić M, Gomerčić T, Lucić H, Dalebout M, Galov A, Škrtić D, Ćurković S, Vuković S, Huber Đ (2006) Biological aspects of cuvier's beaked whale (*Ziphius cavirostris*) recorded in the Croatian part of the Adriatic Sea. Eur J Wildl Res 52(3):182–187
68. Podestà M, D'amico A, Pavan G, Drougas A, Komnenou A, Portunato N (2006) A review of cuvier's beaked whale strandings in the Mediterranean Sea. J Cetacean Res Manag 7 (3):251–261
69. Holcer D, Di Sciara GN, Fortuna CM, Lazar B, Onofri V (2007) Occurrence of Cuvier's beaked whales in the southern Adriatic Sea: evidence of an important Mediterranean habitat. J Mar Biol Assoc U K 87(1):359–362. doi:10.1017/s0025315407055075
70. Kovačić I, Gomerčić MĐ, Gomerčić H, Lucić H, Gomerčić T (2010) Stomach contents of two Cuvier's beaked whales (*Ziphius cavirostris*) stranded in the Adriatic Sea. Mar Biodiversity Rec 3. doi:10.1017/S1755267210000059
71. Pino d'Astore P, Bearzi B, Bonizzoni S (2008) Cetacean strandings in the province of Brindisi (Italy, southern Adriatic sea). Ann Ser Hist Nat 18(1):29–38
72. Fortuna CM, Acquarone M, Annunziatellis A, Arcangeli A, Azzelino A, Baccetti N, Bellingeri M, Bonizzoni S, Borsani FJ, Caliani I, Canese S, Canneri R, Cerioli N, De Lucia A, Dimatteo S, Fanizza C, Filidei E Jr, Fossi C, Garibaldi F, Gaspari S, Giovanardi O, Giusti M, Gnone G, Guidetti P, Holcer D, Lauriano G, Marsili L, Mazzola A, Mo G, Moulins A, Mussi B, Notarbartolo di Sciara G, Orsi Relini L, Pace DS, Panigada S, Pavan G, Podestà M, Pulcini M, Raicevich S, Randi E, Romeo T, Rosso M, Sala A, Tepsich P, Zimmer W, Zizzo N (2013) MSFD Supporting document on the initial assessment on cetaceans, including methodology, data used and results. ISPRA, Rome
73. Dalebout ML, Robertson KM, Frantzis A, Engelhaupt DAN, Mignucci-Giannoni AA, Rosario-Delestre RJ, Baker CS (2005) Worldwide structure of mtDNA diversity among cuvier's beaked whales (*Ziphius cavirostris*): implications for threatened populations. Mol Ecol 14(11):3353–3371
74. Cañadas A (2012) *Ziphius cavirostris* (Mediterranean subpopulation). IUCN 2013. http://www.iucnredlist.org/details/full/16381144/0. Accessed 12 Feb 2014
75. Kruse S, Caldwell D, Caldwell M (1999) Risso's dolphin *Grampus griseus* (G. Cuvier, 1812). In: Ridgway SH, Harrison R (eds) Handbook of marine mammals, vol 6. The second book of dolphins and porpoises. Academic, San Diego, pp 183–212
76. Leatherwood S, Perrin WF, Kirby VL, Hubbs CL, Dahlheim M (1980) Distribution and movements of Risso's dolphin, *Grampus griseus*, in the eastern North Pacific. Fish Bull 77 (4):951–963
77. Azzellino A, Gaspari S, Airoldi S, Nani B (2008) Habitat use and preferences of cetaceans along the continental slope and the adjacent pelagic waters in the western Ligurian Sea. Deep Sea Res Pt I 55(3):296–323. doi:10.1016/j.dsr.2007.11.006
78. Gómez de Segura A, Hammond PS, Raga JA (2008) Influence of environmental factors on small cetacean distribution in the Spanish Mediterranean. J Mar Biol Assoc U K 88(Special Issue 06):1185–1192. doi:10.1017/S0025315408000386
79. Wurtz M, Poggi R, Clarke MR (1992) Cephalopods from the stomachs of a Risso's dolphin (*Grampus griseus*) from the Mediterranean. J Mar Biol Assoc U K 72(4):861–867
80. Podestà M, Meotti C (1991) The stomach contents of a Cuvier's beaked whale *Ziphius cavirostris*, and a Risso's dolphin *Grampus griseus*, stranded in Italy. In: Evans PGH (ed) Fifth annual conference of the European Cetacean Society, Sandefjord, Norway, 21–-23 February 1991 European Research on Cetaceans 5. European Cetacean Society, pp 58–61
81. Blanco C, Raduan MA, Raga JA (2006) Diet of Risso's dolphin (*Grampus griseus*) in the western Mediterranean Sea. Sci Mar 70(3):407–411
82. Bearzi G, Reeves RR, Remonato E, Pierantonio N, Airoldi S (2011) Risso's dolphin *Grampus griseus* in the Mediterranean Sea. Mamm Biol Zeitschrift für Säugetierkunde 76(4):385–400. doi:10.1016/j.mambio.2010.06.003
83. Kolombatović G (1894) Godišnje izvješće C. K. velike realke u Splitu (Yearly report of the Royal High School in Split). A. Zannoni, Split

84. Giglioli EH (1880) Elenco dei Mamiferi: degli Uccelli e dei Rettili ittiofagi appartenento alla fauna italica e catalogo degli anfibi e dei Pesci italiani. Stamperia Reale, Firenze
85. Zucca P, Di Guardo G, Francese M, Scaravelli D, Genov T, Mazzatenta A (2005) Causes of stranding in four Risso's dolphins (*Grampus griseus*) found beached along the North Adriatic Sea coast. Vet Res Commun 29:261–264. doi:10.1007/s11259-005-0057-6
86. Valle A (1900) Sulla comparsa di un *Grampus griseus* nelle acque istriane. Bollettino Società Adriatica Scienze 20:81–87
87. Francese M, Zucca P, Picciulin M, Zuppa F, Spoto M (1999) Cetaceans living in the North Adriatic Sea (Gulf of Trieste–Grado lagoon): intervention protocol for healthy and distressed animals. Eur Res Cetaceans 13:410–415
88. Bilandžić N, Sedak M, Đokić M, Đuras Gomerčić M, Gomerčić T, Zadravec M, Benić M, Prevendar Crnić A (2012) Toxic element concentrations in the bottlenose (*Tursiops truncatus*), striped (*Stenella coeruleoalba*) and Risso's (*Grampus griseus*) dolphins stranded in Eastern Adriatic Sea. Bull Environ Contam Toxicol 89(3):467–473. doi:10.1007/s00128-012-0716-6
89. Gomerčić H, Đuras Gomerčić M, Gomerčić T, Lucić H, Škrtić D, Ćurković S, Vuković S, Huber Đ, Gomerčić V, Bubić Špoljar J (2006) Abundance and mortality of Risso's dolphins (*Grampus griseus*) in the last 15 years in the Croatian part of the Adriatic sea. In: Bessendorfer V, Klobučar GIV (eds) 9th Croatian biological congress, Croatian Biological Society, Rovinj, pp 297–298
90. Hirtz M (1938) Rijetke vrste delfina u vodama Korčule. Priroda 27(1):25–28
91. Holcer D, Fortuna CM (2011) The aerial survey of cetacean abundance in the areas of Kvarner/Kvarnerić and Central Adriatic: August 2010. A project report to State institute for nature protection, Zagreb. Blue World Vis
92. Holcer D, Fortuna CM, Nimak M, Mackelworth CP, Pleslić G, Jovanović J, Krstinić P (2008) Jadranski projekt dupin - Vis. Izvještaj o obavljenom preliminarnom istraživanju dobrih dupina (*Tursiops truncatus*) šireg područja otoka Visa tijekom 2008. godine. Plavi svijet Institut za istraživanje i zaštitu mora, Veli Lošinj
93. Holcer D, Nimak M, Pleslić G, Jovanović J (2008) Adriatic dolphin project research report: Lastovo 2008. Blue World Institute of Marine Research and Conservation, Veli Lošinj
94. Holcer D, Nimak Wood M, Fortuna CM, Mackelworth P, Rako N, Dobrić V, Cukrov M (2010) Utvrđivanje brojnosti i distribucije dupina na području Viškog arhipelaga, te davanje preporuka za očuvanje i održivo korištenje utvrđenih posebno značajnih područja. Plavi svijet, Veli Lošinj
95. Fortuna CM, Vallini C, Filidei E Jr, Ruffino M, Consalvo I, di Muccio S, Gion C, Scacco U, Tarulli E, Giovanardi O, Mazzola A (2010) By-catch of cetaceans and other species of conservation concern during pair trawl fishing operations in the Adriatic Sea (Italy). Chem Ecol 26(Suppl 1):65–76. doi:10.1080/02757541003627662
96. Lauriano G, Panigada S, Fortuna CM, Holcer D, Filidei Jr E, Pierantonio N, Donovan GP (2011) Monitoring density and abundance of cetaceans in the seas around Italy through aerial surveys: a summary contribution to conservation and the future ACCOBAMS survey. In: 63 Meeting of the IWC scientific committee, Tromsø, Norway, 30 May – 11 June 2011, 5pp
97. Giovagnoli L (2013) Adriatic Shipping Company marine mammal sightings in the Adriatic Sea 1988–2000. OBIS SEAMAP. http://seamap.env.duke.edu/dataset/865. 2014
98. Gaspari S, Natoli A (2012) *Grampus griseus* (Mediterranean subpopulation)
99. Canese S, Cardinali A, Fortuna CM, Giusti M, Lauriano G, Salvati E, Greco S (2006) The first identified winter feeding ground of fin whales (*Balaenoptera physalus*) in the Mediterranean Sea. J Mar Biol Assoc U K 86(4):903–907
100. Notarbartolo-Di-Sciara G, Zanardelli M, Jahoda M, Panigada S, Airoldi S (2003) The fin whale *Balaenoptera physalus* (L. 1758) in the Mediterranean Sea. Mamm Rev 33(2):105–150
101. Lipej L, Dulčić J, Kryštufek B (2004) On the occurrence of the fin whale (*Balaenoptera physalus*) in the northern Adriatic. J Mar Biol Assoc U K 84(4):861–862

102. Caputo V, Giovannotti M (2009) Haplotype characterization of a stranded *Balaenoptera physalus* (Linnaeus, 1758) from Ancona (Adriatic Sea, Central Italy). Hystrix 20(1):83–85
103. Panigada S, Notarbartolo di Sciara G (2012) *Balaenoptera physalus* (Mediterranean subpopulation). http://www.iucnredlist.org/. Accessed 26 Feb 2014
104. Drouot V, Berube M, Gannier A, Goold JC, Reid RJ, Palsboll PJ (2004) A note on genetic isolation of Mediterranean sperm whales (*Physeter macrocephalus*) suggested by mitochondrial DNA. J Cetacean Res Manag 6(1):29–32
105. Praca E, Gannier A (2008) Ecological niches of three teuthophageous odontocetes in the northwestern Mediterranean Sea. Ocean Sci 4(1):49–59
106. Bearzi G, Pierantonio N, Affronte M, Holcer D, Maio N, Notarbartolo Di Sciara G (2011) Overview of sperm whale *Physeter macrocephalus* mortality events in the Adriatic Sea, 1555–2009. Mamm Rev 41:276–293. doi:10.1111/j.1365-2907.2010.00171.x
107. 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 Bernaldo QY, 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(5):e19417. doi:10.1371/journal.pone.0019417
108. ACCOBAMS (2016) http://www.accobams.net.
109. Sporazum o zaštiti kitova Cetacea u Crnom moru, Sredozemnom moru i susjednom atlantskom području-Accobams (2008) Official Gazette of Montenegro 7/2008
110. Müllerand M, Bossley M (2002) Solitary bottlenose dolphins in comparative perspective. Aquat Mamm 28(3):9
111. Delfin Joco u Bokokotorskom zalivu 1988. godine. (1988) https://www.youtube.com/watch?v=veOb1x4s70A
112. Nikolić BB (1988) The Dark Side of the Sun
113. Joksimović A, Mandić M, Đurović M (2013) First record of fin whale (*Balaenoptera physalus* Linnaeus, 1758) in Kotor Bay (South Adriatic Sea). J Black Sea Mediterr Environ 19 (1):127–131
114. Zanardelli M, Notarbartolo di Sciara G, Jahoda M (1992) Photo-identification and behavioral observations of fin whales summering in the Ligurian Sea. Eur Res Cetaceans 6:86–89
115. Forcada J, Aguilar A, Hammond PS, Pastor X, Aguilar R (1996) Distribution and abundance of fin whales (*Balaenoptera physalus*) in the western Mediterranean sea during the summer. J Zool 238:23–34
116. Crnković D (1958) The dolphin problem (in Croatian). Morsko Ribarstvo 10:12–14
117. Marelic D (1961) Results of the work for advancement of marine fisheries in 1961. Morsko Ribarstvo 3:5–7
118. Holcer D (1994) Prospective of cetology in Croatia. Eur Res Cetaceans 8:120–121
119. LJ L (1999) U Bokokotorskom zalivu ubijen delfin. "Večernje novosti" daily newspaper (Montenegrin edition), 17.08.1999, p 37
120. Đ. R (2000) U Boki ubijen još jedan delfin. "Vijesti" daily newspaper, 05.02.2000
121. J. P (2001) Ubijeni delfin i dalje na obali. "Vijesti" daily newspaper, Montenegro, 22.10.2001
122. Jaredić G (2002) Što je čovjek na zemlj, to je delfin u vodi. "Respekt" weekly magazine:12–13

Diversity of Vascular Flora of Boka Kotorska Bay

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Abstract Boka Kotorska represents a unique geomorphologic object in the southern part of eastern coastline of Adriatic Sea. Due to the interesting orography of this bay (surrounded by high mountains representing special micro-centers of floristic diversity in this part of Europe), climate characteristics and pedological substrate, etc., the area of Boka Kotorska Bay may be considered one of the floristic hotspots of Balkan Peninsula. In spite of many centuries of anthropogenic impact, diversity of vascular flora was preserved to a significant percentage. The overview of diversity of vascular flora at Boka Kotorska is a compilation of extensive studies presented in more than 200 scientific papers. However, it must be stated that studies of flora were not systematic. Certain parts of Boka Kotorska area are characterized

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by excellent level of study and knowledge of floristic diversity, while some other parts are completely neglected and forgotten by researchers. Area of Boka Kotorska includes a high number of *Locus classicus* units. Literature data have shown presence of 49 endemic taxa, mostly from the Mediterranean–Submediterranean range group. The system of national and international conservation recognizes 47 taxa of vascular plants and among them 26 species belong to family Orchidaceae. The traditional landscape improvement and garden design, present for centuries in area of Boka Kotorska, resulted in extraordinary richness in diversity of ligneous flora.

Keywords Endemic taxa, Ornamental plants, Protected species, Vascular flora, Vegetation

Contents

1 Introduction

The geographical position of the Boka Kotorska Bay and its immediate surroundings, with high mountains that surround it represent indeed a remarkable natural object. This area, inhabited from the period of the first traces of human civilization has undoubtedly, due to such development, lost much of its naturalness and authenticity. Traces of ancient settlements in the area of Boka Kotorska dating years before Christ, as well as of those from the beginning of the last millennium, the remains of medieval urban settlements and military fortresses, the presence of old roads, the remains of the old ports, and the very tradition of people living in this area in a continuity of more than a 2000 years are all evidence of that. On the other hand, there is no doubt that the human population, sharing the living area that is naturally surrounded by the sea, on the one side, and high mountains, on the other, found the modus of coexistence which tended to harm the natural entities the least. The fact confirming this is that even today, after such a long time, in the area of the Boka Kotorska Bay there can be found fragments of some ancient natural vegetation including preserved holm oak trees in its natural distribution. Boka Kotorska being located at an altitude of 0–500 m has a Mediterranean climate, and this is the area that in this short review will be observed in terms of vegetation and flora. Although it might at first seems that this is a common Mediterranean coastal rocky area, the Boka Kotorska Bay conceals in its hidden parts an extraordinarily high diversity of habitat types, which still resist the intense anthropogenic influence that has been present in this area for centuries.

There is no doubt that many researchers of flora could not ignore such a representative natural object. The Boka Kotorska Bay and its cities were visited by many botanists, and there is a several hundred years old tradition of its research. Even though it is evident that there are published data of the area in almost 200 scientific papers, monographs, and reports, it is clear that in most cases, these studies of flora in the area of the Boka Kotorska Bay were partially performed around large settlements. Some parts of the Boka Kotorska Bay are therefore floristically completely uninvestigated and there are almost no any scientific data on the plant species and their habitats. Namely the 114 km of its coastline is not only a strict contact area between the sea and land in the form of rocky, stony, and sandy beaches. Those are the numerous meadows extremely moist, well-preserved fragments of forest stands, steep cliffs and taluses, sections of grassy vegetation on limestone karst, and degradation levels of evergreen Mediterranean forest with all the beautiful wealth of species hiding inside. Of course there are specific coastal habitats such as salt marshes, walls and sides of the old fortifications. It is simply a mosaic of microhabitats which is enriched with a large diversity of vegetation entities and exceptional diversity of plant taxa with special ecological and evolutionary solutions that make this region interesting for different types of botanical research. Almost all types of habitats from the Boka Kotorska Bay have been partially surveyed. This is obvious not only from the numerous scientific publications, but from the very extensive herbarium material as well which is stored in large scientific herbarium collections recognizable by the material from the Balkan Peninsula. Old researchers' herbarium exsiccates, as well as the more recent collected material, hide incredible specimens of rare and endemic taxa, often belonging to the very narrow distribution type. A particular plant species present specificity of this area.

The first floristic researches related to the area of the Boka Kotorska Bay date from the first half of the nineteenth century. Then was for the first time scientifically described the Illyrian endemic species *Petteria ramentacea* (Sieber) C. Presl [1]. The researches continued already in 1827, when *Muzzio Tommasini* arrived in the Boka Kotorska Bay. The researcher sent his material to Padua and Vienna, to the then-known researchers of his time (Visiani, Host) for determination [2]. Tommasini publishes the results of his trips to the Boka Kotorska Bay in 1835 [3], and the researchers who determined his exsiccates later publish new taxa based on the material obtained from this researcher. Because of that, and out of special gratitude, *Muzzio Tommasini* is one of the botanists to whom a special tribute is paid by naming a significant number of taxa after him [2]. There is no doubt that the special mark on the floristic work in the nineteenth century in the region of the Boka Kotorska Bay was left by the Paduan physician and botanist *Roberto Visiani*. Devotedly working on collecting the botanical and herbarium material, as well as analyzing the materials sent to him by other botanists who were his contemporaries, this researcher, the author of the famous work Flora

Dalmatica [4–6] became recognizable for a larger number of taxa some of which are described from the area of the Boka Kotorska Bay (*Seseli globiferum* Vis., *Stachys menthifolia* Vis. et al.). Then there come later works by Visiani [7–9], *Emanuel Weiss* [10, 11], research results of the environment of Kotor [12–15], the Islands of Mamula, and the Cape Oštra [16], as well as the hill Vrmac Tivat [17, 18]. A large number of botanists and many others exploring the environment passed through the Boka Kotorska Bay [19–25] contributing to the research and knowledge of the flora in this area. Academician Vukić Pulević in detail wrote about them and described their work in his books *Montenegro doors of Balkans* [26] and *Botanists and Montenegro* [2].

Many Serbian botanists starting with *Josif Pančić* [27] and *Lujo Adamović* [28–30] explored the area of the Boka Kotorska Bay in their own method and made an outstanding contribution to the knowledge of its flora and vegetation. After World War II, research in this area has been intensified by works presenting results of new floristic data for this area, but they became significant for the broader region as well [31–44]. Fragments of the laurel and chestnut vegetation communities [45], laurel and oleander vegetation communities [46], as well as vegetations of the salt marshes of Tivat [47, 48] were especially studied. Specific habitats such as the remains of ancient fortresses and walls around these sites were researched as well and the findings from these studies became a part of an exceptional corpus of work dedicated to the flora and vegetation of the Boka Kotorska Bay [49].

However, despite the extraordinary botanical materials, we are not able to precisely define the exact number of species that is characteristic for this area. On the one hand, we see that this is an area that has been thoroughly studied, with an exceptional number of references published since the middle of nineteenth century to the present day, with a rich herbarium material stored in the relevant European herbarium collections, whereas, on the other hand, there is no scientifically conducted study of the floristic diversity of the Boka Kotorska Bay. One of the most studiously researched localities is the eastern part of the Boka Kotorska Bay with the hill of Vrmac and the field of Tivat for which there have been recorded 866 taxa at the level of species, subspecies, and lower infraspecific taxa [42]. This study has greatly consolidated the existing knowledge on the floristic diversity of the eastern part of the Boka Kotorska Bay, however, in its own thorough researches it has recorded another 279 taxa that were registered for the first time for the studied area [42]. For the area of the saline marshes of Tivat there have been registered 307 taxa of species, subspecies, and lower taxonomic entities [48], and on the hill of St. Ivan above Kotor alone, which includes a geomorphological unit at the height of only 260 m with the city walls and ramparts, there has been registered 301 taxa at the level of species and subspecies [50]. The estimated number of taxa at the level of species and subspecies for the studied area, excluding the allochthone species that represent a special part of the current floristic list, certainly is over 1000, however, there are no precise data on that.

2 Characteristics of Vegetation in the Boka Kotorska Bay

Based on vegetation papers on the Boka Kotorska Bay, the oldest of which date back to 1900 [28–30, 45–47, 51–54], Prodomus of the plant communities of Montenegro [55], and the natural potential vegetation map [56] in this area have been recorded 15 major plant formations: bushes, maritime pine forests (*Pinus halepensis*) (Fig. 1), black pine forests (*Pinus nigra*), laurel forests (*Laurus nobilis*) (Fig. 2), evergreen oak forests (*Quercus ilex*, *Quercus pseudosuber*, *Quercus coccifera*) (Fig. 3), carob forests (*Ceratonia siliqua*) (Fig. 4), deciduous oak forests, deciduous shrubs (Fig. 5), hedges and fences, pastures and rocky and karstic terrains (Fig. 6), rocks and walls (Fig. 7), seashore (Figs. 8 and 9), ponds and marshes (Fig. 10), weeds, and culture plants (Fig. 11). However, despite a good general overview of the vegetation, a detailed list of vegetation units, their mapping, and analysis of vegetation changes still have not been systematized and compiled.

In terms of biogeography the area of the Boka Kotorska Bay belongs to the Mediterranean region, within which, according to the classification by Stevanović [57], we distinguish two subregions: the Euro-Mediterranean and Euro-Submediterranean. In terms of vegetation the first subregion is characterized by formations of evergreen leathery leaves holm oaks and their degradation products, while the second subregion is characterized by thermophilic forests and thickets butcher's broom and hornbeam and their degradation forms. Starting from the coast, depending on the nature of its substrate in the vicinity of water grow different plant communities belonging to *Crithmo-Staticetalia*, *Limonetalia*, *Thero-*

Fig. 1 Maritime pine forests (*P. halepensis*) (Photo by Dmitar Lakušić)

Fig. 2 Laurel (*L. nobilis*) (Photo by Vesna Mačić)

Fig. 3 Evergreen oak forest (*Q. pseudosuber*) (Photo by Vesna Mačić)

Salicornietalia, *Juncetalia maritimi,* and *Phragmitetalia australis*. The rocky coast and sea cliffs are overgrown by sparse vegetation almost entirely consisting of species of the genus *Limonium* (*Limonium cancellatum* and *Limonium anfractum*) and *C. maritimum*, whereas the floristic composition on more distant rocks becomes richer. This type of habitat is included in the NATURA 2000: 1240 Vegetation of the Mediterranean Sea cliffs covered with endemic species of the genus *Limonium*

Fig. 4 Carob forests (*C. siliqua*) (Photo by Vesna Mačić)

Fig. 5 Deciduous shrubs (Photo by Dmitar Lakušić)

[ass. *Crithmo-Limonietum anfracti* (H-ić) Ilijanić; *Plantagini-Staticetum cancellatae* H-ić (1934) 1939].

On the muddy-clay substrate of the Tivat salinas and a part of the Tivat field, on very salty and flooded habitats, there are communities of glassworts ass. *Salicetum herbacea* Jank. et Stev. 1984 and *Arthrocnemum fruticosi* Br.-Bl. 1928 of the order *Thero-Salicornietalia*. They are included in the NATURA 2000 habitat: 1310 – Annual vegetation glasswort (*Salicornia*). In the less saline and wet environments

Fig. 6 Karstic terrains (*Nerium oleander)* (Photo by Dmitar Lakušić)

Fig. 7 Rocks and walls (Photo by Vesna Mačić)

thrives the community of *Limonio-Artemisietum caerulescentis* H-ic (1933) 1934 of the order *Limonetalia*, while in places where there are brackish waters grows the community of *Junco maritimo-Acute* H-ic 1934 from the order of *Juncetalia*. These communities belong to the NATURA 2000 habitat: 1410 – Mediterranean saline

Fig. 8 Seashore (*Crithmum maritimum and Limonium anfractae*) (Photo by Dmitar Lakušić)

Fig. 9 Seashore (Photo by Danijela Stešević)

water fields (*Juncetalia maritimi*) on mud and sand. The community of *Scirpetum maritimi* Br.-Bl. 1934 from the order of *Phragmitetalia* is registered on ponded and brackish locations and this habitat is also included in NATURA 2000: 2190 – Humid dune slacks.

Fig. 10 Ponds and marshes (*Arthrocnemum fruticosum*) (Photo by Dmitar Lakušić)

Fig. 11 Culture plants (Photo by Danijela Stešević)

According to a map of potential vegetation [56] by the very coast of the Boka Kotorska Bay, at an altitude of 300 (500) m.a.s.l. dominated stiff leaved forest vegetation of holm oaks (ass. *Quercetum ilicis adriaprovincialis* Trinajstić 1975). Preserved parts of this community at the end of the 1990s were recorded only in the southern part of the peninsula of Luštica [42]; however, the intensified anthropogenic influence has decreased their representativeness, and reduced their stands to fragments only. Today, the entire area of the Boka Kotorska Bay, in this high-altitude area and slopes exposed to the south dominate degradation forms of the evergreen holly oak forests, found in thick and impassable macchia (ass. *Orno-Quercetum ilicis* H-ić (1956) 1958; *Orno-Quercetum ilicis myrtetosum* H-ić 1963), garrigue (ass. *Erico-Cistetum cretica* H-ić 1958), and dry fields and rocky pastures (communities of the alliance *Cymbopogo-Brachypodion ramosi* H–ić (1956) 1958). The following NATURA 2000 habitats contribute to a special biological value to the area: fragments of macchia with the dominating juniper *Juniperus phoenicea*, which are recorded in Luštica in the bay of Trašte (5210 – Macchia with Mediterranean junipers (*Juniperus* spp.)) [58], fragments of the preserved communities of laurel (ass. *Lauretum nobilis adriaticum* Lakušić, 1983) in Kostajnica and in Luštica (5230 * High bushes of laurel), xerophile bushy formations characteristic of the thermomediterranean zone in Luštica, which include a very specific relict communities of woody spurge (*Euphorbia dendroides*) – 5330 Thermomediterranean pre-desert shrubs; natural stands of laurel and oleander near Risan (ass. *Andropogono distachyi-Nerietum oleandri* (Jovanović and Vukićević 1978) Jasprica et al. 2007) – 92D0 southern coastal galleries and thickets (*Nerio-Tamaricetea*), and 6220 * Eumediterranean xerophylous grasslands (*Thero-Brachypodietea*).

According to the general vertical zonation the region of evergreen elements shifts to thermophilic deciduous forests and shrubs of fresh *Ostryo-Carpinion orientalis* H-ić 1967. However, on the northern slopes of the Bay this type of vegetation is lowered to the sea, so that there is no evergreen vegetation belt. This unusual phenomenon can be explained by the exposure, proximity of the high mountain ranges, and influence of colder Oromediterranean climate. Thermophilic deciduous vegetation is represented by the following communities: *Rusco-Carpinetum orientalis* Blečić & Lakušić 1966, *Paliuretum adriaticum* H-ić 1958, and *Paliuretum adriaticum carpinetosum orientalis* H-ić 1963. Depending on the degree of degradation, the community of butcher's broom and hornbeam appears either in the form of a forest, or dense or sparse shrub. Communities with Christ's thorn (*Paliurus spina-christi*) are dominated by a more degraded, rocky environment. In the zone of holly oak forests there is ass. *Paliuretum adriaticum typicum*, and in the zone of thermophilic deciduous vegetation we can find a subassociation of *Paliuretum adriaticum – Carpinetosum orientalis* H-ić 1963. The ultimate degradation of bushy formations forms rocky pastures thriving with the bond of *Scorzonero-Chrysopogonetalia* H-ić & Horvat (1956) 1958. The communities of rocky pastures form a part of the network NATURA 2000 habitats (62A0- East Submediterranean dry grasslands *Scorzoneratalia villosae).*

A dendrological specificity of the Boka Kotorska Bay certainly are the chestnut forests (ass. *Lauro-Castanetum sativae* M. Jank. 1966) (Fig. 12), which grow under the direct influence of the Mediterranean climate and sea, which are, thanks to the relief and exposure, protected from excessive insolation and summer droughts. They are registered in Stoliv, Lepetane, in the area above Tivat, Kostanjica between

Fig. 12 Chestnut forests (ass. *Lauro-Castanetum sativae*) (Photo by Vesna Mačić)

Morinj and Kamenari, on Savina. They form a part of the network NATURA 2000 habitats as well (9260 Chestnut forests). Together with the natural stands of laurel and oleander near Risan, halophyte flora and vegetation along the coastline of the Bay of Tivat, flora and vegetation of the peninsula of Vrmac, vegetation on the steep rocks and screes that rise above the sea, in 1979 this type of forests was proposed to be under the measures of protection and rational use [34].

As an azonal vegetation type, vegetation of rocks is except the supralittoral splach zone present on all altitude ranges. It consists of the communities belonging to the following classes: *Adianthetea capilli-veneris* Br.-Bl. 1947 and *Asplenietea rupestris* (H. Meier) Br-Bl. [34]. The total vegetation diversity of the area is contributed by a number of anthropogenic communities in ruderal and cultivated areas.

3 Balkan Endemic Plants in the Flora of Boka Kotorska

The term "endemism" attracted scientists since ancient times and there are many definitions attempting to explain this phenomenon. Knowledge of endemic flora of certain areas may explain its biogeographical history, and the percentage share of the endemic species in given flora determines the degree of isolation and the age of a given territory [59].

By now there has not been produced a detailed study on the endemic flora of Montenegro. The oldest data on the endemic flora of Montenegro originate from Turill [60], who divided the Balkan Peninsula according to the phytogeographic and floristic terms into 16 districts. For the district of Montenegro he recorded 210 endemic plant taxa. According to the Blečić [61], who cites Turill [60] including the most recent data of the time, in the flora of Montenegro there were recorded 220 Balkan and 20 Montenegro endemic species. According to the Stevanović et al. [62], the Balkan endemic plant taxa in the flora of Montenegro make 223 which is 11.7 % of the total flora of Montenegro. Endemism of the Montenegrin flora cannot be observed without the endemic flora of the Balkan Peninsula, or at least its western part. Flora of the Western Balkans, of the Dinarids to be more precise, central Mediterranean (Adriatic coast) and Submediterranean is characterized by a high percentage of endemism. The largest number of endemic species in the Western Balkans was recorded on high limestone mountains, in canyons and river gorges, as well as on the Dalmatian islands, and, generally speaking, in the coastal (Adriatic) region [63].

A review of the research data on the area of the Boka Kotorska Bay revealed the presence of 49 Balkan endemic plant taxa (Table 1). Balkan endemic plants are, by definition, such plant taxa that are with their distribution restricted to the territory of the Balkan Peninsula [60, 64, 65].

The first described plant taxon in the territory of Montenegro was a plant under the common name Dalmatian Laburnum *Cytisus ramentaceus*, which was later named *Petteria ramentacea* (Fig. 13). It was described by the German botanist *Fr. W. Sieber* 1822 on materials collected in the vicinity of Kotor. It turned out that this “debut” in the flora of Montenegro was also the endemic plant of the Western Balkans. It grows only in karst rocky Dalmatia, Bosnia and Herzegovina, Montenegro, and Albania.

It is not unusual that the first described plant in the flora of Montenegro originated from the area of the Boka Kotorska Bay. The Bay with Paštrovići belonged to the Austro-Hungarian province of Dalmatia in terms of territory and policy in the nineteenth century, and was a place from which “all roads” led to Montenegro as well. It attracted researchers who made some first significant floristic records from Boka Kotorska and its hinterland, Tommasini [3], Bartolommeo [66], and Ebel [67]. One of them, *Roberto Visiani* that had actually never done any botanical researches in Montenegro, made description based on herbarium material that he had received from other botanists, which were a number of new species for the science, such as *Amphoricarpos neumayerianus*, *Lonicera glutinosa*, *Achillea abrotanoides,* and others. *Locus classicus* of these plant species is located on Orjen. From the area of the Boka Kotorska Bay the following are described: *Cytisus tommasinii*, *Seseli globiferum*, *Clinopodium dalmaticum,* and *Stachys menthifolia*. All of the aforementioned plant taxa are Balkan endemic species of wider or narrower distribution (see Table 1). Visiani published these significant

Table 1 Review of the endemic taxa of the vascular flora of Boka Kotorska

Number	Species	Subspecies	Locality	Life form	Floristic elements, chorological group
1.	*Cerastium grandiflorum* Waldst. & Kit.		Kotor, hill of St. Ivan	Ch	SEM
2.	*Cerastium ligusticum* Viv.	Subsp. *trichogynum* (Möschl) P. D. Sell and Whitehead	Peninsula Luštica: village Klinci	Ch	MED–SUBM
3.	*Petrorhagia obcordata* (Margot and Reuter) Greuter & Burdet		Tivat, hill of St. Ivan	T	MED–SUBM
4.	*Dianthus ciliatus* Guss.	Subsp. *dalmaticus* (Čelak.) Hayek	Kotor, hill of St. Ivan	Ch	MED–SUBM
5.	*Consolida uechtritziana* (Pancic ex Huth) Soó		Kotor	T	MED–SUBM
6.	*Erysimum linariifolium* Tausch	Subsp. *linariifolium*	Vrmac	Ch	SEM
7.	*Cardamine rupestris* (O.E. Schultz) K. Malý		Kotor, near Krašići	T/H	MED–SUBM
8.	*Viola suavis* M. Bieb.	Subsp. *austrodalmatica* Mereda and Hodálová	Zelenika	H	MED–SUBM
9.	*Euphorbia glabriflora* Vis.		Kotor, hill of St. Ivan	Ch	MED–SUBM
10.	*Rhamnus intermedius* Steud. & Hochst.		Luštica, hill of St. Ivan	NP	MED–SUBM
11.	*Rhamnus orbiculata* Bornm.	Subsp. *orbiculata*	Donji Stoliv, Vrmac	NP	MED–SUBM
12.	*Trifolium dalmaticum* Vis.	Subsp. *dalmaticum*	Vrmac, Tivat	T	MED–SUBM
13.	*Trifolium pignantii* Fauché & Chaub.		Vrmac	H	MED–SUBM
14.	*Cytisus tommasinii* Vis	Subsp. *tommasinii*	Vrmac	Ch	SEM
15.	*Petteria ramentacea* (Sieber) C. Presl		Vrmac	NP	MED–SUBM
16.	*Genista sylvestris* Scop.	Subsp. *dalmatica* (Bartl.) Lindb.	Luštica	Ch	MED–SUBM
17.	*Seseli globiferum* Vis.		Hill of St. Ivan	H	MED–SUBM

(continued)

Table 1 (continued)

Number	Species	Subspecies	Locality	Life form	Floristic elements, chorological group
18.	*Chaerophyllum coloratum* L.	Subsp. *coloratum*	Luštica, Vrmac, hill of St. Ivan	T	MED–SUBM
19.	*Limonium dictyophorum* (Tausch) Degen		Pržno	H	MED–SUBM
20.	*Moltkia petraea* (Tratt.) Griseb.		Vrmac, hill of St. Ivan	Ch	MED–SUBM
21.	*Onosma stellulata* Waldst. & Kit.		Vrmac	Ch	SEM
22.	*Teucrium arduinii* L.	Subsp. *arduinii*	Kotor, hill of St. Ivan	Ch	MED–SUBM
23.	*Sideritis romana* L.	Subsp. *purpurea* (Talbot ex Benth.) Heywood	Kotor, Luštica, Vrmac	T	MED–SUBM
24.	*Stachys menthifolia* Vis.	Subsp. *menthifolia*	Kotor, Vrmac, hill of St. Ivan	H	MED–SUBM
25.	*Clinopodium alpinum* (L.) Kuntze	Subsp. *majoranifolium* (Mill.) Govaerts	Kotor, Vrmac, hill of St. Ivan	H	MED–SUBM
26.	*Clinopodium dalmaticum* (Benth.) Bräuchler & Heubl		Kotor, Hill of St. Ivan	Ch	MED–SUBM
27.	*Micromeria kerneri* Murb.		Kotor surroundings	Ch	MED–SUBM
28.	*Satureja horvatii* Šilić	Subsp. *horvatii*	Kotor surroundings	Ch	MED–SUBM
29.	*Satureja subspicata* Bartl. ex Vis.	Subsp. *subspicata*	Hill of St. Ivan above Kotor	Ch	SEM
30.	*Vincetoxicum huteri* Vis. & Ascherson		Luštica, Vrmac, hill of St. Ivan	H	SEM
31.	*Asperula scutellaris* Vis.		Kotor, hill of St. Ivan	Ch	MED–SUBM
32.	*Galium firmum* Tausch		Vrmac, hill of St. Ivan	Ch	MED–SUBM
33.	*Galium procurrens* Ehrend.		Kotor, Vrmac	H	CEUR
34.	*Viburnum maculatum* Pant		Vrmac	NP	CEUR
35.	*Knautia visianii* Szabó		Tivat, Vrmac	H	MED–SUBM

(continued)

Table 1 (continued)

Number	Species	Subspecies	Locality	Life form	Floristic elements, chorological group
36.	*Campanula austroadriatica* D. Lakušić & Kovačić		Kotor, Tivat, Vrmac, Risan	Ch	MED–SUBM
37.	*Edraianthus tenuifolius* (A.DC.) A. DC.		Vrmac	Ch	MED–SUBM
38.	*Tanacetum cinerariifolium* (Trevir.) Sch.Bip.		Vrmac, Luštica, hill of St. Ivan	H	MED–SUBM
39.	*Centaurea glaberrima* Tausch	Subsp. *glaberrima*	Luštica	H	MED–SUBM
40.	*Hieracium baldaccianum* Bald.		Kotor	H	SEM
41.	*Hieracium heterogynum* (Froelich) Gutermann	Subsp. *heterogynum*	Vrmac	H	SEM
42.	*Hieracium heterogynum* (Froelich) Gutermann	Subsp. *pachychaetium* (Nägeli & Peter) Greuter	Kotor	H	SEM P
43.	*Hieracium thapsiformoides* K. Malý		Kotor	H	SEM
44.	*Hieracium tommasinianum* K. Malý	Subsp. *tommasinianum*	Kotor	H	CEUR
45.	*Allium guttatum* Steven	Subsp. *dalmaticum* (A. Kerner ex Janchen) Stearn	Tivat, hill of St. Ivan	G	MED–SUBM
46.	*Fritillaria messanensis* Raf.	Subsp. *gracilis* (Ebel) Rix	Vrmac, hill of St. Ivan	G	JEP
47.	*Crocus dalmaticus* Vis.		Kotor, Luštica, Vrmac	G	MED–SUBM
48.	*Iris pseudopallida* Trinajstić		Kotor, hill of St. Ivan	G	MED–SUBM
49	*Sesleria robusta* Schott & al.	Subsp. *robusta*	Kotor surroundings	H	SEM

findings in his most famous work, "*Flora Dalmatica*" which was printed in three volumes [4–6].

Some other endemic plants such as *Viburnum maculatum* (Vrmac near Kotor, [68]), *Vincetoxicum huteri* (on the road from Risan towards Crkvice, [21]) (Fig. 14),

Fig. 13 *Petteria ramentacea* (Sieber). (Photo by Snežana Vuksanović)

Fig. 14 *Vincetoxicum hutteri* Vis. and Ascherson. C. Presl (Photo by Danijela Stešević)

Rhamnus orbiculatus (Kotorska župa, [13]), and *Galium proccurens* [69] have also been described from the area of Boka Kotorska Bay.

After the World War II Montenegro local botanists and botanists from the neighboring countries explore the flora. We are going to mention the Bosnian-Herzegovinian botanists Čedomil Šilić who described the new species of endemic heather *Satureja horvatii* on the material collected on the mountain of Orjen (Kabao–Subra) [70]. This plant was also recorded in the vicinity of Kotor (Table 1). In recent years, thanks to molecular analysis, certain plant families, and/or groups have been revised and some new to science endemic species from the area of the Boka Kotorska have been described, like *Viola suavis* subsp. *austrodalmatica* [71], *Cardamine rupestris* [72], and *Campanula austroadriatica* [73].

Table 1 presents the 49 Balkan endemic plant species and subspecies that were recorded in the flora of Boka Kotorska. The taxonomic status of the endemic plants is given in accordance with the existing bibliographic sources [64, 74–80] and electronic databases [81–84]. Locality, life form and areal group are given for each taxon. Meusel [85–88] method was used to define the areal (chorological) groups, as well as their appropriate classification, which is according to Tomović et al. [65] modified and adapted for the territory of Montenegro. Taxa are listed in the following chorological groups: the MED–SUBM (Mediterranean–Submediterranean); SEM (South European mountain); and CEUR (Central European). Taxon classification in terms of life form is done by the system Raunkiaer [89], which was revised by Mueller-Dombois and Ellenberg [90] and elaborated by Stevanović [88]. Taxa are classified as follows: nanophanerophytes (NP), chamaephytes (Ch), hemicryptophytes (H), geophytes (G), and therophytes (T).

The chorological structure of the endemic flora of Boka Kotorska showed that it is the largest Mediterranean–Submediterranean group with 34 taxa, followed by 12 taxa belong to the South European mountain group and only three taxa belong to the central European one. In the biological spectrum of flora chamaephytes are the most numerous with 18 taxa, followed by hemicryptophytes with one taxon less, i.e. 17, therophytes numbering six taxa and geophytes and nanophanerophytes each having four taxa.

The immediate and strong Mediterranean influence caused the largest number of endemic taxa of Boka Kotorska to belong Mediterranean–Submediterranean areal group. Members of this group inhabit xerophilous and thermophilic communities which make a significant share of the habitats in Boka Kotorska. In addition, a strong anthropogenic influence that leads to the spread of secondary vegetation types (rocky habitats, xerophilous grass communities, and various forms of shrubs), at the expense of the potentially forest and shrub types of habitats, contributes to the increasing number of endemic taxa belonging to the Mediterranean–Submediterranean chorological group [59]. Southern Europe mountain group that is represented with 12 taxa is characteristic of the high mountainous type of endemism. A relatively small number of endemic taxa belong to it and they inhabit the slopes of Vrmac and the slopes of the hill of St. Ivan. Given that the coastal mountains of Lovćen and Orjen immediately rise over Boka Kotorska, which are considered centers of high mountain endemism in the Balkans and in Europe [57], it is not surprising that some orophytes found refuge on the northern slopes of the hill in Boka. The Central European areal group is represented with only three taxa inhabiting the broad leaf forests and mesophilic pastures of the central and western Balkans. Their contribution is, therefore, insignificant in the total number of the endemic flora of Boka Kotorska.

Life forms of the plants reflect the basic features of habitats as well as the continuity of weather changes on it and they are the result of the adjustment process during the evolution of the species [91]. Chamaephytes are the most numerous life form in the biological spectrum of endemic flora of Boka Kotorska. Endemic dwarf shrubs in the Boka Kotorska usually inhabit cracks of the thermophilic limestone cliffs and rocky areas. Plants that live in such habitats have by the rule slower growth and they are resistant to drought [92]. Hemicryptophytes represent the most numerous life form in the temperate zone and in the Balkan Peninsula, and we therefore expect their large distribution in the endemic flora of Boka Kotorska. The life form of therophytes in the endemic flora mainly belongs to the plants that predominantly inhabit the Mediterranean region. Therophytes inhabit the less productive habitats such as dry meadows and rocky places where they are exposed to drought or habitats that are under strong anthropogenic influence. Geophytes life form belongs to the plants that inhabit the Mediterranean and Submediterranean thermophilic and xerophilous habitats. Nanophanerophytes are represented by four species in the endemic flora of Boka Kotorska, which is expected, considering that there are not many Balkan endemic taxa among the bushy plants.

4 Protected and Rare Species of Vascular Plants in the Flora of Boka Kotorska Bay

According to the available studies and our own field data there are 47 species of national and/or international protection status, which are grouped into 15 families in the area of Boka Kotorska (Table 2). In accordance with ancient research data there are two more species in Boka that are protected in Montenegro: *Pancratium maritimum* L. (Trašte [16, 93]) and *Echinophora spinosa* L. (Trašte [16], Tivat [18]. The above-mentioned species have not been reported in Boka for more than a century, and we believe that they are extinct in this area due to urbanization.

Two species – *Galanthus nivalis* L. and *Ruscus aculeatus* L., which have numerous populations in Montenegro, they are listed in the ANNEX V Habitat Directive. Furthermore 27 recorded taxa have been listed by the CITES convention.

National legislation protects 46 species, whereby is the category of endangered defined only for *Polygonum maritimum* (IUCN category VU, B2ab Criteria (iii, v) (Fig. 15) [94]. Taxa of the Orchidecaeae family are protected in Montenegro, so that the greatest number of protected species (26) in Boka Kotorska belong to this family. Some of these species have a wide distribution and a number of populations in the Mediterranean and Submediterranean area of Montenegro, like *Orchis morio*

Table 2 Review of taxa of the vascular flora of Boka Kotorska with the corresponding level of protection

Taxon	National status of protection[a]	International status of protection
Polygonaceae		
Polygonum maritimum L.	+	
Chenopodiaceae		
Salicornia europaea L.	+	
Salicornia fruticosa (L.) A. J. Scott.	+	
Salsoda kali L.	+	
Salsola soda L.	+	
Caryophyllaceae		
Spergularia salina J. Presl & C. Presl	+	
Brassicaceae		
Cakile maritima Scop.	+	
Euphorbiaceae		
Euphorbia paralias L.	+	
Rhamnaceae		
Rhamnus intermedius Steudel & Hochst	+	
Apiaceae		
*Chaerophyllum coloratum*L.	+	
Eryngium maritimum L.	+	
Primulaceae		
*Cyclamen hederifolium*Aiton.	+	
Cyclamen repandum Sm.	+	
Plumbaginaceae		
Limonium angustifolium Tausch	+	
Asclepiadaceae		
Vincetoxicum huteri Vis. & Ascherson	+	
Lamiaceae		
Micromeria kerneri Murb.	+	
Satureja inodora Host.	+	
Asteraceae		
Aster tripolium L.	+	
Centaurea glaberrima Tausch.	+	
Posidoniaceae		
Posidonia oceanica (L.) Delile	+	
Zosteraceae		
Zostera marina L.	+	
Zostera noltii Hornem.	+	
Liliaceae		
Ruscus aculeatus L.		Anex V Habitat Directive

(continued)

Table 2 (continued)

Taxon	National status of protection[a]	International status of protection
Amaryllidaceae		
Galanthus nivalis L.	+	CITES; Anex V Habitat Directive
Orchidaceae		
Anacamptis pyramidalis (L.) Rich.	+	CITES
Epipactis microphylla (Ehrh.) Swartz	+	CITES
Dactylorhiza saccifera (Brongn.) Soó	+	CITES
Ophrys apifera Hudson	+	CITES
Ophrys araneola Rchb.	+	CITES
Ophrys bertolonii Moretti (Fig. 16)	+	CITES
Ophrys bombyliflora Link	+	CITES
Ophrys holosericea (Burm.) Greuter	+	CITES
Ophrys reinholdii Spruner ex Fleischm	+	CITES
Ophrys scolopax Cav. subsp. *cornuta* (Steven) Camus	+	CITES
Ophrys sphegodes Miller subsp. *montenegrina* H. Baumann & Künkele	+	CITES
Ophrys sphegodes Miller subsp. *sphegodes*	+	CITES
Orchis coriophora L.	+	CITES
Orchis laxiflora Lam.	+	CITES
Orchis morio L. supsp. *morio*	+	CITES
Orchis morio L. supsp. *albanica*	+	CITES
Orchis pauciflora Ten.	+	CITES
Orchis quadripunctata Cirillo ex Ten.	+	CITES
Orchis simia Lam.	+	CITES
Orchis tridentata Scop.	+	CITES
Platanthera bifolia (L.) Rich.	+	CITES
Serapias cordigera L.	+	CITES
Serapias lingua L.	+	CITES
Serapias vomeraceae (Burm.) Briq.subsp. *laxiflora* (Soó) Göltz & Reichard	+	CITES
Serapias vomeraceae (Burm.) Briq.subsp. *vomeraceae*	+	CITES
Spiranthes spiralis (L.) Chevall.	+	CITES

[a]National status of protection is given in accordance with the document "Decision on the protection of certain animal and plant species" (Decision published in Official Gazette MNE No 76/06 of 12th December 2006)

L., for example. However, there are some that have been reported only in Boka Kotorska and only on one locality: *Ophrys bombyliflora* Link (Muo above Kotor: [4]) *Ophrys reinholdii* Spruner ex Fleischm (Mrkovi in Boka Kotorska: [40]). We do not have any information on the population size of these rare orchids.

Fig. 15 *Polygonum maritimum* L. (Photo by Snežana Vuksanović)

Fig. 16 *Ophrys bertolonii* Moretti (Photo by Snežana Vuksanović)

In addition to the protected species, it is important to mention the ones that are not protected, but that are very rare. They were recorded in Montenegro only in Boka Kotorska, on one or two localities. These are: *Aeluropus litoralis* (Gown) Parl. (Tivat saline fields [42, 47]; St. Ivan above Kotor [42]), *Aira caryophyllea* L. (Vrmac [42]), *Ajuga iva* (L.) Schreber (road Krtole – Luštica [95], Mirišta [42]), *Andrachne telephioides* L. (Luštica [96]), *Anogramma leptophylla* (L.) Link (Rose, Vrmac [16]), *Anthemis ruthenica* Bieb. (Lastva near Tivat [97]), *Asplenium petrarchae* (Guerin) DC. (Kotor [98]), *Bupleurum tenuissimum* L. (Tivat fields, saline field *Consolida incana* (ED Clarke) Munz ([10], *Daphne gnidium* L. (near Kotor [4]), *Elymus elongatus* (Host) Runemark (Tivat saline fields: [47], Tivat saline fields [42]), *Eryngium creticum* Lam. (Muo, Dobrota [16]), *Fumana arabica* (L.) Spach (Trinity bay Trašte [16]), *Lamium hybridum* Vill. (Lepetane, Stoliv [42]), *Lavatera punctata* All. (Vrmac [25]), *Linaria chalepensis* (L.) Miller (Boka Kotorska [16]), *Lotus cytisoides* L. (Mamula, vicinity of Kotor [16]), *Medicago coronata* (L.) Bartal. (Vrmac [3]), *Medicago tuberculata* (Retz.) Willd. (Boka Kotorska: [16]), *Narcissus papyraceus* (Gornja Lastva: [42]), *Orobanche hederae* Duby (Lepetane [42]), *Orobanche lavandulacea* Reichenb. (St. Ivan above Kotor [16]), *Orobanche ramosa* L. (St. Ivan above Kotor [16]), *Orobanche sanguinea* C. Presl. (Near Kotor [16]), *Parapholis filiformis* (Roth) C. E. Hubbard, *Plantago maritima* L. (Tivat saline fields [47, 48]), *Plumbago auriculata* Lam. (Tivat, Ostrvo cveća [96]), *Potentilla sterilis* (L.) Garcke (Prčanj and Stoliv [6], Meljine and Vrmac [16]), *Puccinellia festuciformis* (Host) Parl. (Tivat saline fields [42, 47, 48]), *Rumex confertus* Willd. (Lepetane [42]), *Ruppia cirrhoza* (Petagna) Grande (Kotor [21], Tivat saline fields [47]), *Santolina chamaecyparissus* L. (between Škaljari and Kotor [16]), *Scandix australis* L. (Kotor [11]), *Schoenoplectus litoralis* (Schrad.) Palla (Tivatske salt pans [47]), *Sedum rubens* L. (Zelenika [10]) *Sedum stellatum* L. (Kostanjica the Gulf Morinj [99], *Senecio leucanthemifolius* Poir. (Kotor [5]), *Silene bupleuroides* L. (Škaljari [3]), *Spergularia media* (L.) C. Presl (environment Kotor [23]) *Triglochin maritima* L. (saline fields in the Bay of Tivat [32], Tivat bay, the saline fields [47]), *Vicia articulata* Hornem (Muo, Prčanj [3]).

It is particularly interesting to mention the orchid *Neotinea maculata* (Desf.) Stearn, which is in Montenegro recorded only on two localities in Boka: Spilica near Kotor [100] and at Činovica hill at the foot of the peninsula of Vrmac [42]. This is one of the two species that are identified representatives of Orchidaceae family in Montenegro, which is not protected by the national legislation, despite the fact that it is very rare.

5 The Decorative Flora of the Boka Kotorska Bay

Several millennia coexistence of man and nature in the area of Boka Kotorska reflected on man's relationship with nature as its primordial environment. Respect for nature is reflected in the tradition and culture of living of the people who have been inhabiting these areas for centuries. For these reasons, and in particular, bearing in mind the tradition of enriching the living space with the natural surroundings, the settlements in the area of Boka Kotorska from ancient times have been having parks, gardens, and green areas. Cultivating these areas was made easier by the fact that sailing as a recognizable occupation of the inhabitants of Boka Kotorska, often followed the tradition of bringing seedlings of rare species of trees that enriched the already recognizable beautifully landscaped gardens and parks. Area of Boka Kotorska did not bypass the traditional enrichment of dendroflora from the period of the Roman civilization, and particularly in the eighteenth and nineteenth centuries. At that time, the introduction of species into Europe from distant places was intense. The impression of a raised awareness of the importance of cultivation of the ambient areas is complemented by extraordinarily nicely and cleanly decorated squares, ancient tree-lined boulevards, and in particular extremely well-designed gardens and parks in the courtyards of the monastery buildings. Private gardens and yards of residential buildings and houses are nonetheless beautifully designed. One of the equally important arboreal properties in the area of Boka are exceptionally well designed and decorated the old city cemeteries, where there can also be found outstanding examples of rare species originating from distant countries. On the other hand, the residents of Boka Kotorska with equal care nourished the fragments of natural arboreal properties in their environment. Appreciating the importance of the forest vegetation in the preservation of the natural surroundings and healthy environment, over the older towns one can easily find fragments of the preserved natural stands that have survived over the millennium anthropogenic pressure.

The fact that the dendroflora of the Boka Kotorska Bay is enriched with a significant number of species, intensive work on the renovation of gardens, parks, alleys, and avenues provoked the interest of researchers to thoroughly treat this segment floristic diversity as well. Although the city cadastres have records of the qualitative composition of the landscaped urban areas, there undoubtedly lies a true treasure of decorative dendroflora in the diversity of species that have been planted somewhere in the hidden corners of the private properties and gardens. In the second half of twentieth century, particularly in the late 1960s and early 1970s several studies were conducted which were important for the understanding of the decorative flora of Boka Kotorska. First of all those are the studies referring to the landscaping of the Montenegrin beaches, and then the analyses of the potential natural and decorative dendroflora in the horticultural landscaping of the coastal area of Montenegro [101, 102]. But the real studies thoroughly researching the species that are used for landscaping parks and avenues, alleys, and gardens, as well as their relationship with the nearby dendroflora and special descriptions of the ambient areas in the area of the Boka Kotorska Bay were made especially for the outer part of the bay and the surroundings of Herceg Novi [52] and the inner part of the bay [53, 103]. Unfortunately, to date, these are the only botanical reports on the dendroflora of Boka Kotorska.

Climatic characteristics of the area and pedological substrate have facilitated the breeding of many species of plants for ages, especially the so-called southern species. Even today we may notice remnants of the once developed complexes for breeding of the certain species in Boka Kotorska, although they do not constitute the primary activity and occupation of the inhabitants of Kotor today. Olives have been the main characteristic of the farming in this area from the ancient times (*Olea europaea* L.), the evidence of which is found in the remains of old olive trees all over the area of the Bay area. Intensive planting of olive trees in the area of the bay originates from the period when the Boka Kotorska was under the government of the Venetian Republic. The success in planting depended in certain parts on the very configuration of the field, but they generally planted up to 500 m.a.s.l. The largest areas were on the peninsula of Luštica, where, according to the available data, prior to World War II there were planted about 90,000 trees [52]. Besides olives, some smaller fig plantings can be found in the area of Boka Kotorska as well (*Ficus carica* L.) vines, different kinds of fruit trees and species with drupes. Finally, private gardens and yards in residential areas and along roads are rich in smaller citrus plantations forming small orangeries. Apart from their economic value, they undoubtedly extremely contribute to the enrichment of environmental scenery and complement the Mediterranean landscape. These are mainly *Citrus aurantium* L., *C. medica* L., and *C. nobilis* Lour., which are having today's a huge number of hybrids and varieties.

In the whole area, especially in the coastal region, on the promenades along the sea, in parks, in a private gardens, etc., there are palm trees as a distinctive element of decoration of the Mediterranean cities. Certainly, the most frequent palm is the canary date palm *Phoenix canariensis* Hort ex Chabaud, while in the parks by the height stands out the *Washingtonia filifera* (Linden ex André) H. Wendl. There are also often two kinds of palmettos *Chamaerops humilis* L. (otherwise autochthonous in the Western Mediterranean and North Africa), as well as *Trachycarpus excelsa* Wendl. which can grow high up to 15 m. Although rarely, the coconut palm *Cocos australis* Mart has also been planted in the Boka Kotorska Bay. But these are rare specimens that are not especially noticeable. Among the less common representatives of the family of palm trees that are grown in the area of the Boka Kotorska Bay, there are also specimens of *Sabal palmetto* (Ealter) Loddo. ex Schult. et Schult.f. and *Livistona chinensis* (Jacq.) R.Br. ex Mart. Besides the palm trees the succulent representatives of the genus *Agave* are often grown, the species which also occurs naturally in the rocky parts of the coast and steep rocky sides facing the sea can reach extremely old age. Representatives of the genus *Yucca* may also be found, which likewise conquer the space outside the landscaped areas. Along the roads there is the cactus *Opuntia ficus-indica* (L.) Mill. which is considered to be domesticated species, although it is an allochthonous representative that became domesticated and spontaneously spread to natural habitats.

Based on studies from the second half of twentieth century there are more than 100 species of dendroflora [52, 103] in the area of the Boka Kotorska Bay. As the more recent data have not been synthesized yet and can be found exclusively in the local tree cadastres, we assume that this number is significantly higher. The fact that today many other species are used in the landscape architecture, and that they are included in the processes of afforestation and landscaping of the parks and avenues of trees (*Lagerstroemia indica* L., Lythraceae or *Rhazia stricta* Decne., Apocynaceae), justifies our assumption that the 50 years old data are different now.

The decorative flora of the Boka Kotorska, there are many known plant species of Gymnosperms group. This primarily includes *Cycas revoluta* Thunb. as well as some other representatives of this primitive group of plants, e.g., *Dioon edule* Lindl. There is also the inevitable ginkgo tree *Ginkgo biloba* L., which in its own, recognizable way contributes the dynamics of landscaped areas. The use of coniferous species in planting and landscape architecture is common in the area of the Boka Kotorska Bay. Around and in particular over the cities there are plantations of autochthon conifers among which dominates the black pine (*P. nigra* F. Arnold) in combination with many other species including pine (*P. heldreichii* Christ)

[103]. However, one of the most planted conifers certainly is the *P. halepensis* Mill., along with *P. brutia* Ten., P. *pinaster* Ait. pine nuts, and *P. pinea* L., which is often found in single-species, and rarely in small groups. Cypress *Cupressus sempervirens* L. is often grown, but it is often spontaneously present in the preserved fragments of natural or semi-natural stands. In the area of the Boka Kotorska Bay it occurs in varieties var. *horizontalis* (Mill.) Loudon and var. *pyramidalis* (O. Targ. Tozz.) Nyman. The most frequently planted are the representatives of *Cedrus deodara* (Roxb. Ex D.Don) G.Don, *Abies cephalonica* Loudon, *Picea pungens* Engelm., *Calocedrus decurrens* (Torr.) Florin, *Chamaecyparis pisifera* (Siebold et Zucc.) Endl., *Cryptomeria japonica* (Thunb. ex Lf) D.Don, and many others. As a real rarity, most often planted in private gardens of the towns of Boka, are the two species of Patagonian firs, i.e., *Araucaria araucana* (Molina) K. Koch and *A. columnaris* (G. Forst) Hook.

Enormous treasure of species, being the main cause of the distinctive colorfulness of the Mediterranean plants, gives us a large range of species of woody dicotyledonous representatives. First of all these are the forms of decorative species of *Magnolia grandiflora* L. (Fig. 17) and *M. x soulangeana* Soul.-Bod. frequent species in the tree-lined avenues. There are also recognizable camellias *Camellia japonica* L. (Fig. 18) However, what makes the entire coast of the Boka Kotorska Bay in the early spring months recognizable is *Acacia dealbata* Link. that is found growing both spontaneously and in the orchards and gardens. Families of legumes a favorite in the Mediterranean as the cultivated species of trees. There are therefore several species of the Mimosaceae families in the area of the Boka Kotorska Bay; together with the species of the genus Acacia, *A. retinoides* Schltdl and

Fig. 17 *Magnolia grandiflora* L. in garden. (Photo by Vesna Mačić)

Fig. 18 *Camellia japonica* L. (Photo by Vesna Mačić)

A. floribunda (Vent.) Willd., *Albizia julibrissin* Durazzo., there is carob from the family of Cesalpinaceae – *C. siliqua* L., as well as the ornamental species of *Cercis siliquastrum* L., *Gleditsia triacanthos* L. and *Caesalpinia gilliesii* (Hook.) D. Dietrare. As one of the most common ornamental species planted along the entire Montenegrin coast, and thus in the Boka Kotorska Bay as well, the Chinese species of *Pittosporum tobira* Ait. is especially grown. This species covers a wide area and it often found as a standalone tree or plant that successfully tolerates pruning and is used as a hedge. Rare are the representatives of the *Casuarina equisetifolia* L. species, originating from Australia as well as banana trees.

There is no doubt that the centuries-long tradition of decorating gardens, yards, parks, and squares with greenery led to the fact that today we can find in the area of the Boka Kotorska Bay some examples of extremely rare tropical plants. However, as the tradition of bringing seedlings of rare plants and herbs by the sailors has nowadays almost entirely disappeared, the preservation of this wealth in diversity is one of the main tasks of the local administration. By this we mean the preservation of arboreal sites of the landscaped areas.

6 Conclusions

Area of Boka Kotorska is undeniably one of diversity hotspots for flora of Montenegro and Balkan Peninsula. Although exposed to many centuries of anthropogenic pressure, flora of Boka Kotorska managed to significantly preserve its natural character due to presence of primary habitats – numerous microhabitats with conserved elements of natural vegetation. The peculiar character of this flora is evidenced by rich results of botanical studies performed in this area during a long period of time. The qualitative composition of flora in area of Boka Kotorska sparked considerable interest, leading to a vast amount of data collected in numerous publications, particularly in the 19th and the first half of twentieth century. Unfortunately, the floristic studies in area of Boka Kotorska were not performed in any systematic manner, and data pertain only to certain isolated localities or individual floristic data. The data in detailed floristic studies of several regions (Vrmac, Brdo Sv.Ivan, parts of Luštica, Tivatsko polje etc.) are not sufficient for creating an all-including overview of floristic diversity, which is only glimpsed during the survey of literature data.

This overview of floristic diversity of Boka Kotorska is a compilation of existing results collected by numerous researchers, including the authors of this paper. The collected data on presence of endemic taxa at species and subspecies level indicate an interesting florogenesis of this area. The placement of endemic taxa in appropriate chorological groups clearly shows that these are not exclusively endemics of Mediterranean–Submediterranean chorological type, as there is also a significant presence of representatives of South European-mountain chorological group, in spite of significantly lower altitudes in the area. The quality of endemic flora of Boka Kotorska is obviously significantly influenced by high mountain massifs which are part of mountain systems of Western Balkans.

The list of species placed under the appropriate conservation system has multiple implications: it supports the recorded prominent floristic diversity, as in addition to species included in European and World lists (species of Orchidaceae and species from the CITES list) it also abounds in representatives not included in these lists. On the other hand, this area shows an unusual richness in microhabitats. The list is characterized by representatives preferring different habitats and vegetation units. And finally, the list of taxa under the appropriate protection regime still reflects the significant anthropogenic pressure imposed on this area for many centuries. This is particularly evident in taxa recorded in this area in the past but lacking any newer records.

Diversity of flora of ligneous plants at Boka Kotorska includes both autochthonous species and a significant number of species introduced for needs of landscaping design, including parks, streets, public areas, and private gardens. The ancient tradition of bringing plants from distant journeys was unfortunately partially continued even after such journeys became uncommon. In spite of this, the modern decorative flora in the area of Boka Kotorska may be considered particularly rich. In addition to usual decorative tree species, parks, and arboretums may also host extremely rare and valuable individuals of South American, African and Asian species.

The researchers in fields of flora and conservation biology are presented with an overview of floristic richness of a unique natural object. In the immediate future it is necessary to involve the research potential from Montenegro in order to study the area of Boka Kotorska from the floristic standpoint as soon as possible. It would lead to valid quantitative representation of flora and all its potentials. On the other hand, fast and intensive urbanization in the coastal area is the leading threat to survival of preserved microhabitats, which, as we concluded earlier, are the main pillars of the pronounced floristic diversity of Boka Kotorska. Therefore activities on detection, marking and conservation of these localities are priority tasks for the national environmental conservation service.

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References

1. Sieber FW (1822) Neue und seltene Gewächse. Flora Regensburg 5(1):241–248
2. Pulević V (2006) Botanists and Montenegro. Natural History Museum of Montenegro, special edition, vol 2, edit. Vizi, O. Natural History Museum of Montenegro, Podgorica, p 458
3. Tommasini M (1835) Botanische Wanderungen im Kreise von Cattaro. Flora (Regensb) 2:1–59
4. Visiani R (1842) Flora Dalmatica, vol 1. F. Hofmeister, Lipsiae
5. Visiani R (1847) Flora Dalmatica, vol 2. F. Hofmeister, Lipsiae
6. Visiani R (1850–1852) Flora Dalmatica, vol 3. F. Hofmeister, Lipsiae
7. Visiani R (1872) Florae dalmaticae supplementum. Mem Inst Veneto 16:1–189
8. Visiani R (1877) Florae dalmaticae supplementum alterum, adjectis plantis in Bosnia, Hercegovina et Montenegro crescentibus. Pars I. Mem Inst Veneto 20
9. Visiani R (1882) Florae dalmaticae supplementum alterum, adjectis plantis in Bosnia, Hercegovina et Montenegro crescentibus. Pars II. Mem Inst Veneto 21
10. Weiss E (1866) Floristisches aus Istrien, Dalmatien und Albanien. Verh Zool-Bot Ges, Wien 16:571–584
11. Weiss E (1867) Floristisches aus Istrien, Dalmatien und Albanien, I, II. Verh Zool-Bot Ges 17:753–762
12. Čelakovský L (1885) *Dianthus dalmaticus* sp. Nova (*S.ciliatus* var. *cymosus*Vis.). Öesterr Bot Zeitschr 35:189–194
13. Bornmüller J (1887) *Rhamnus orbiculata* Bornm. n. sp. Öesterr Bot Zeitschr 37:225–227
14. Bornmuller J (1889) Beitrag zur Flora Dalmatiens. Öesterr Bot Zeitschr 39:333–337
15. Lindberg H (1906) Verzeichnis der auf einer Reise in Oesterreich-Ungarn im Mai und Juni 1905 gesammelten Gefasspflanzen. Finsk Vetensk Soc Forhandl 43(13):1–128
16. Studniczka C (1890) Beitrage zur Flora Süddalmatien. Verh Zool Bot Ges 40:55–84
17. Hirc D (1911) Iz bilinskoga svijeta Dalmacije. III. Oko Bokeljskog zaliva. Glas Hrv Prir Duštva, Zagreb 24(1):33–52
18. Hirc D (1912) Iz bilinskoga svijeta Dalmacije. Glas Hrv Prir Društva, Zagreb 24(2-3):94–109
19. Biasoletto B (1841) Relazione del viaggio fatto nella primavera dell'anno 1838 dalla Maesta del Re Federico Augusto di Sassonia. Trieste
20. Ebel W (1842) Bericht ueber eine Reise in Montenegro. Monatsber Verh Ges 132–141
21. Ascherson P (1869) Beitrag zur Flora Dalmatien. Öesterr Bot Zeitschr 19:65–71
22. Kerner A (1872) Zur flora von Dalmatien. Croatien und Ungarn. Öesterr Bot Zeitschr 23:23–67
23. Pantocsek J (1874) Adnotationes ad Floram et Faunam Hercegovinae, Crnagorae et Dalmatiae. Verhandlungen des Vereines FürNaturkunde in Presburg 2:1–143
24. Veselý J (1890) Ein Ausflug in die Krivošije und auf den Orjen. Gart-Zeit 15:383–388
25. Baldacci A (1894) Contributo alla conoscenza della flora Dalmata, Montenegrina, Albanese. Epirota e Greca Nuovo Gior Bot Ital 1(2):90–103
26. Pulević V, Vincek D (1991) Crna Gora vrata Balkana, putopisi i zapisi evropskih botaničara. Obod, Cetinje

27. Pančić J (1874) Botanische Bereisung von Montenegro im Jahre 1873. Öesterr Bot Zeitschr 24:82–85
28. Adamović L (1900) Zimzeleni pojas Jadranskog primorja. Glas SANU, Beograd 61(23)
29. Adamović L (1911) Biljnogeografske formacije zimzelenog pojasa Dalmacije, Hercegovine i Crne Gore. Rad, JAZU, Zagreb 188(50):1–54
30. Adamović L (1911) Die Pflanzenwelt Dalmatiens. Leipzig
31. Šmarda J (1968) Vysledky biogeografickych cest do Jugoslavie v letech 1964-1967. Československa Akademie Ved – Geograficky UStav v Brne
32. Pulević V (1973) Prilog flori Crne Gore. Glasn Republ Zav Zašt Prir–Prirod Muz, Titograd 6:77–83
33. Pulević V (1977) Prilog poznavanju taksonomije i horologije Crocus tommasinianus Herbert (Iridaceae). Polj Šum, Titograd 23(1):53–60
34. Pulević V (1979) O flori i vegetaciji Boke Kotorske i po trebi njihove zaštite. Boka (Herceg Novi) 10(2):209–220
35. Pulević V (1982) Zaštita flore i vegetacije u Crnog Gori. MANU, Odel Biol Med Nauka, Prilozi, Skopje 3(1):109–124
36. Pulević V (1983) Zaštićene biljne vrste u SR Crnoj Gori. Glas Rep Zavoda Zašt Prir Titograd 16:33–54
37. Pulević V (1984) Euphorbia prostrata Aiton, nova adventivna vrsta u flori Jugoslavije. Drugi kongres o korovima, Osijek 113–117
38. Trinajstić I (1974) Prilog poznavanju horologije neofita Tagetes minutes L. na području Jugoslavije. Acta Bot Croat 33:231–235
39. Obradović M (1985) Endemske biljke roda *Campanula* (zvončići) u flori Herceg-Novog i okoline. Boka 17:437–443
40. Parolly G (1992) Die Orchideenflora Montenegros. Mitt Bl Arbeitskr Heim Orch Baden-Wurt 24(2):141–391
41. Parolly G (1995) Ergaenzunfen zur Flora von Montenegro. Wildenowia 25:57–74
42. Karaman V (1997) Flora istočnog dela Bokokotorskog zaliva. Magistarski rad, Biološki fakultet, Univerzitet u Beogradu
43. Budak PV, Mačić LJV, Mačić KLJ, Anačkov G (2001) Endemic species in flora of St. Ivan hill in the vicinity of the city of Kotor (Montenegro, Yugoslavia). Endemske biljke u flori brda Sv. Ivan u okolini Kotora. (Crna Gora, Jugoslavija). Zbornik Matice Srpske Prirodne Nauke 101:85–94
44. Stešević D (2005) Biljni svijet Grblja, Monografija »Grbalj kroz vjekove«. Grbalj, p 673–694. ISBN: 86-86761-00-X
45. Janković M (1966) *Lauro-Castanetum sativae* M. Jank., nova termofilna i eumediteranska zajednica pitomog kestena i lovora u Boki kotorskoj. Arhiv bioloških nauka 18(1):9–10
46. Jovanović B, Vukićević E (1976) Fitocenoza sa oleandrom (*Nerium oleander* L.) kod Risna u Boki Kotorskoj. Referat na Simpozijumu zaštite čovjekove sredine, Herceg Novi
47. Janković MM, Stevanović V (1983) Prilog poznavanju slatinske vegetacije Boke Kotorske. Zbornik Roberta Visianija Šibenčanina, Muzej grada Šibenika 10:377–396
48. Čađenović N (2007) Flora starih Tivatskih Solana (Crna Gora) - komparativna analiza flore, procjena diverziteta, značaj njihove konverzacije, diplomski rad. PMF, Novi Sad
49. Jovanović S, Stevanović V (1995) Mural flora of the old fortress of the south Adriatic coast (Montenegro). VIII OPTIMA meeting, abstracts, Seville, p 87
50. Budak V, Mačić V, Mačić LJ, Anačkov G (2000) Flora brda Sv Ivan u okolini Kotora. Zbornik radova o flori jugoistočne Srbije i susjednih područja. Abstract
51. Grebeščikov OS (1960) The vegetation of the Kotor Bay seaboard (Crna Gora, Yugoslavia) and some comparative studies with the Caucasia seabord of the Black Sea. Bjuletten M.va Isp, Prirodi. Otd Biologiji 65(6):99–108
52. Popović D, Sterniša A (1971) Flora i vegetacija hercegnovskog područja s posebnim osvrtom na parkovsko bilje. Skupština opštine Herceg Novi i Turistički savez Boke Kotorske, Herceg Novi

53. Đakonović F (1977) Ekološke karakteristike priobalnog dela unutrašnjeg Bokokotorskog zaliva. Glasn Šum Fak-Jubilarni broj Beograd 52:221–224
54. Jovanović B, Vukićević E, Đakonović F (1979) Exploration of current and potential natural vegetation in the evaluation of countryside. Boka 10(2):165–172
55. Blečić V, Lakušić R (1976) Prodromus biljnih zajednica Crne Gore. Glasnik republičkog zavoda za zaštitu prirode i prirodnjačkog muzeja u Titogradu 9:57–98
56. Fukarek P, Jovanović B (ed) (1983) Karta prirodne potencijalne vegetacije SFR Jugoslavije. Naucno vece vegetacijske karte Jugoslavije, Univerzitet Kiril i Metodije, Skopje
57. Stevanović V (1995) Biogeografska podela teritorije Jugoslavije u Stevanović V, Vasić V, uredn., Biodiverzitet Jugoslavije sa pregledom vrsta od međunarodnog značaja. Ekolibri, Biološki fakultet, Beograd 117–127
58. Petrović D, Hadžiablahović S, Vuksanović S, Mačić V, Lakušić D (2012) Catalogue of habitat types of EU importance of Montenegro, Podgorica. Beograd, Zagreb
59. Tomović G (2007) Phytogeographical reference, distribution and diversity centres of the Balkan endemic flora in Serbia. PhD thesis, University of Belgrade, Belgrade
60. Turrill WB (1929) The plant life of the Balkan peninsula. A phytogeographical study. Clarendon, Oxford, p 49
61. Blečić V (1958) O nekim karakteristikama flore i vegetacije Crne Gore. Zaštita Prirode 13:1–6
62. Stevanović V, Jovanović S, Lakušić D, Niketić M (1995) Diverzitet vaskularne flore Jugoslavije sa pregledomvrsta od međunarodnog značaja. In: Stevanović V, Vasić V (eds) Biodiverzitet Jugoslavije sa pregledom vrsta od međunarodnog značaja. Ecolibri, Biološkifakultet, Beograd, p 183–217
63. Lubarda B, Stupar V, Milanović Đ, Stevanović V (2014) Chorological characterization and distribution of the Balkanendemic vascular flora in Bosnia and Herzegovina. Bot Serbica 38:167–184
64. Strid A, Tan K (eds) (1997) Flora Hellenica, vol 1. Koeltz Scientific Books, Königstein, p 547
65. Tomović G, Niketić M, Lakušić D, Ranđelović V, Stevanović V (2014) Balkan endemic plants in Central Serbia and Kosovo regions: distribution patterns, ecological characteristics and centres of diversity. Bot J Linn Soc 176:173–202
66. Bartolommeo B (1841) Relazione del viaggio fatto nella primavera dell'anno 1838 Della Maesta del re Federico Augusto di Sassonia nell'Istria, Dalmazia e Montenegro
67. Ebel W (1844) Zwölf Tage in Montenegro (und ein Blick auf Dalmatien) IV. J. H. Bon, Königsberg, p 176
68. Pantocsek J (1873) Plantae novae quas aestate anni 1872 per Hercegovinam etMontenegro collexit et descripsit. Öesterr Bot Zeitschr 23(1):4–6; 23(3):79–81; 23(9):265–268
69. Ehrendorfer F, Ančev M (1975) *Galium procurrens*, a new diploid relic species of the G. sylvaticum-group from Balkan Peninsula. Plant Syst Evol 124:1–6
70. Šilić Č (1974) Conspectus generum *Satureja* L, *Calamintha* Moench, *Micromeria* Bentham, *Acinos* Moench et *Clinopodium* L florae Jugoslaviae. Glasnik Muzeja Bosne i Hercegovine 13:106–128
71. Mereďa PJR, Hodálová I, Kučera J, Zozomová-Lihová J, Letz RD, Slovák M (2011) Genetic and morphological variation in *Viola suavis* s.l. (Violaceae) in the western Balkan Peninsula: two endemic subspecies revealed. Syst Biodivers 9(3):211–231
72. Kučera J, Marhold K, Lihová J (2010) *Cardamine maritima* group (Brassicaceae) in the amphi-Adriatic area: a hotspot of species diversity revealed by DNA sequences and morphological variation. Taxon 59(1):148–164
73. Lakušić D, Liber Z, Nikolić T, Surina B, Kovačić S, Bogdanović S, Stefanović S (2013) Molecular phylogeny of the *Campanula pyramidalis* species complex (Campanulaceae) inferred from chloroplast and nuclear non-coding sequences and its taxonomic implications. Taxon 62(3):505–524
74. Greuter W, Burdet HM, Long G (eds) (1984–1989) Med-checklist, vols 1, 3, 4. Conservatoire et Jardin botaniques de la Ville de Gèneve Med-Checklist Trust of OPTIMA, Geneva

75. Jalas J, Suominen J (eds) (1972–1994) Atlas Florae Europaeae. Distribution of vascular plants in Europe, vols 1–10. Committee for Mapping the Flora of Europe & Societas Biologica Fennica Vanamo, Helsinki
76. Jalas J, Suominen J, Lampinen R (eds) (1996) Atlas Florae Europaeae. Distribution of vascular plants in Europe, vol 11. Committee for Mapping the Flora of Europe & Societas Biologica Fennica Vanamo, Helsinki
77. Jalas J, Suominen J, Lampinen R, Kurtto A (eds) (1999) Atlas Florae Europaeae. Distribution of vascular plants in Europe, vol 12. Committee for Mapping the Flora of Europe & Societas Biologica FennicaVanamo, Helsinki
78. Kurtto A, Lampinen R, Junikka L (eds) (2004) Atlas Florae Europaeae. Distribution of vascular plants in Europe, vol 13. Committee for Mapping the Flora of Europe & Societas Biologica Fennica Vanamo, Helsinki
79. Kurtto A, Fröhner SE, Lampinen R (eds) (2007) Atlas Florae Europaeae. Distribution of vascular plants in Europe, vol 14. Committee for Mapping the Flora of Europe & Societas Biologica Fennica Vanamo, Helsinki
80. Tutin TG, Heywood VH, Burges NA, Moore DM, Valentine DH, Walters SM, Webb DA (eds) (1964–1980) Flora Europaea, vols 1–5. Cambridge University Press, Cambridge
81. Euro+Med (2006) Euro+Med Plant Base—the information resource for Euro-Mediterranean plant diversity. http://ww2.bgbm.org/EuroPlusMed/. Accessed 28 Apr 2016
82. International Organization for Plant Information (2016) Authorized WWW server page. In: Wilson K (ed). http://plantnet.rbgsyd.nsw.gov.au/iopi/iopihome.htm. Accessed 20 Apr 2016
83. The International Plant Names Index (2012) http://www.ipni.org. Accessed 27 Apr 2016
84. The Plant List (2013) Version 1.1. Published on the Internet. http://www.theplantlist.org/. Accessed 26 Apr 2016
85. Meusel H, Jäger E, Weinert E (1965) Comparative horology of the Central European flora 1. Gustav Fischer, Jena
86. Meusel H, Jäger E, Weinert E (1978) Comparative horology of the Central European flora 2. Gustav Fischer, Jena
87. Meusel H, Jäger E (1992) Comparative horology of the Central European flora 3. Karten, Liter. Register. Gustav Fischer, German, Jena, Stuttgart, New York
88. Stevanović V (1992) Floristička podela teritorije Srbije sa pregledom viših horiona i odgovarajućih flornih elemenata. In: Sarić MR (ed) Flora Srbije, vol 1. Srpska akademija nauka, Belgrade, pp 47–56
89. Raunkiaer C (1934) The life forms of plants and statistical plant geography. Clarendon, London
90. Mueller-Dombois D, Ellenberg H (1974) Aims and methods of vegetation ecology. Wiley, New York
91. Stevanović B, Janković M (2001) Ekologija biljaka sa osnovama fiziološke ekologije biljaka. NNK International, Belgrade
92. Larson DW, Matthes U, Kelly PE (2000) Cliff ecology: pattern and process in cliff ecosystems. Cambridge University Press, Cambridge
93. Berger R (1914) Beitrage zur Kenntnis der Flora von Suddalmatien und der angrezenden Herzegowina. Allgem Bot Zeitschr 20:11–16
94. Petrović D, Stešević D (2010) Materials for the red book of vascular flora of Montenegro (second contribution). Biologica Nyssana 1(1–2):27–34
95. Pulević V, Bulić Z (1990) Novosti iz flore Crne Gore. Bilten Društva ekologa Bosne i Hercegovine B(5):85–88
96. Lakušić B, Lakušić D (2004) Rasprostranjenje vrsta roda *Teucrium* L. (Lamiaceae) u Crnoj Gori. Glasnik Republičkog Zavoda Zaštite prirode 27–28:51–70
97. Aalto M, Hamet-Ahti L, Rauuhijarvi R, Suominen J, Taarna L, Uotila M, Uotila P, Vitikainen O (1972) Jugoslavian retki 11.-25. VI 1971 (Botanical excursion to western Yugoslavia in 11.25. VI. 1971, including a list of the collected vascular plants). Helsingin yliopiston kasvimuseon monisteita 5

98. Berger R (1913) Beitrage zur Kenntnis der Flora von Suddalmatien und der angrezenden Herzegowina. Allgem Bot Zeitschr 19:177–182
99. Stevanović V (1996) Zvezdasti bobovnik (*Sedum stellatum* L., Crassulaceae) – nova vrsta za floru Jugoslavije. Ekologija 31(2):79–82
100. Rohlena J (1923) Additamenta ad floram dalmaticam. Preslia 2:98–102
101. Sterniša A (1970) Hortikulturni problem Crnogorskog primorja. Hortikultura 1
102. Bunuševac T, Vukićević E, Mijanović O, Sterniša A, Djakonović F (1979) Dekorativne biljke Bokokotorskog zaliva i njihov značaj u turizmu. Boka 10(2):125–141
103. Đakonović F (1978) Dendroflora priobalnog dela unutrašnjeg Bokokotorskog zaliva. The Dendroflora of the interior coastal part of the Boka Kotorska Gulf. Glasnik Republičkog Zavoda Zaštite Prirode-Prirodnjačkog Muzeja 11:99–132

Regional Climate Change in the Boka Kotorska Bay

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Abstract In this chapter we are analyzing the observed regional climate change in the region of the Boka Kotorska Bay basing on a set of key meteorological parameters: near-surface air temperature, sea-level pressure, atmospheric precipitation, snow cover, wind speed, and cloud cover over the past 60 years. For the analysis of meteorological parameters we used monthly and daily data from the NCEP/NCAR Reanalysis, NOAA CIRES Twentieth Century Global Reanalysis Version 2c, ERA-20C, JRA-55 for the 1950–2010 time period.

Keywords Air temperature, Atmospheric precipitation, Boka Kotorska Bay, Cloud cover, Montenegro, Regional climate change, Sea-level pressure, Snow cover, Wind speed

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Contents

1 Introduction

The Boka Kotorska Bay is one of the most beautiful places in the Adriatic Sea. It attracts numerous tourists and residents due to its beautiful landscapes, picturesque views, long summer, warm sea, warm and mild climate. The Institute of Hydrometeorology and Seismology of Montenegro observes changes in regional climate which is a result of global climate change and warming [1]. These changes are reflected in a set of basic meteorological parameters, which, in turn, have a significant impact on the Boka Kotorska Bay environment, physical, chemical, and biological processes in the Bay. Regional climate change also has a significant impact on local economy, agriculture, and tourism which is a main driver of economy in Montenegro. Thus, knowledge about the observed tendencies in regional climate change is of vital importance for understanding of future climate in Montenegro, and in the region of the Boka Kotorska Bay, in particular.

A short overview of the basic climatic characteristics in the Boka Kotorska Bay is based on meteorological measurements in Herceg Novi and Kotor [2–4]. The Boka Kotorska Bay has a typical maritime climate with the highest temperature and minimum precipitation in July, and the highest amount of precipitation in November. The average annual temperature varies from 15.3°C in Kotor to 15.7°C in Herceg Novi for the period 1961–1990. The maximum monthly temperature is from 20.1°C in Kotor to 20.3°C in Herceg Novi, while the minimum monthly temperature is from 11.2°C to 11.7°C, respectively.

The rainiest month is November with the average sum of 258 mm in Herceg Novi and 240 mm in Kotor. Autumns and winters have an abundant amount of precipitation. The period from November to January receives 39% of average annual precipitation while the period from June to August – only 10%. Snow cover is a very rare type of precipitation in the Boka Kotorska Bay. The most probable months to expect snow are January and February. The maximum daily amount of snow in Herceg Novi was 15 cm measured in February 1963.

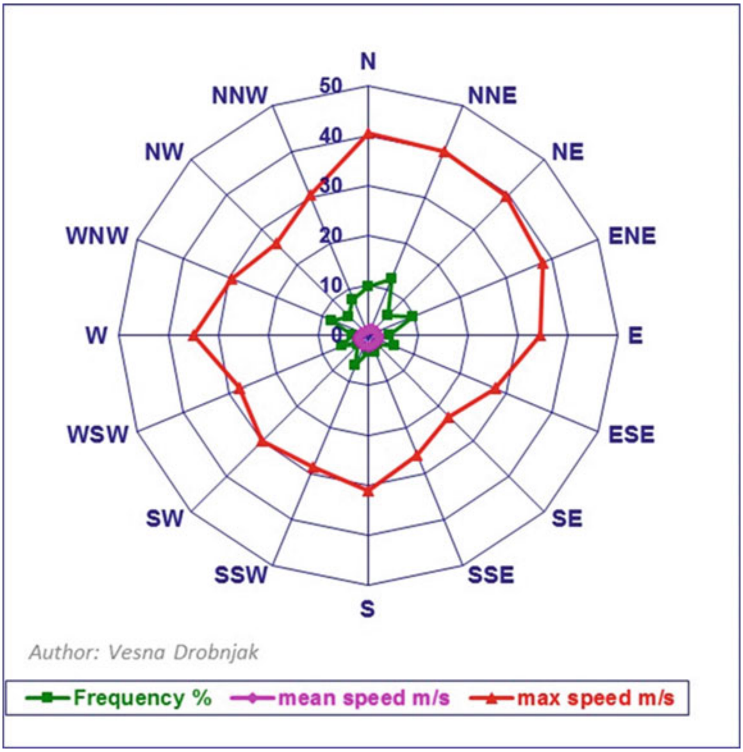

Fig. 1 The annual wind rose for Herceg Novi

In the period 1981–1995, the maximum wind speed in Herceg Novi was from the northern direction (40.6 m/s), while the most frequent wind was NNE (12.3%). Calms were 3.4% (Fig. 1). There are no long-term wind measurements in Kotor.

The sunshine duration is maximal in July – 292 h in average (i.e., 10.9 h/day), while the lowest sunshine duration is in December – in average 3.2 h/day. The number of days with cloudiness >8/10 has the highest values from November to February and lowest in July (Fig. 2).

The average atmospheric pressure, its maximum and minimum values are presented in Fig. 3 for Herceg Novi. The highest variation of atmospheric pressure could be expected from October to April (Fig. 3).

2 Data and Methods

We are analyzing meteorological data on near-surface air temperature, sea-level pressure, atmospheric precipitation, snow cover, wind speed, and cloud cover over the past 60 years (1950–2010) in the region focused on the Boka Kotorska Bay for

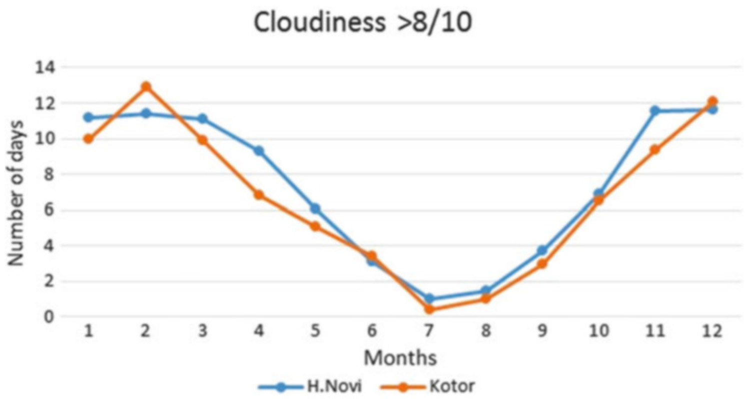

Fig. 2 Average monthly values of cloudiness >8/10 for the period 1961–1990 in Herceg Novi and 1980–1990 in Kotor

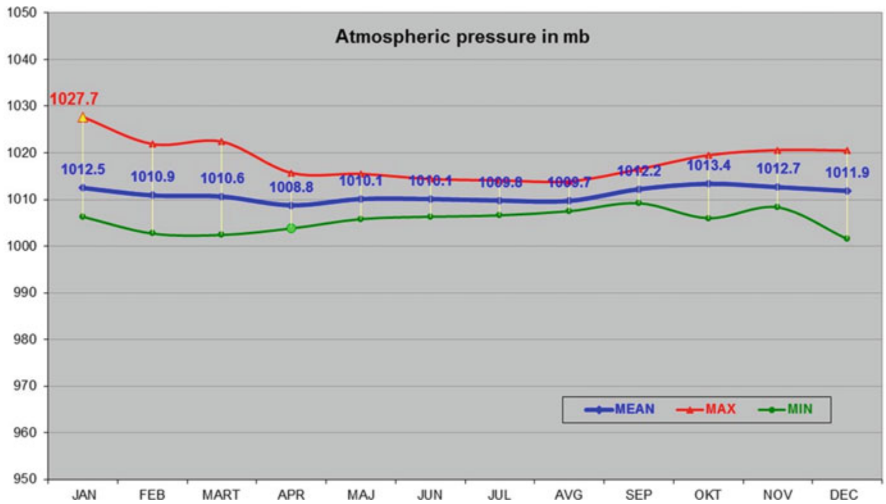

Fig. 3 Average atmospheric pressure in Herceg Novi and its maximum and minimum values for the period 1961–1990 (Author: Vesna Drobnjak, NMHS of Montenegro)

determining the characteristics of the observed regional climatic change. For the analysis of meteorological parameters we used monthly and daily data from the NCEP/NCAR Reanalysis, NOAA CIRES Twentieth Century Global Reanalysis Version 2c, ERA-20C, JRA-55 for the 1950–2010 time period [5–8]. All these databases have spatial resolution of about 1° × 1°, which is much larger than the size of the Boka Kotorska Bay. Therefore, we had to choose the region 42°–43°N and 18°–19°E with the Bay in its center for the analysis (Fig. 4).

Fig. 4 Map of Montenegro. The chosen research region (42°–43°N; 18°–19°E) is shown by the *red rectangle*

For every meteorological parameter we calculated and drew three types of graphs. The first one is seasonal and interannual variability of the parameter with a linear trend calculated for the whole time period based on monthly data. Then, working with anomalies, we removed the seasonal signal from the initial data by subtracting the average annual variation. Based on the monthly data, linear trends of the change in meteorological parameters were calculated by the least squares method for the study period. The produced 1-year and 8-year moving average is shown in the second graph. Also, we calculated accumulated sums of the anomalies after removing the linear trend. For the entire study period we also calculated the average values of the anomalies separately for warm (April–September) and cold (October–March) periods for every year. All this is shown in the second graph by different colors. Based on the daily data, the spectra of the time series were calculated using the method of the Fast Fourier Transform (FFT). The corresponding spectra of the red noise and 95% confidence intervals were built and shown in the third type of graphs.

3 Air Temperature

Figure 5 shows seasonal and interannual variability of the mean monthly air temperature near the surface (height of 2 m) for the period 1950–2010 and the corresponding linear trend. During these 60 years, the average air temperature in the

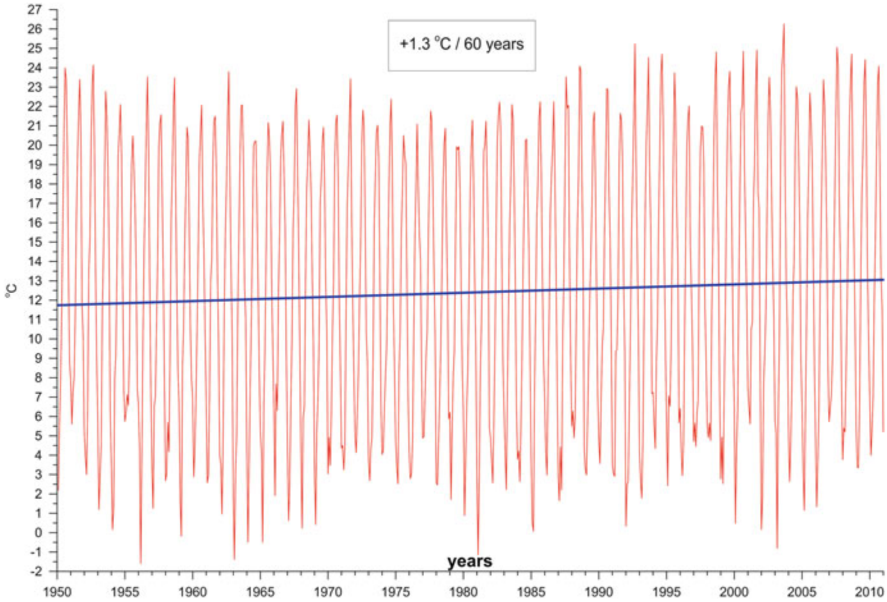

Fig. 5 Seasonal and interannual variability of the monthly mean 2 m air temperature and its linear trend (*blue line*)

region grew by more than 1.3°C, which, apparently, is a consequence of global climate warming [1, 9]. Seasonal (intra-annual) temperature variations are of the order of 20°C, which corresponds to the maritime climate of the region. Negative winter temperatures rarely stay more than a month. The coldest winters were observed in the 1950s and 1960s, then they became rare with exceptional events in 1981 and 2003. Irregular cycling of relatively cold winters with 5–15 year periods can be detected. Warm summers with the air temperature over 22°C were observed about 10 times in 1950–1975, and more than 20 times from 1985 to 2010, i.e. almost yearly. The summer of 2003 was the warmest in the 1950–2010 period with the monthly mean air temperature exceeding 26°C (Fig. 5).

Figure 6 shows air temperature anomalies relative to changes in seasonal variations which were smoothed by the 1-year and 8-year moving average. Averaging displayed decadal (over 10 years) and interannual (from 1 to 10 years) fluctuations. Interannual fluctuations have an amplitude from 0.5 to 2°C. The main decadal fluctuation has a period of about 25 years and an amplitude of about 0.5°C. The graph of the accumulated sum of a series of monthly anomalies (after removing the linear trend) shows two breaking points: in approximately 1972 and 1999. As to decadal variability, until 1970 the temperature in this region remained virtually unchanged, then was decreasing till 1978, and since 1979 it showed a steady increase till the end of the observed time period. It is interesting to note that the largest negative anomalies (more than −1.5°C) were related with warm seasons in the end of the 1970s (1976, 1978, and 1980). And vice versa, the

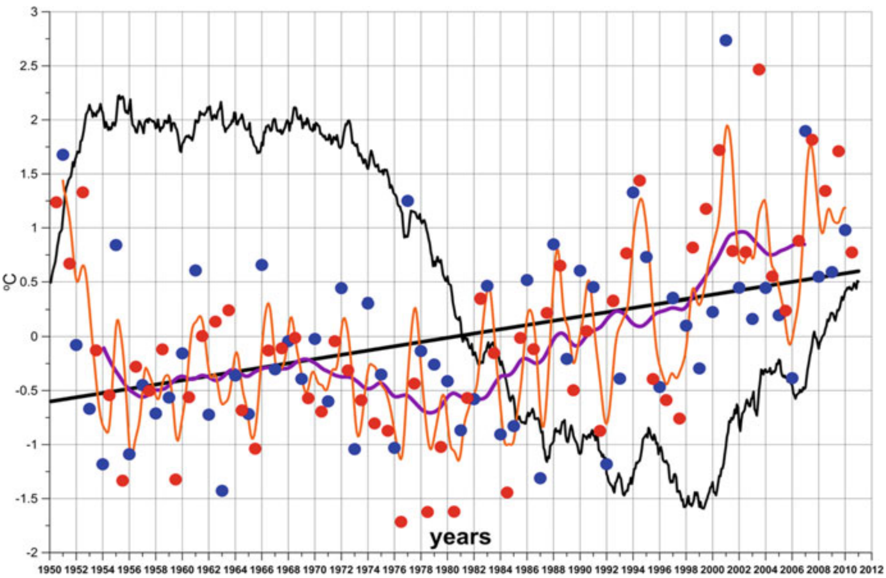

Fig. 6 Changes in anomalies of the 2 m air temperature (relative to seasonal variation). The smoothed 1-year (*orange line*) and 8-year (*purple line*) moving average are shown. Their linear trend and the accumulated amount after removing the linear trend are shown by *black lines*. Average anomalies for warm (*red circles*) and cold (*blue circles*) seasons are shown in the graph

largest positive anomalies (more than +2.5°C) were related with cold and warm seasons in early 2000s (for example, the extremely cold winter of 2000/2001 and extremely hot summer of 2003). Also, it is well visible that from one year to another, cold seasons have larger positive and negative anomalies than anomalies in warm seasons (Fig. 6).

Air temperature anomalies display interannual variations with an amplitude of the order of 2°C (Fig. 6). The corresponding peaks with periods close to 2.9 and 5.6 years are well seen in the spectrum of daily temperature anomalies (Fig. 7). These peaks may be associated with the influence of El Niño – Southern Oscillation (ENSO), which, in turn, is supposedly governed by the 11-year cycle of solar activity [10]. Also, in the spectrum there is an increase of the spectral density at periods of 20–30 years, which may be related to quasi-60-years climate cyclicity. For the periods from 2 to about 30 days, the average slope of the spectrum approximately follows the "-5/3" law, which corresponds to the reverse energy transfer (the so-called negative viscosity), in which the energy of synoptic atmospheric structures (cyclones and anticyclones) is transferred to larger atmospheric features, such as "blocking" anticyclones and stationary areas of low atmospheric pressure. The long-period part of the spectrum (>30 days) looks like the white noise spectrum (Fig. 7).

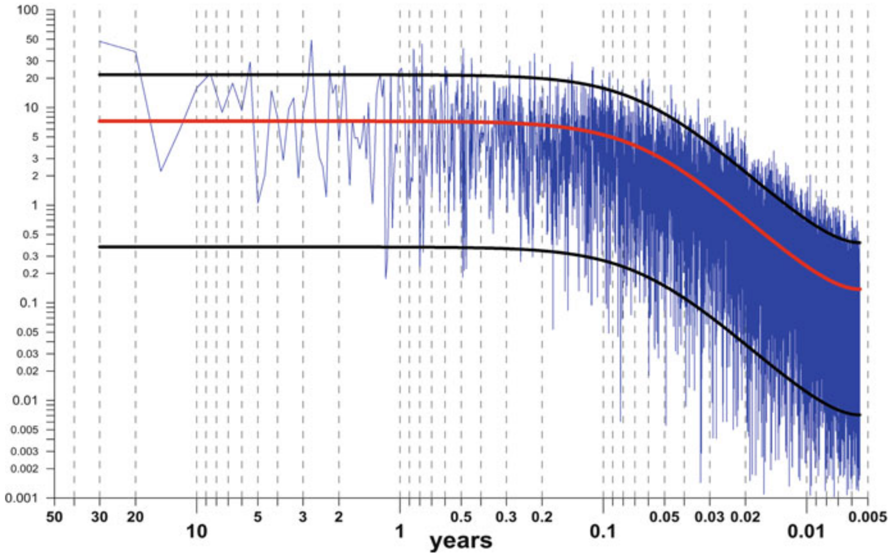

Fig. 7 The energy spectrum of the daily anomalies of the 2 m air temperature relative to seasonal variation for the period 1950–2010. A confidence interval from 5% (*bottom black line*) to 95% (*upper black line*) and the red noise spectrum (*red line*) are shown in the graph

4 Sea-Level Pressure

Figure 8 shows temporal (seasonal and interannual) variability of monthly mean sea level pressure. During the observed 60 years (1950–2010) sea level pressure increased from about 1,016 to 1,017 hPa. It is interesting that positive anomalies as large as 15 hPa can be observed with periods of about 5–10 years, but large negative anomalies can reach only 6–7 hPa, but with smaller periods (2–5 years), i.e. they are more frequent. The analysis of anomalies has shown that in 1950–1970 the prevailing period of variability was about 2 years, then till 1986 it was suddenly about 2 times longer, then it returned back to 2-year long variability (Fig. 9). The 8-year moving average revealed a long-term period of about 8 years. Similar to air temperature anomalies, sea level pressure anomalies in cold seasons were several times larger than in warm periods of the year. Thus, positive and negative anomalies in cold seasons could reach 4 hPa, while positive and negative anomalies in warm seasons reached only 1.0–1.5 hPa (Fig. 9). The largest negative anomalies in cold seasons were observed from 1950 to 1970, while the largest positive anomalies in cold seasons – from 1989. Thus, years 1989, 1990, and 1992 had the largest (and almost equal) positive anomalies for a cold season. As to warm periods, we cannot identify a similar type or even any kind of temporal patterns (Fig. 9). As to frequency analysis, we can identify only one peak at a 1-year period, and the 15-year period as a characteristic feature for decadal variability (Fig. 10).

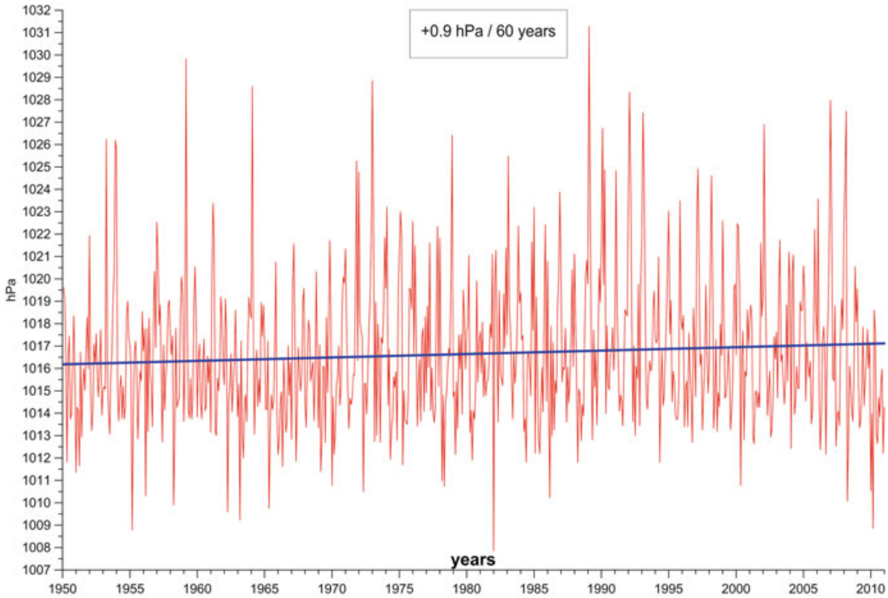

Fig. 8 Seasonal and interannual variability of monthly mean sea level pressure and its linear trend (*blue line*) in 1950–2010

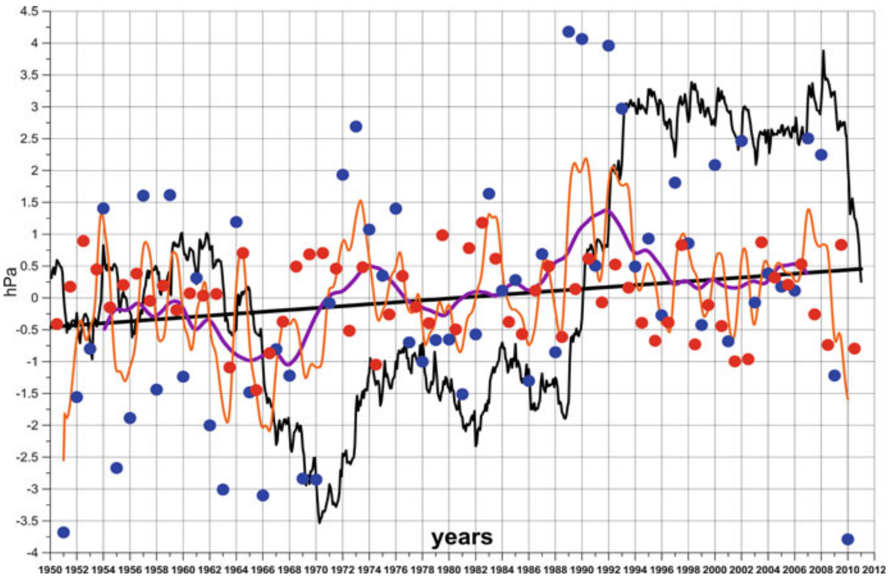

Fig. 9 Changes in mean anomalies of sea level pressure (relative to seasonal variation). The smoothed 1-year (*orange line*) and 8-year (*purple line*) moving average are shown. Their linear trend (*straight black line*) and the accumulated amount of anomalies after removing the linear trend (*black line*) are shown. Average sea level pressure anomalies for warm (*red circles*) and cold (*blue circles*) seasons are indicated in the graph

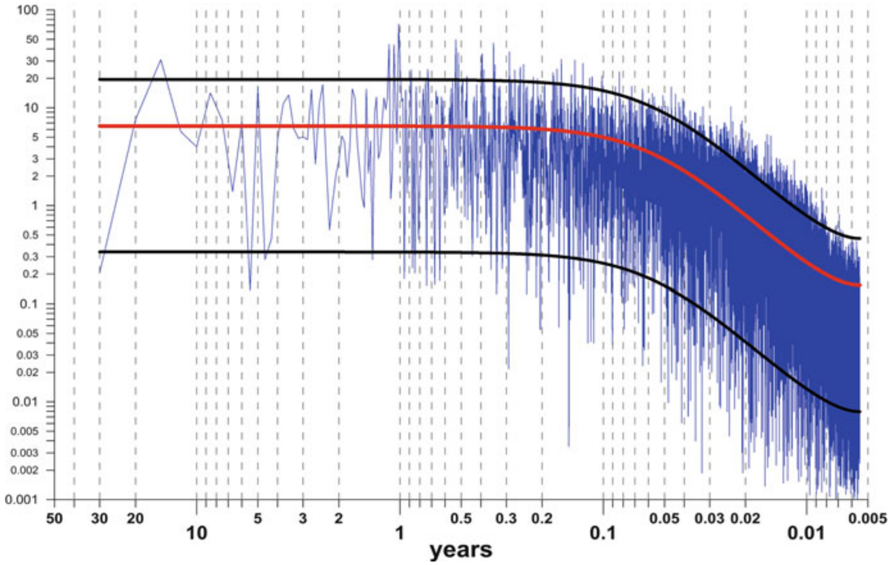

Fig. 10 The energy spectrum of the daily anomalies of sea level pressure relative to seasonal variation for the period 1950–2010. A confidence interval from 5% (*bottom black line*) to 95% (*upper black line*) and the red noise spectrum (*red line*) are shown in the graph

5 Atmospheric Precipitation

Atmospheric precipitation over the investigated region was analyzed in terms of monthly mean and daily "total column rain water" measured in kg/m^2. Figure 11 shows a little decreasing trend of about 0.00006 kg/m^2 during the 60-year period. This is consistent with an increase in atmospheric pressure taking in mind that the higher is atmospheric pressure, the higher is anticyclonic activity, which is in general characterized by less rain. Seasonal and interannual variability of precipitation shows peaks which are irregular in time and amplitude. These peaks can be 4 times larger than the average value of precipitation (Fig. 11). From year to year variability of anomalies shows that they are much larger in cold seasons (both positive and negative anomalies) than in warm seasons (Fig. 12). We observe steady reduction of precipitation from 1965 till 1991, and then it is increasing. This agrees well with the climate shift that occurred in the North Atlantic in 1992, which, in turn, could be associated with the eruption of Mount Pinatubo on the island of Luzon, Philippine in June 1991. The eruption led to a drop in global temperatures by about 0.5°C in 1991–1993 and a substantial increase in ozone depletion. Frequency analysis did not show any significant peaks at periods more than 1 year (Fig. 13). The spectrum looks more like white noise rather than red, indicating the chaotic nature of rainfall in the region.

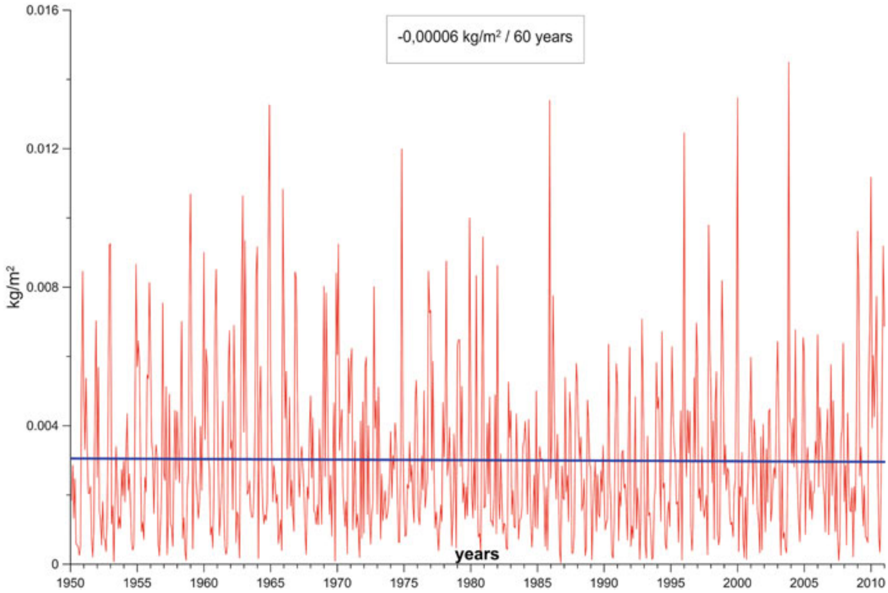

Fig. 11 Seasonal and interannual variability of monthly mean values of total column rain water and its linear trend (*blue line*)

6 Snow Cover

Snow cover in the region under investigation is very small and rare, but the analysis of its interannual variability has clearly showed a decrease in snow cover during 60 years (1950–2010). Snowy winters became much rare and snow depth during these events became about 2 times less than in 1950–1970 (Fig. 14). Anomalies of snow cover have revealed periodicity of about 8–10 years (Fig. 15). Frequency analysis did not demonstrate any notable periods of snow cover variability (Fig. 16). It means that this process is chaotic like accumulated precipitation in the same region, and it is not related to any global indices like NAO, ENSO, etc.

7 Wind Speed

Figure 17 shows seasonal and interannual variability of the zonal wind component U at 10 m over the surface of the investigated region. Positive values mean a wind directed from west to east, and, vice versa, negative values – a wind directed from east to west. Mean monthly eastward wind has an order of 1 m/s and is observed, in general, in summer. Mean monthly westward wind is about 50% stronger, and it is observed, in general, in winter, and may reach 2.5 m/s. Thus the amplitude of seasonal variability is of the order of 2–3 m/s. As westward wind prevails during the

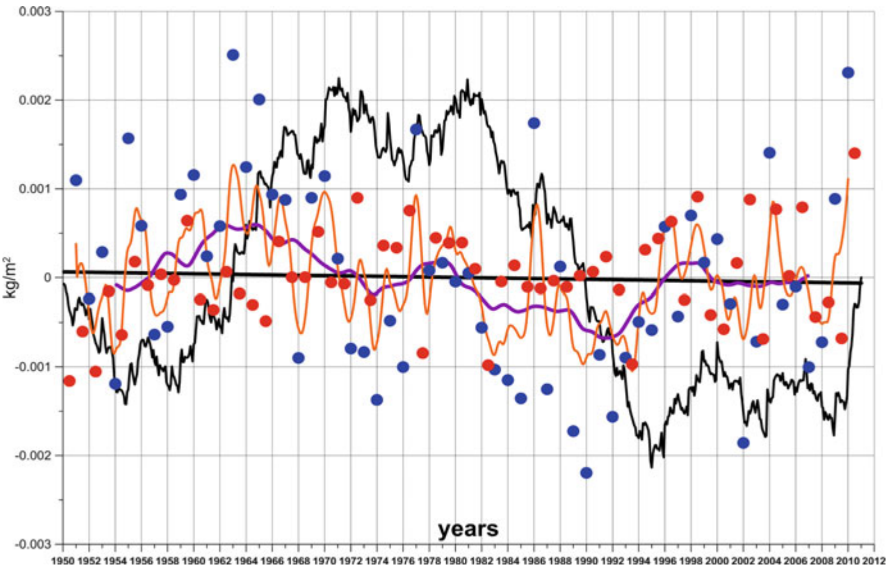

Fig. 12 Changes in mean anomalies of total column rain water (relative to seasonal variation). The smoothed 1-year (*orange line*) and 8-year (*purple line*) moving average are shown in the graph. Their linear trend and the accumulated amount of the anomaly (after removing the linear trend) are drawn by *black lines*. Average anomalies for warm (*red circles*) and cold (*blue circles*) seasons are also indicated

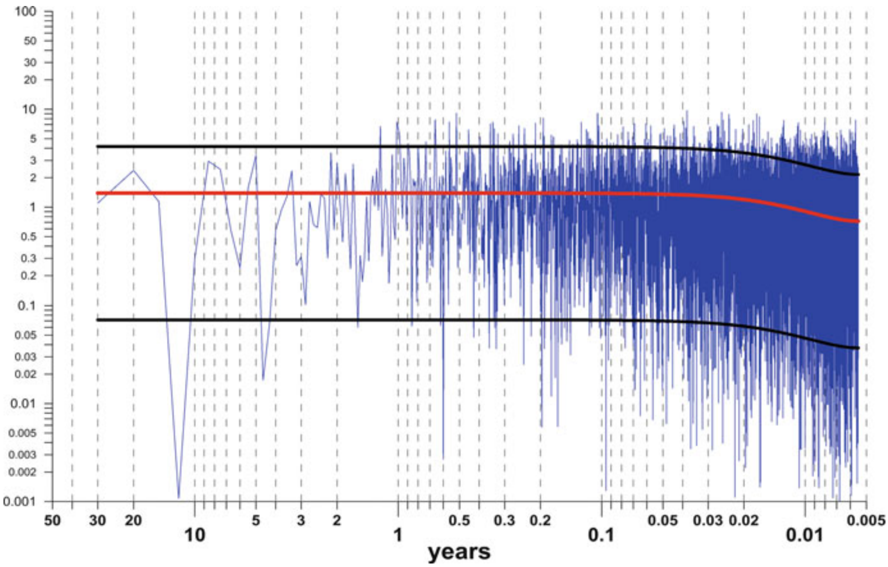

Fig. 13 The energy spectrum of the daily anomalies of total column rain water relative to seasonal variation for the period 1950–2010. A confidence interval from 5% (*bottom line*) to 95% (*upper line*) and red noise spectrum (*red line*) are shown in the graph

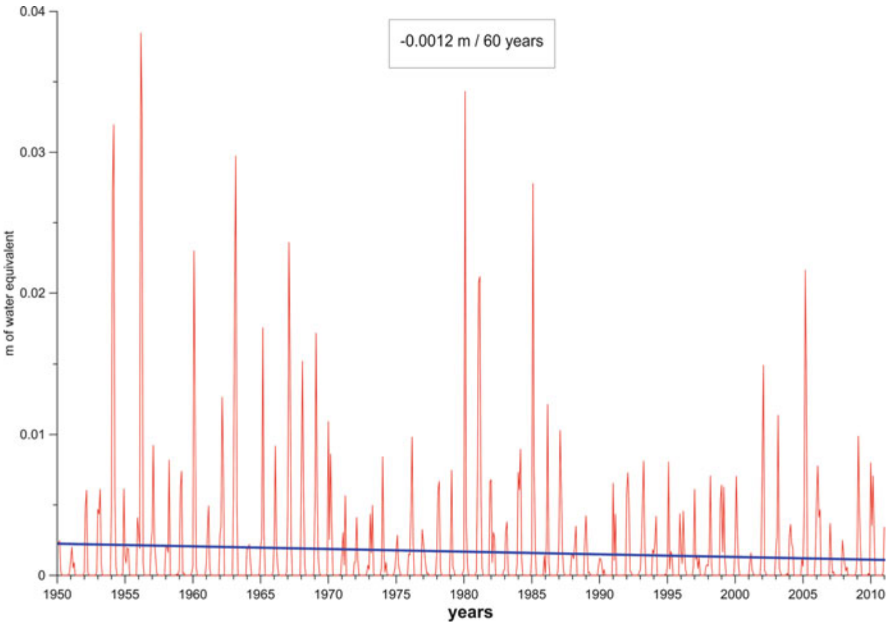

Fig. 14 Seasonal and interannual variability of monthly mean values of snow cover (in meters of water equivalent) and its linear trend (*blue line*) in 1950–2010

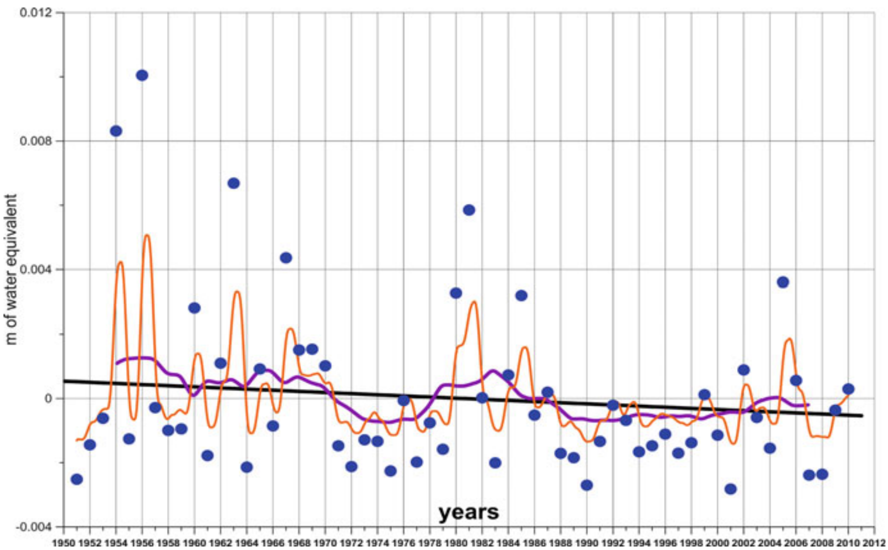

Fig. 15 Changes in mean anomalies of snow cover (relative to seasonal variation) in 1950–2010. The smoothed 1-year (*orange line*) and 8-year (*purple line*) moving average are shown. Their linear trend (*black line*) and average seasonal anomalies of snow cover (*blue circles*) are indicated in the graph

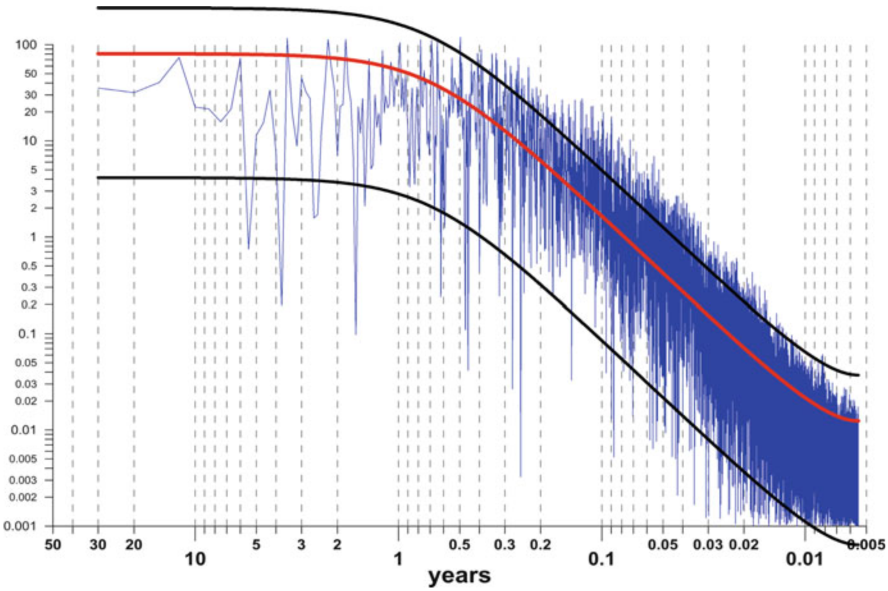

Fig. 16 The energy spectrum of the daily anomalies of snow cover relative to seasonal variation for the period 1950–2010. A confidence interval from 5% (*bottom black line*) to 95% (*upper black line*) and red noise spectrum (*red line*) are shown in the graph

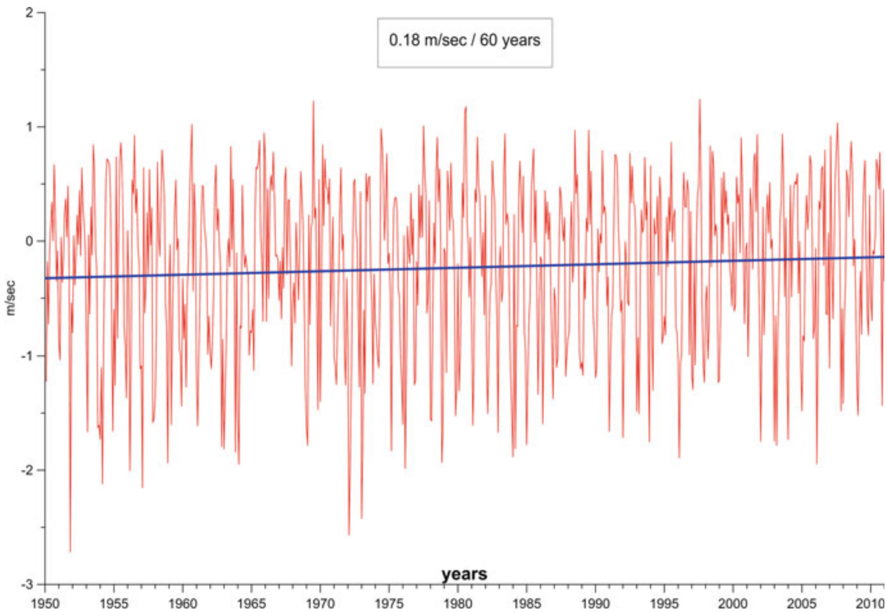

Fig. 17 Seasonal and interannual variability of monthly mean values of the 10 m zonal wind component U and its linear trend (*blue line*)

year, the average wind speed is negative and a linear trend lies below zero. In general, the analysis showed a positive trend of about 0.18 m/s during 60 years of observation, and by 2010 an average zonal wind component had reached −0.15 m/s, i.e. almost a balance between westward and eastward wind components (Fig. 17).

Figure 18 shows that positive and negative anomalies of a zonal wind component in a cold season are much larger than positive and negative anomalies in a warm season. Interannual variability of anomalies from 1950 to mid-1980s was much larger than in the next time period, from the mid-1980s till 2010. The same conclusion is valid for average anomalies both in warm and cold seasons. The 8-year moving average revealed a couple of periodical fluctuations of the order of 12–13 years. This periodicity (13.5 years) is a characteristic feature for the Pacific Decadal Oscillation (PDO), which is a pattern of Pacific climate variability similar to ENSO, but with longer periods. PDO, like ENSO, has an influence on general circulation of the atmosphere [11]. Finally, the behavior of an accumulated amount of anomalies showed several breaking points, i.e. years when a wind regime had significantly changed (Fig. 18). This occurred at least in 1965, 1971, 1983, and 1999.

A frequency analysis has shown two peaks at periods of 2.1 and 3.8 years, which is a characteristic feature for quasi-2-year fluctuation of equatorial wind in the upper layers of troposphere and of ENSO variability (Fig. 19), which is supposedly governed by 11-year long periods of solar activity (taking in mind that 3.8 years is

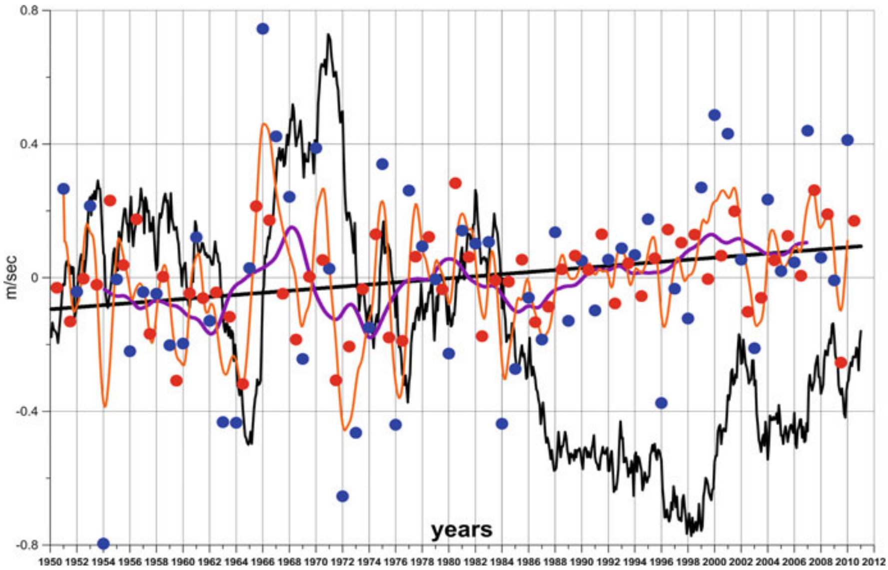

Fig. 18 Changes in mean anomalies of the 10 m U wind component (relative to seasonal variation). The smoothed 1-year (*orange line*) and 8-year (*purple line*) moving average are shown. Their linear trend and the accumulated amount of anomalies (after removing the linear trend) are shown by *black lines*. Average anomalies for warm (*red circles*) and cold (*blue circles*) seasons are also shown in the graph

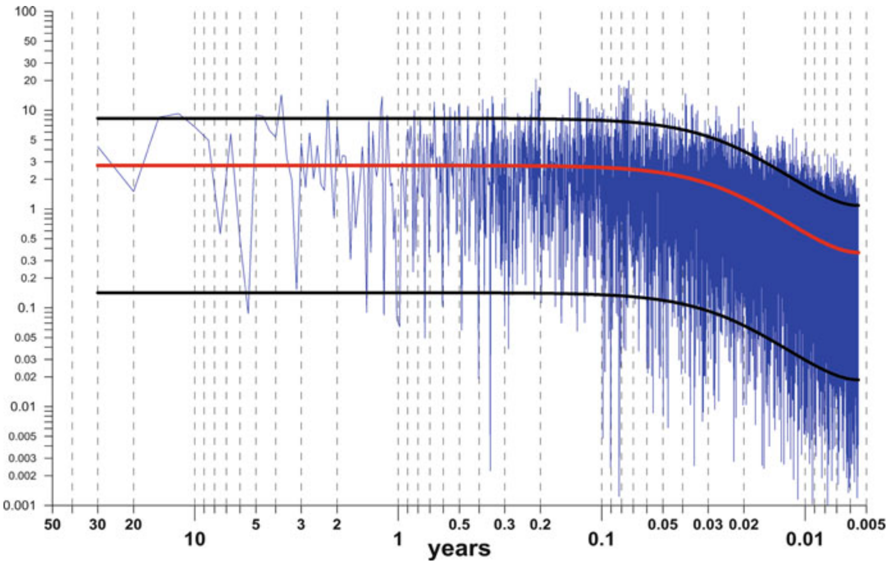

Fig. 19 The energy spectrum of the daily anomalies of the 10 m U wind component relative to seasonal variation for the period 1950–2010. A confidence interval from 5% (*bottom line*) to 95% (*upper line*) and red noise spectrum (*red line*) are shown in the graph

its super harmonica 1:3). A small increase in spectral density at periods of about 5 years can also be associated with ENSO, but the same periodicity is a characteristic feature for NAO.

Figure 20 shows seasonal and interannual variability of the meridional wind component V at 10 m over the surface of the investigated region. On average, we can see little dominance of a north-south transfer of air masses, which during 1950–2010 increased by 0.16 m/s. At the same time, positive peaks (northward wind component) are notably larger than the southward one (Fig. 20). Analysis of anomalies has showed that in cold seasons anomalies (both positive and negative) are much larger than in warm seasons (Fig. 21). The behavior of an accumulated amount of anomalies has showed several breaking points, i.e. years when a wind regime significantly changed. This occurred at least in 1965, 1981 and in 1993, which is only partially consistent with the zonal component of wind (1965, 1971, 1983, and 1999). Frequency analysis has shown that there are no statistically significant peaks at periods more than 2 years, although the peak period of 2.9 years is close to the 95% level of significance (Fig. 22).

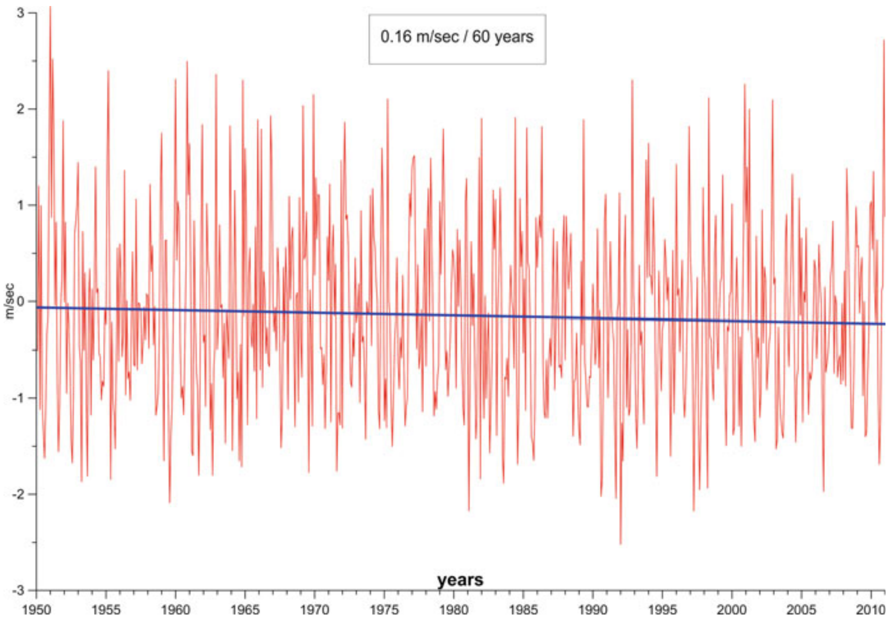

Fig. 20 Seasonal and interannual variability of monthly mean values of the 10 m meridional wind component V and its linear trend (*blue line*)

8 Cloud Cover

Cloud cover in the region demonstrates strong seasonal variability, when in winter it is as large as 75%, and in summer it is often less than 25% (Fig. 23). A notable decreasing trend was detected, which means that cloud cover, in average, had decreased by about 4% during 60 years. This is in good agreement with a detected positive trend in atmospheric pressure (Fig. 8). This is a logical link, because larger values of atmospheric pressure, in general, mean more of anticyclonic activity in the atmosphere, which suggests more of a clear sky. Interannual variability of cloud cover in this region (Fig. 24) is related to cyclonic activity in the atmosphere, which, in turn, is related to NAO oscillation [12]. Analysis of anomalies of cloud cover has shown that from the mid-1950s till the mid-1980s, there was a steady rise of cloud cover over the region with significant interannual variability (Fig. 24). Then, from the end of the 1980s till the mid-1990s, we have observed a sharp drop of cloud cover with several anomalously clear sky winters (cold season) – 1989, 1990, 1992, and 1993. This is in good agreement with the climatic shift in the North Atlantic Ocean, observed in the end of the 1980s and at the beginning of the 1990s. This shift probably resulted in the cloud cover change over the region of the Boka Kotorska Bay. From the mid-1990s, cloud cover settled at the same level. Frequency analysis revealed spectral peaks at periods of 1, 2.1, 2.4 and 3.6 years (Fig. 25), which partially may be correlated with NAO.

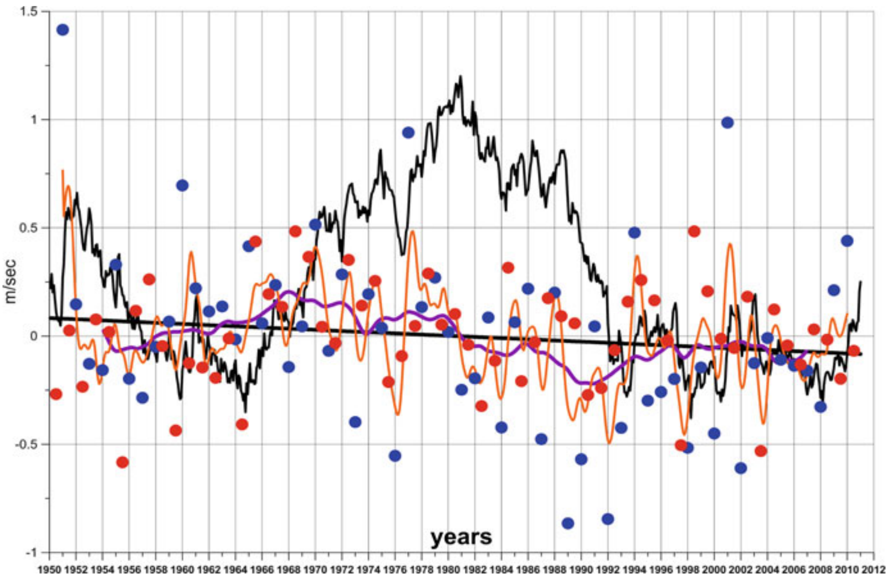

Fig. 21 Changes in mean anomalies of the 10 m V wind component (relative to seasonal variation). The smoothed 1-year (*orange line*) and 8-year (*purple line*) moving average are shown. Their linear trend and the accumulated amount of anomalies (after removing the linear trend) are shown by *black lines*. Average anomalies for warm (*red circles*) and cold (*blue circles*) seasons are also shown in the graph

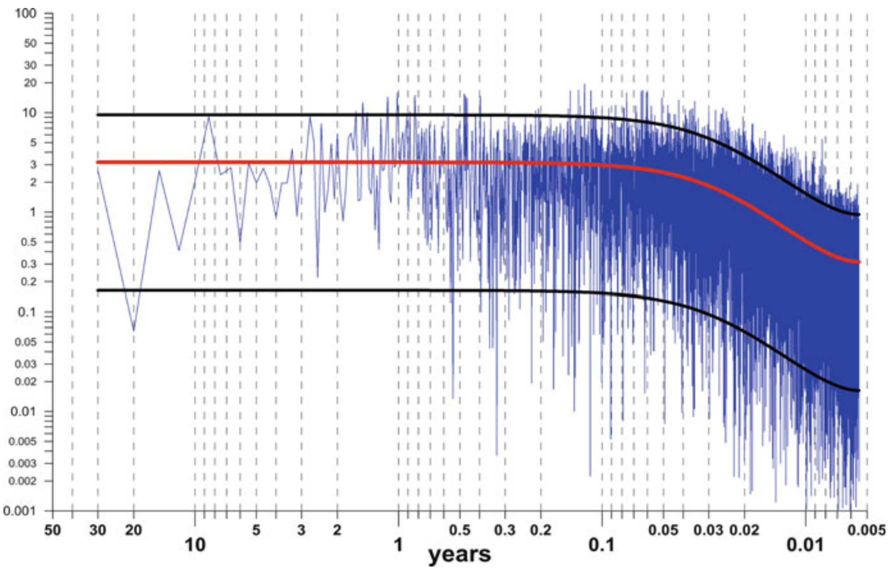

Fig. 22 The energy spectrum of the daily anomalies of the 10 m V wind component relative to seasonal variation for the period 1950–2010. A confidence interval from 5% (*bottom line*) to 95% (*upper line*) and red noise spectrum (*red line*) are shown in the graph

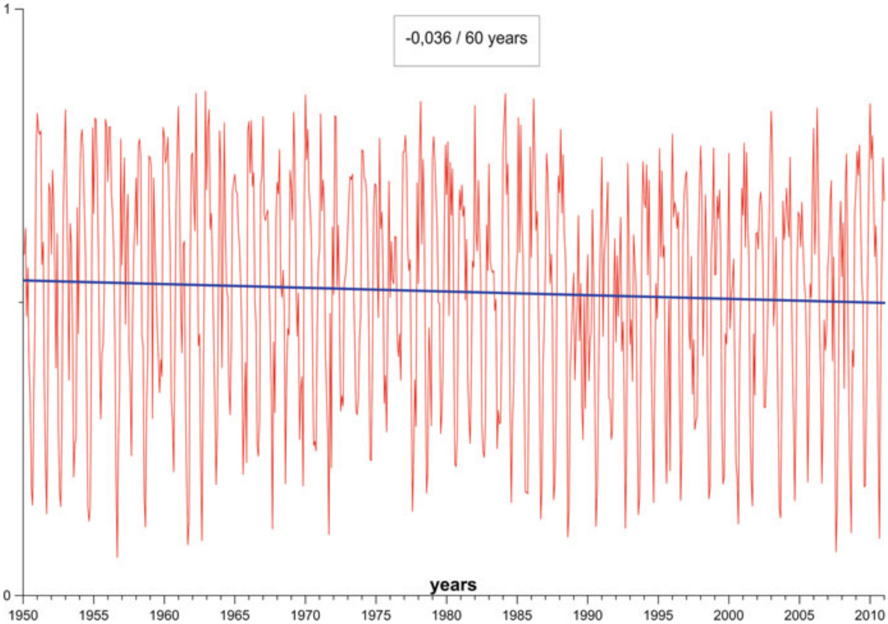

Fig. 23 Seasonal and interannual variability of monthly mean values of total cloud cover (in %, where 1 is 100%) and its linear trend (*blue line*)

9 Conclusions

In this chapter we have analyzed the observed regional climate change in the region of the Boka Kotorska Bay basing on a set of key meteorological parameters: near-surface air temperature, sea-level pressure, atmospheric precipitation, snow cover, wind speed, and cloud cover over the past 60 years (1950–2010). For the analysis of meteorological parameters, we used monthly mean and daily data from the NCEP/NCAR Reanalysis, NOAA CIRES Twentieth Century Global Reanalysis Version 2c, ERA-20C, JRA-55 for the 1950–2010 time period. For every parameter we produced three types of analysis of: (1) seasonal and interannual variability, (2) anomalies, including anomalies calculated both for warm and cold seasons; and (3) frequency analysis.

During 60 years between 1950 and 2010, the average air temperature in the region grew by more than 1.3°C, which, apparently, is a consequence of global climate warming. Sea level pressure only increased from about 1,016 to 1,017 hPa. Atmospheric precipitation over the investigated region in terms of "total column rain water" shows a little decreasing trend of about 0.00006 kg/m^2. Snow cover in the region clearly shows a decreasing trend as well. Snowy winters became much rare and snow depth during these events became about 2 times less than in 1950–1970. Interannual variability of zonal and meridional wind components shows that westward and southward wind components prevailed during the observed time period. It means

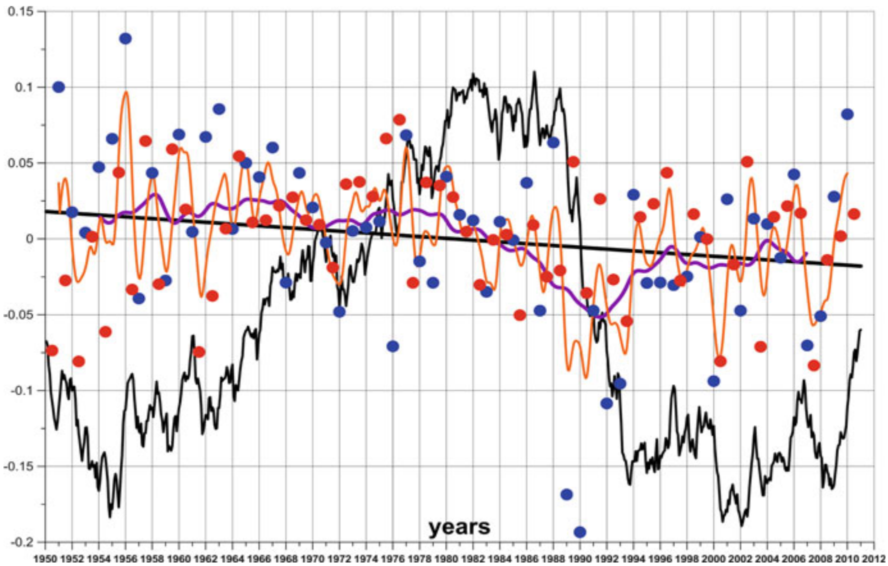

Fig. 24 Changes in mean anomalies of total cloud cover (relative to seasonal variation). The smoothed 1-year (*orange line*) and 8-year (*purple line*) moving average are shown. Their linear trend (*straight black line*) and the accumulated amount of anomalies after removing the linear trend (*black line*) are indicated in the graph. Average anomalies of cloud cover for warm (*red circles*) and cold (*blue circles*) seasons are also presented in the graph

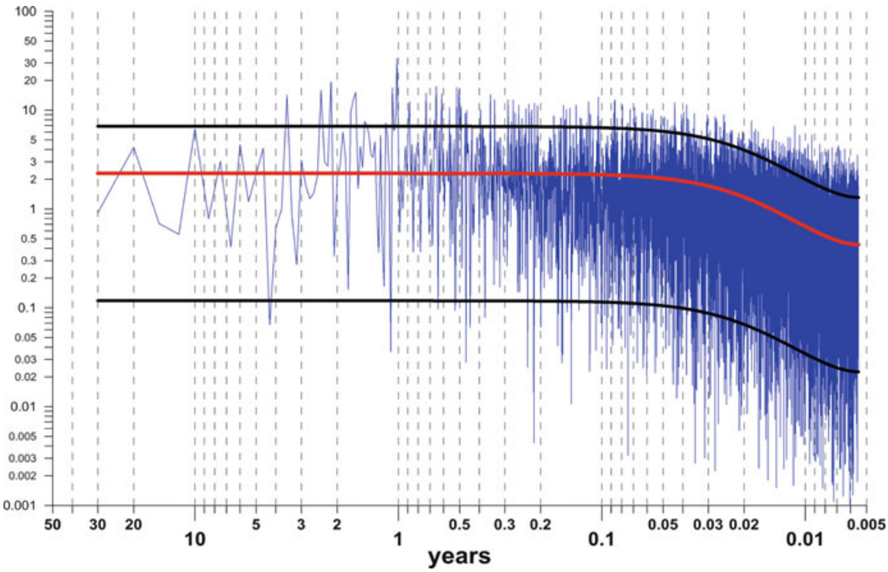

Fig. 25 The energy spectrum of the daily anomalies of total cloud cover relative to seasonal variation for the period 1950–2010. A confidence interval from 5% (*bottom line*) to 95% (*upper line*) and red noise spectrum (*red line*) are shown in the graph

that the general air mass transfer was directed from north-east to south-west. Cloud cover in the region demonstrates strong seasonal variability, when in winter it is as large as 75%, and in summer it is often less than 25%. A notable decreasing trend was detected, which means that cloud cover, in average, had decreased by about 4% during 60 years.

The analysis of the obtained anomalies and energy spectrum of anomalies of all investigated parameters require further deeper analysis, comparison and investigation in order to reveal the correspondence of the detected prevailing periods with the well-known regional and global climate oscillations, such as NAO, ENSO, and PDO.

Acknowledgments The research of Russian scientists was supported by the Russian Science Foundation under the Project N 14-50-00095. The research was partially done in the framework of collaboration between Prof. Andrey G. Kostianoy and Dr. Marilaure Grégoire from the Interfacultary Center for Marine Research (MARE) and Modelling for Aquatic Systems (MAST), University of Liège, Belgium.

References

1. IPCC (2013) Climate change 2013: the physical science basis. In: Contribution of WG1 to the V assessment report of the IPCC, Cambridge and New York, 1535 pp
2. Drobnjak V (2001) Climate analysis of meteorological parameters based on the IHMS database. http://www.meteo.co.me/
3. Micev S. Climate analysis of meteorological parameters based on the IHMS database. http://www.meteo.co.me/
4. Ivanov M. Climate analysis of meteorological parameters based on the IHMS database. http://www.meteo.co.me/
5. Kalnay E, Kanamitsu M, Kistler R, et al. (1996) The NCEP/NCAR 40-year reanalysis project. Bull Am Meteorol Soc 77:437–471
6. Compo GP, Whitaker JS, Sardeshmukh PD, et al. (2011) The twentieth century reanalysis project. Q J Roy Meteorol Soc 137:1–28
7. Stickler A, Brönnimann S, Valente MA, et al. (2014) ERA-CLIM: historical surface and upper-air data for future reanalyses. Bull Am Meteorol Soc 95(9):1419–1430
8. Kobayashi S, Ota Y, Harada Y, et al. (2015) The JRA-55 reanalysis: general specifications and basic characteristics. J Meteorol Soc Jpn 93(1):5–48
9. IPCC (2007) Climate change 2007: the physical science basis. In: Contribution of WG1 to the IV assessment report of the IPCC, Cambridge and New York, 996 pp
10. Vakulenko NV, Sonechkin DM (2011) Evidence of the solar activity's effect on El Nino Southern Oscillation. Oceanology 51(6):935–939
11. Goddard L (2014) Heat hide and seek. Nat Clim Chang 4:158–161
12. Maslova V, Voskresenskaya E, Bardin M (2010) Variability of the cyclone activity in the Mediterranean-Black Sea region. J Environ Prot Ecol 11(4):1366–1372

Satellite Remote Sensing of the Boka Kotorska Bay

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Abstract In the chapter we show capabilities of satellite remote sensing for environmental monitoring of the Boka Kotorska Bay. A small size of the Bay requires usage of high-resolution satellite data from the Landsat, SPOT, Radarsat-2, QuickBird, FORMOSAT-2, Sentinel-1A, Sentinel-2A, and other space platforms

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with spatial resolution of 1–30 m. Most of high-resolution satellite data are very expensive; this is why we focus on those data, which are available free of charge. Examples of processed satellite imagery in true color, sea surface temperature, water turbidity, chlorophyll-a concentration, and sea surface roughness are presented. Forest fires, which constitute a yearly problem in Montenegro, are also well detected on satellite imagery.

Keywords Chlorophyll-a concentration, Forest fires, Infrared imagery, Optical imagery, Satellite monitoring, Satellite remote sensing, Sea surface temperature, Suspended matter, Synthetic aperture radar, The Boka Kotorska Bay

Contents

1 Introduction

The Boka Kotorska Bay (Fig. 1) environment experiences significant changes caused by human anthropogenic impact and regional climate change. This is proved by numerous physical, chemical, and biological experimental data [1]. Tourism, shipping and port activities, fishery, construction in the coastal zone, agriculture, and other human activities on the shores of the Bay affect the quality of the environment, seawater, air, and life. One of the main reasons of pollution of the Bay is wastewater discharge. The Bay then faces bacterial growth and eutrophication as a result of slow water circulation, little water ventilation, and exchange with the Adriatic Sea. On the other hand, regional climate change results in warming of seawater in the Bay, which also leads to amplification of eutrophication.

Regional climate change has direct and indirect impact on the Boka Kotorska Bay environment. Under the direct impact we understand changes in physical, chemical, and biological characteristics of the Bay under warming of the air and sea, changes in atmospheric precipitation and cloudiness, wind speed and direction, and extreme events like frosts, heat waves, heavy rains, etc. Under the indirect impact we understand growth of tourism (in the form of coastal tourism, shipping and port activities, construction of hotels and infrastructure, and agriculture) due to an increasing attractiveness of the area caused by regional warming and prolongation of the tourist season. Thus, in its turn, tourism growth, having evident benefits

Fig. 1 Satellite view of the coastal zone of Montenegro, the Boka Kotorska Bay, and Lake Skadar [Source of raw data: Virtual Earth (https://en.wikipedia.org/wiki/Bing_Maps_Platform)]

for the local economy, may have negative impacts on the Boka Kotorska Bay environment in the future.

The Institute of Marine Biology (Kotor, Montenegro) in cooperation with the Centre for Ecotoxicological Researches for the Environmental Protection Agency (Podgorica, Montenegro), University of Montenegro (Podgorica), and other national and international organizations performs a series of sea monitoring programs devoted to in situ monitoring of the marine environment [1]. The Ministry of Sustainable Development and Tourism of the Government of Montenegro adopted the Integrated Coastal Area Management Program (ICAMP) of Montenegro dedicated to comprehensive and integrated protection of the area of the Boka Kotorska Bay. The Montenegrin National Strategy of Integrated Coastal Area Management will further develop the system of spatial development and encourage further strengthening of coordination mechanisms, development of result-oriented management practices, and introduction of systematic monitoring of coastal processes.

Development of ICAMP and monitoring systems for the coastal zone of Montenegro and for the Boka Kotorska Bay in particular requires establishment of permanent integrated satellite monitoring based on the multisensor and multiplatform approach [2]. Today, satellite monitoring is lacking in existing monitoring programs in Montenegro.

An integral part of any program of modern environmental monitoring of land or seas is satellite monitoring, which has more comprehensive options and advantages compared to land-based monitoring facilities. Satellite methods play an important role along with the analysis of in situ hydrological, chemical, and biological data. Satellite methods allow to regularly receive a variety of thermohydrodynamic, geochemical, biological, and meteorological parameters with high spatial (1–1,000 m) and temporal (1–10 days) resolution over large water areas. This makes satellite data the cheapest, fastest, and objective method of ecological monitoring of seas and oceans.

Satellite monitoring of coastal areas is one of the most important methods of control of their ecological status. It is based on reception of digital data from various radiometers, scanners, spectrometers, radars, altimeters, and scatterometers, mounted on satellites, such as NOAA, Terra, Aqua, TOPEX/Poseidon, Jason-1/Jason-2/Jason-3, GFO, ERS-2, ENVISAT, Radarsat-1/Radarsat-2, Sentinel-1A/Sentinel-2A, TerraSAR-X, COSMO-SkyMed, QuikSCAT, Landsat, IRS, KOMPSAT-2, EROS A, IKONOS, SPOT, QuickBird, FORMOSAT-2, EarlyBird-1, GeoEye-1, WorldView-1, WorldView-2, WorldView-3, WorldView-4, and many others. This equipment provides data with high spatial and temporal resolution on the sea surface temperature, suspended matter, chlorophyll concentration, optical characteristics of the water and land surface, oil pollution, as well as on sea level anomalies, current variability, mesoscale and small-scale water dynamics, wind speed and wave height, etc.

Satellite monitoring has a particular value in the integrated system of any industrial environmental monitoring and control during construction and operation of offshore gas and oil platforms and pipelines, port facilities, shipping activities, and transboundary water pollution [3]. Since 2003, in cooperation between the P.P. Shirshov Institute of Oceanology (Moscow) and its Atlantic Branch in Kaliningrad, Russian Space Research Institute (Moscow), Geophysical Center (Moscow), and Marine Hydrophysical Institute (Sevastopol), we elaborated several operational satellite monitoring systems for oil and gas companies in Russia and performed integrated satellite monitoring of the ecological state of coastal waters in the Baltic, Black, Caspian, and Kara seas in a fully operational regime (24/24 and 7/7) [4–21]. Our experience includes but is not limited by the following environmental monitoring projects:

1. Elaboration of the integrated satellite monitoring system (2004) and monitoring of the LUKOIL-KMN Ltd. D-6 oil rig in the Southeastern Baltic Sea in 2004–2016
2. Elaboration of the integrated satellite monitoring system (2007) and monitoring (2010) of the underwater gas pipeline "Dzhubga-Lazarevskoe-Sochi" construction in the Eastern Black Sea

3. Elaboration of the integrated satellite monitoring system (2006) and monitoring (2010–2013) of the "Nord Stream" underwater gas pipeline construction and exploitation in the Gulf of Finland, the Baltic Sea
4. Elaboration of the integrated satellite monitoring system for the underwater gas pipeline "Bovanenkovo-Ukhta" construction in the Baydaratskaya Guba, the Kara Sea (2007)
5. Elaboration of the integrated satellite monitoring system for the Caspian Sea (2008)
6. Elaboration of the structure and principles of the integrated satellite monitoring system organization for all coastal seas of Russia (2009–2010)
7. Numerical modeling of risks of oil pollution caused by shipping along the main maritime shipping routes in the Gulf of Finland, the Baltic Proper, and in the Southeastern Baltic Sea (2004–2016)
8. Numerical modeling of risks of oil pollution caused by oil production at the D-6 oil rig and oil transportation onto the shore via the connecting underwater oil pipeline (2004–2016)

The abovementioned satellite monitoring systems differ from the existing ones by the analysis of a wide spectrum of satellite, meteorological and oceanographic data, as well as numerical modeling of oil spill transformation and transport in real weather conditions. The known accidents with tankers in the sea or the one on the BP oil platform "Deepwater Horizon" on 20 April 2010 in the Gulf of Mexico showed that the absence of such a permanent integrated satellite monitoring system lessens the impact of cleaning operations at sea and on the shore during the first days after the accident [2, 8, 17].

There is no satellite monitoring system created specifically for the Boka Kotorska Bay. This is why in this chapter we show only the capabilities of satellite remote sensing for environmental monitoring of the Bay. A small size of the Bay requires usage of high-resolution satellite data from space platforms with spatial resolution of 1–30 m. Most of high-resolution satellite data are very expensive; this is why we focus on those data, which are available free of charge (Landsat, Sentinel-1A, Sentinel-2A). Examples of processed satellite imagery in true color, sea surface temperature, water turbidity, chlorophyll-a concentration, and sea surface roughness are presented. Finally, we show that forest fires in Montenegro are also well detected on satellite imagery.

2 Optical Imagery

High-resolution optical imagery of the Boka Kotorska Bay allows us to detect a set of physical (mesoscale and small-scale water dynamics, currents, eddies, dipoles, jets, fronts, river plumes, wind waves, internal waves, sea roughness, slicks at the

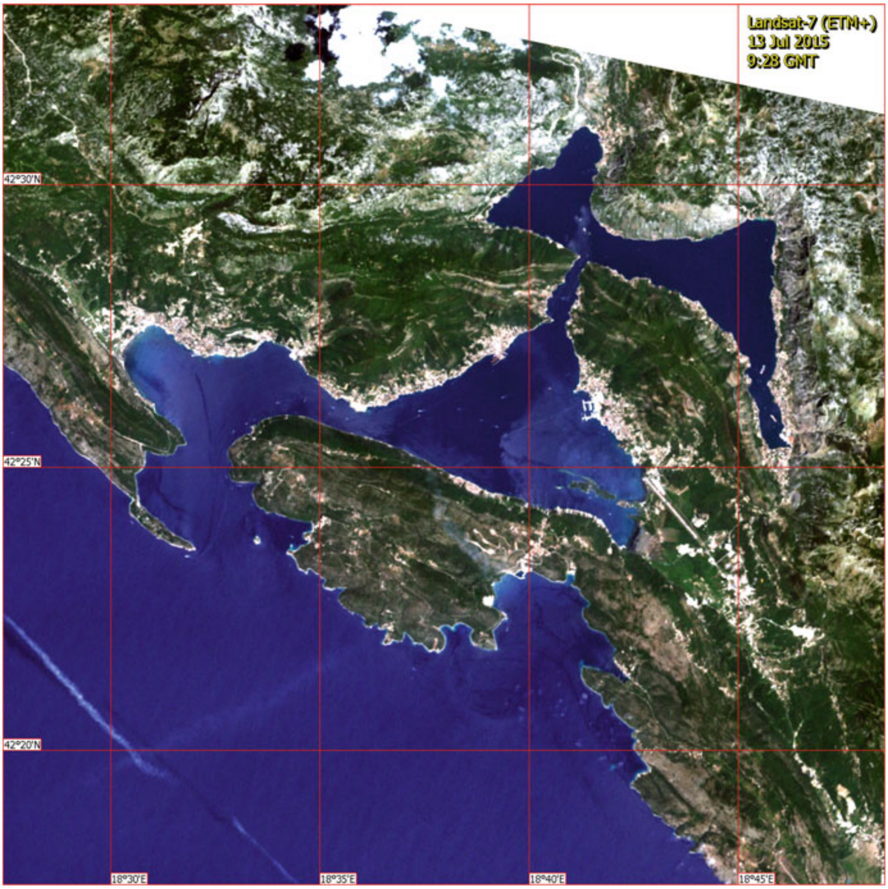

Fig. 2 Landsat-7 (ETM+) image of the Boka Kotorska Bay acquired on 13 July 2015 (09:28 GMT)

sea surface, etc.), chemical (water turbidity, total suspended matter concentration), and biological (chlorophyll-a concentration, algal bloom) processes and shipping activities (ship traffic, location of ships, ship wakes, waves generated by ships, etc.). The same imagery may be used to detect forest fires, changes in the landscape, forest areas, construction activities on the coast, snow cover, etc.

Landsat-7 Enhanced Thematic Mapper Plus (ETM+), Landsat-8 Operational Land Imager (OLI), and Sentinel-2A satellite imagery are very useful for investigation and monitoring of the abovementioned processes, phenomena, and natural and anthropogenic impact on the Boka Kotorska Bay environment (Figs. 2, 3, 4, 5,

Fig. 3 Landsat-8 (OLI) image of the Boka Kotorska Bay acquired on 6 August 2015 (09:28 GMT)

6, 7, and 8). The Landsat Enhanced Thematic Mapper Plus (ETM+) sensor onboard the Landsat-7 satellite has been acquiring images of the Earth surface nearly continuously since July 1999 with a 16-day repeat cycle. The Landsat-7 ETM+ images consist of eight spectral bands with spatial resolution of 30 m for bands 1–7 and 15 m for the panchromatic band 8. The approximate scene size is 170 km north–south by 183 km east–west [22].

The Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) are instruments onboard the Landsat-8 satellite, which was launched in February 2013. The satellite collects images of the Earth surface with a 16-day repeat cycle, which is in an 8-day offset to Landsat-7. OLI has the same scene size as in ETM+, and the

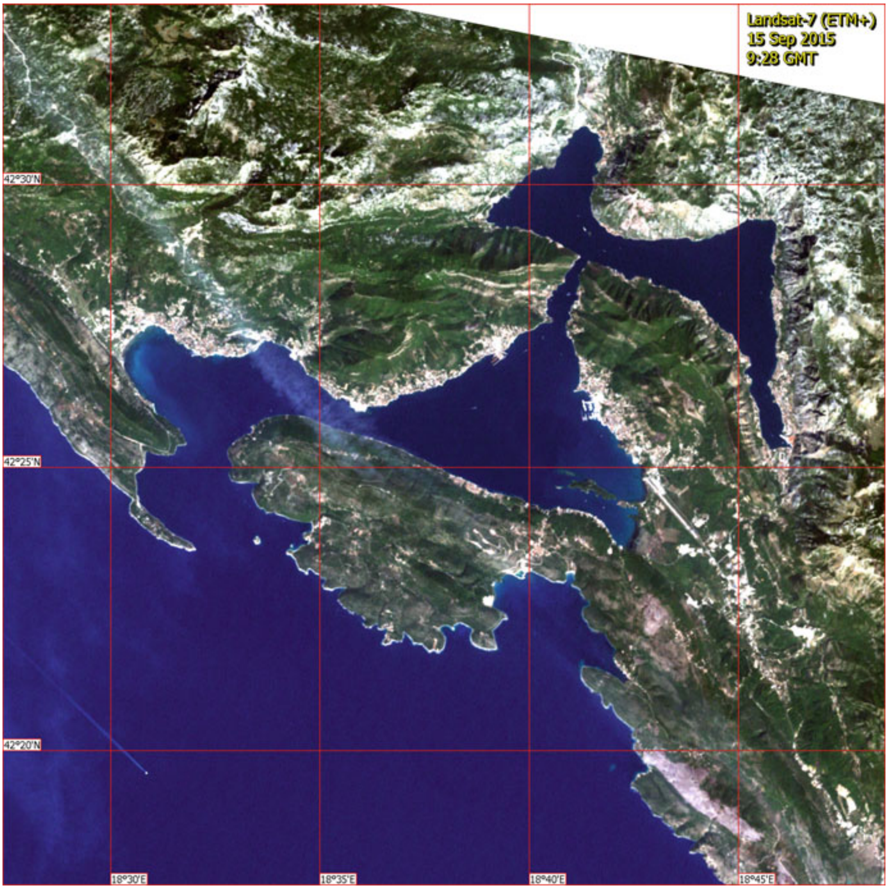

Fig. 4 Landsat-7 (ETM+) image of the Boka Kotorska Bay acquired on 15 September 2015 (09:28 GMT)

spectral bands similar to ETM+, but with the addition of two new spectral bands: a deep blue visible channel (band 1) specifically designed for water resources and coastal zone investigation and a new infrared channel (band 9) for the detection of cirrus clouds [23].

Sentinel-2A was launched on 23 June 2015. It carries a wide swath (290 km) high-resolution multispectral imager with 13 spectral bands (four visible and near-

Fig. 5 Landsat-8 (OLI) image of the Boka Kotorska Bay acquired on 7 July 2016 (09:28 GMT)

infrared bands at 10 m resolution, six red-edge/shortwave-infrared bands at 20 m, and three atmospheric correction bands at 60 m) for monitoring of ocean, land, and vegetation. In 2017, it will be joined by its identical twin, Sentinel-2B, then two satellites will cover any area of the Earth surface every 5 days.

Figures 2, 3, 4, 5, 6, 7, and 8 show ships as bright white dots or small lines in case of large tourist vessels, ship wakes as dark or white bands behind the ships, slicks at the sea surface as dark bands and areas, shallow areas in the coastal zone and even bottom topography peculiarities in the shallow areas, and turbid waters in coastal

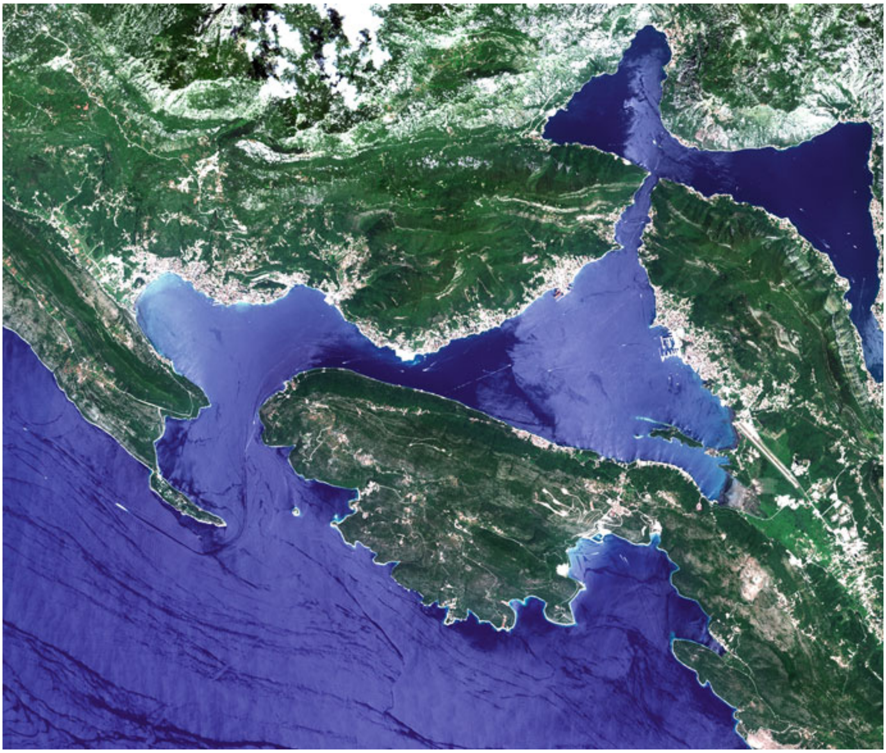

Fig. 6 Sentinel-2A (true color) image of the Boka Kotorska Bay acquired on 9 July 2016 (09:28 GMT)

zones, as well as coastal infrastructure, ports, settlements, roads, Tivat Airport, forests, etc. Figure 6 is the most spectacular due to the highest color contrast and a number of different phenomena. Figure 7 is a zoom on the entrance to the Boka Kotorska Bay, where we see the ship, which rounds Cape Oštro on the Prevlaka Peninsula. The ship is quite large (its name can be detected by the Automatic Identification System (AIS) of ships), and it leaves a straight wake behind it, which is visible as a dark blue line, as well as a set of regular waves generated by ship movement. Figure 7 also features a number of slicks, visible as dark blue bands of irregular forms, caused by a presence of biogenic films at the sea surface. These slicks are usually elongated along local currents or wind.

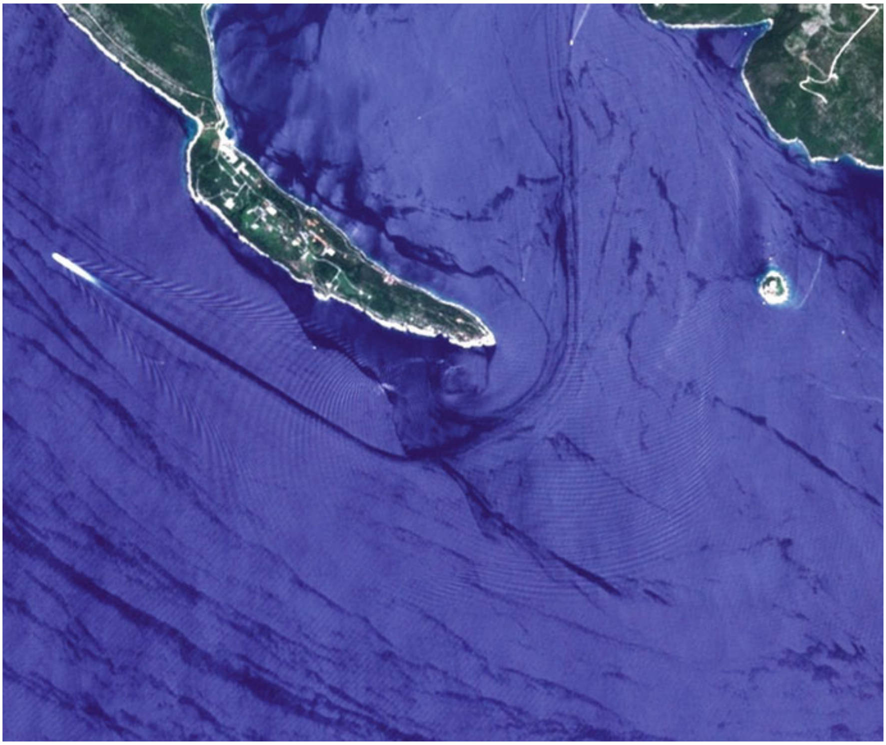

Fig. 7 Sentinel-2A (true color) image (a zoom) of the entrance to the Boka Kotorska Bay acquired on 9 July 2016 (09:28 GMT)

3 Sea Surface Temperature

High-resolution thermal imagery of the Boka Kotorska Bay allows for detection of a set of physical processes and phenomena: mesoscale and small-scale water dynamics, currents, eddies, dipoles, jets, fronts, river plumes, water exchange between different parts of the Bay and exchange with the Adriatic Sea, heating and cooling processes, seasonal and interannual thermal regime, etc.

The Landsat-8 TIRS sensor is a very interesting radiometer which provides high-resolution (100 m) mapping of the sea surface temperature (SST), which is about ten times better than AVHRR (NOAA) and MODIS (Terra and Aqua) (1,000 m). Thermal Infrared Sensor (TIRS) is an instrument onboard the Landsat-8 satellite with a 16-day repeat cycle, the approximate scene size of 170 km north–south by 183 km east–west, and two thermal bands acquired at 100 m resolution, but is resampled to 30 m in the delivered data product [23].

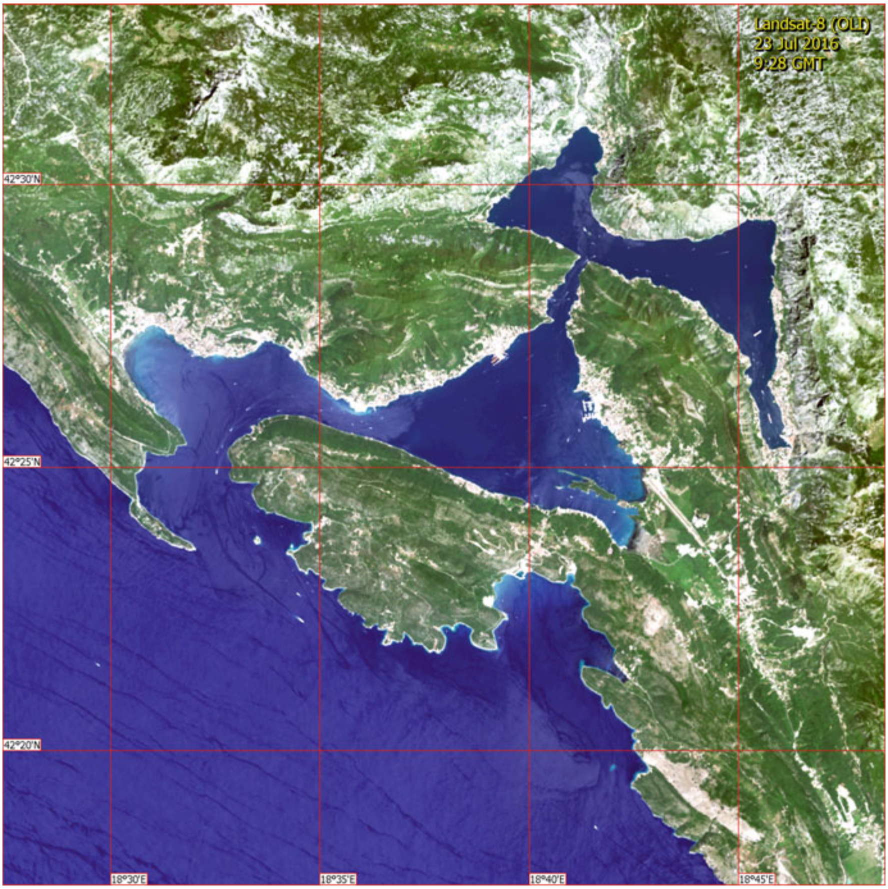

Fig. 8 Landsat-8 (OLI) image of the Boka Kotorska Bay acquired on 23 July 2016 (09:28 GMT)

SST image of the Boka Kotorska Bay on 21 July 2015 shows a contrast of temperatures from about 20 to 25°C (Fig. 9). The coldest spots are caused by small river plumes of Ljuta and Morinj Rivers, which bring cold and freshwater from the surrounding mountains (see Figs. 9, 10, 11, and 12). In general, the coastal band and shallow waters are usually warmer than the central parts of the Bay, but significant SST variability in different parts of the Bay, which is observed from one image to another, can be explained by different small-scale atmospheric processes (local winds, rains, cloudiness, etc.) which should be controlled for correct interpretation

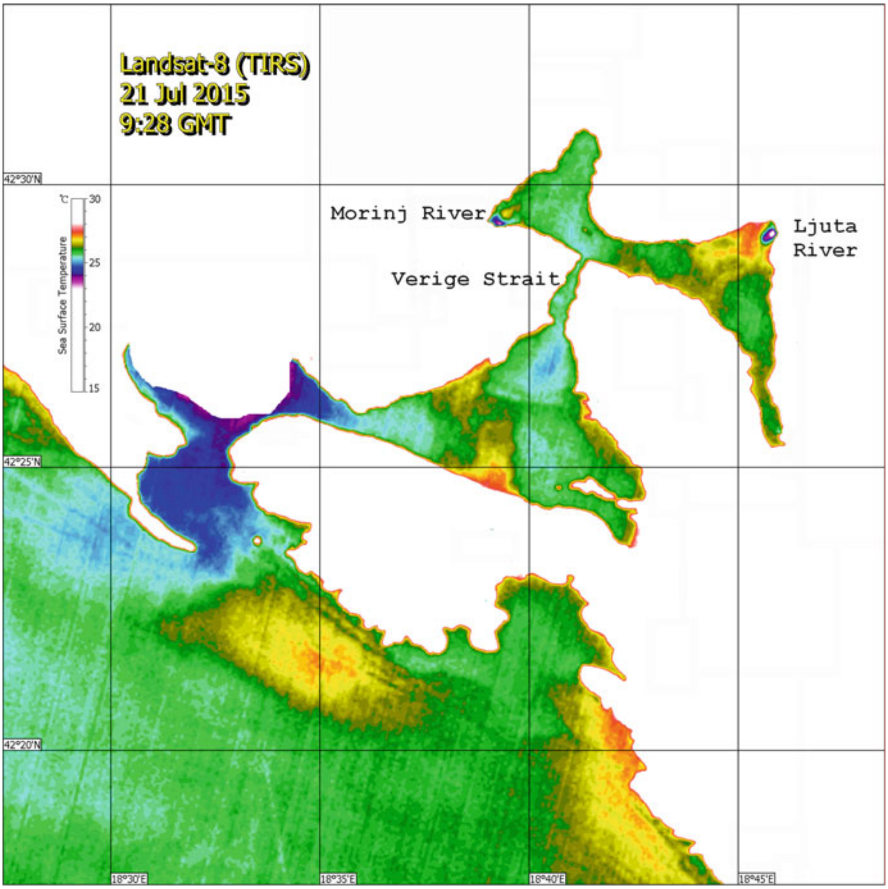

Fig. 9 Landsat-8 (TIRS) SST image of the Boka Kotorska Bay acquired on 21 July 2015 (09:28 GMT)

of the SST maps. For example, on 21 July 2015, we observed a large pool of relatively cold water at the entrance to the Boka Kotorska Bay and three warm patches in the inner parts of the Bay. Two separate warm patches are well detected in the Adriatic coastal zone, which can be explained by local insolation (Fig. 9). Two weeks later, on 6 August 2015, the SST field is much more uniform, in general, but with the same peculiarities as the Ljuta and Morinj River plumes and a small relatively cold patch of water southward of the Verige Strait (Fig. 10). Figure 11 (7 July 2016) features that sometimes this phenomenon can be as large as one half of the Tivat Bay and have an SST contrast of 3°C. Figure 12 (23 July 2016) shows that sometimes the Kotor, Risan, and Tivat Bays can be 1–2°C warmer than the Herceg Novi Bay and even the coastal zone of the Adriatic Sea.

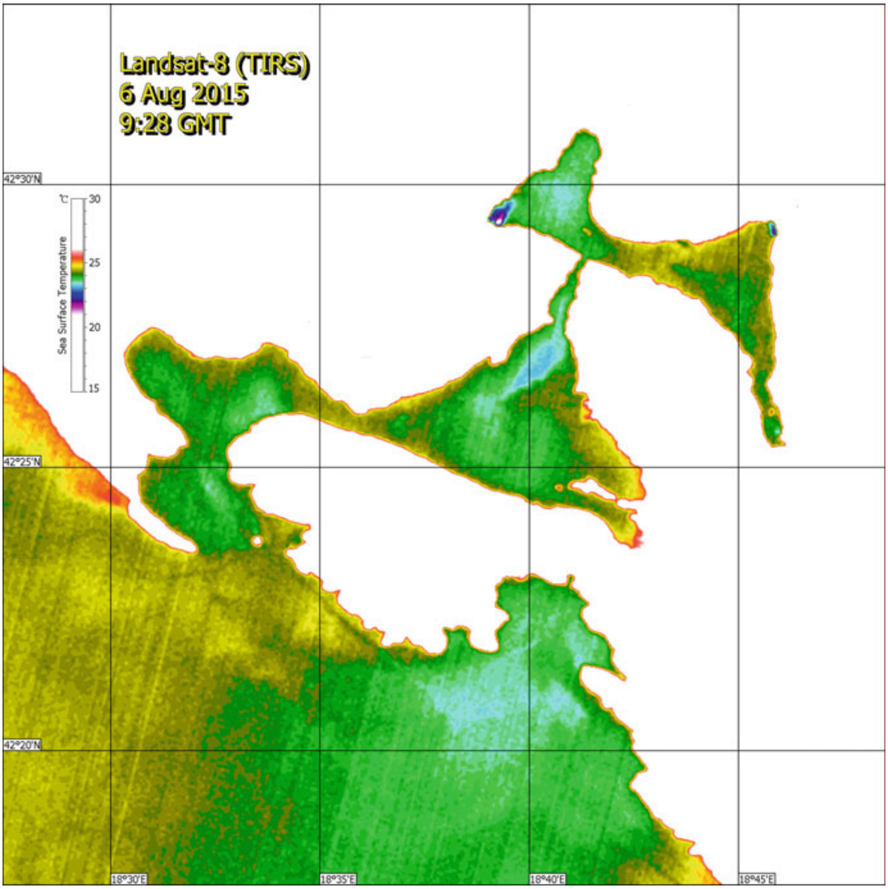

Fig. 10 Landsat-8 (TIRS) SST image of the Boka Kotorska Bay acquired on 6 August 2015 (09:28 GMT)

4 Chlorophyll-a

Chlorophyll-a concentration (Chl-a) is usually used as an index of productivity and trophic conditions of estuaries, coastal and oceanic waters [24]. There is generally good agreement between primary production and algal biomass, and Chl-a concentration is an excellent trophic state indicator [24]. Water quality of the Boka Kotorska Bay is an essential environmental concern because periods of eutrophication are noticeable [25–27]. To determine the existing status of water quality and to avoid potential catastrophic events, assessment and monitoring of water quality using remote sensing supported by in situ measurement are of paramount importance [28]. Seawater monitoring campaigns are rather expensive since they require costly equipment and materials and trained technicians taking samples in scheduled intervals, sometimes with high transport costs and delays in obtaining results.

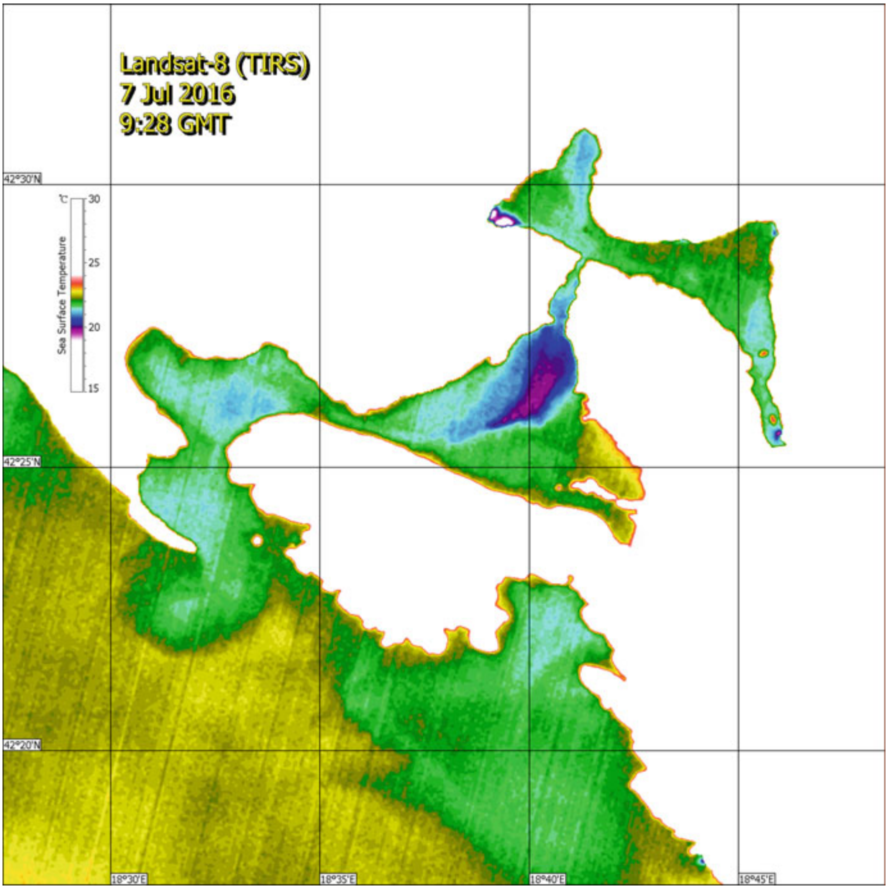

Fig. 11 Landsat-8 (TIRS) SST image of the Boka Kotorska Bay acquired on 7 July 2016 (09:28 GMT)

However, technological progress gives us a means for overcoming these issues. Satellite remote sensing is considered in numerous studies [29–31] for monitoring ecosystems as an addition to sampling campaigns that can provide a more detailed top-down view.

Landsat-8 (L8) [32] is the newest satellite of the Landsat family of land-observing satellites operated by the United States Geological Survey (USGS) whose data are available free of charge [33]. L8's sensor, Optical Land Imager (OLI), has a high spatial resolution and spectral resolution. It has several bands in visible spectrum that can be used for Chl-a monitoring. The increased spatial resolution allows for monitoring of the Chl-a in small inlets like the Boka Kotorska Bay. A study [34] has demonstrated a great potential for monitoring of near-shore water based on simulated L8 data. However, the L8 has one considerable flaw, which is its relative low temporal resolution, since it overflies the Bay only every 16 days.

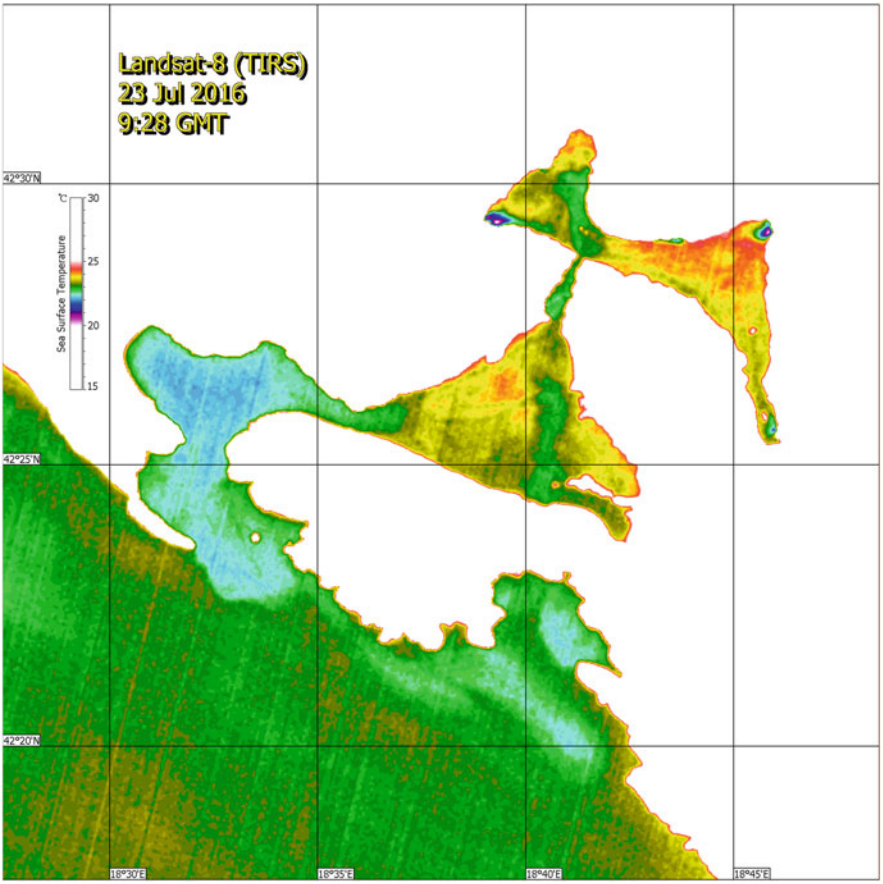

Fig. 12 Landsat-8 (TIRS) SST image of the Boka Kotorska Bay acquired on 23 July 2016 (09:28 GMT)

A Chl-a monitoring campaign using satellites can be divided into two components: the ground truth (GT) campaign and the satellite remote sensing campaign. The ground truth campaign, performed by the Institute of Marine Biology (Kotor, Montenegro), consists of performing measurements of Chl-a at preset locations in the Boka Kotorska Bay during the satellite overflight. The measurement is performed by collecting water samples (2L) from the surface using 5L Niskin bottles (HydroBios, Germany). The samples are then processed and analyzed using spectrometry in the lab according to the methodology specified in [35]. These samples are then used to train the remote sensing algorithm.

The remote sensing part of the campaign, mainly performed by the BIO-ICT, consists of procuring the L8 satellite data and its processing in order to produce maps of Chl-a concentrations in the Boka Kotorska Bay. The L8 data is acquired via GloVis [36] web interface. The data are extracted [37] and top-of-the-atmosphere (TOA) reflectances are calculated [38]. The atmospheric correction algorithm based

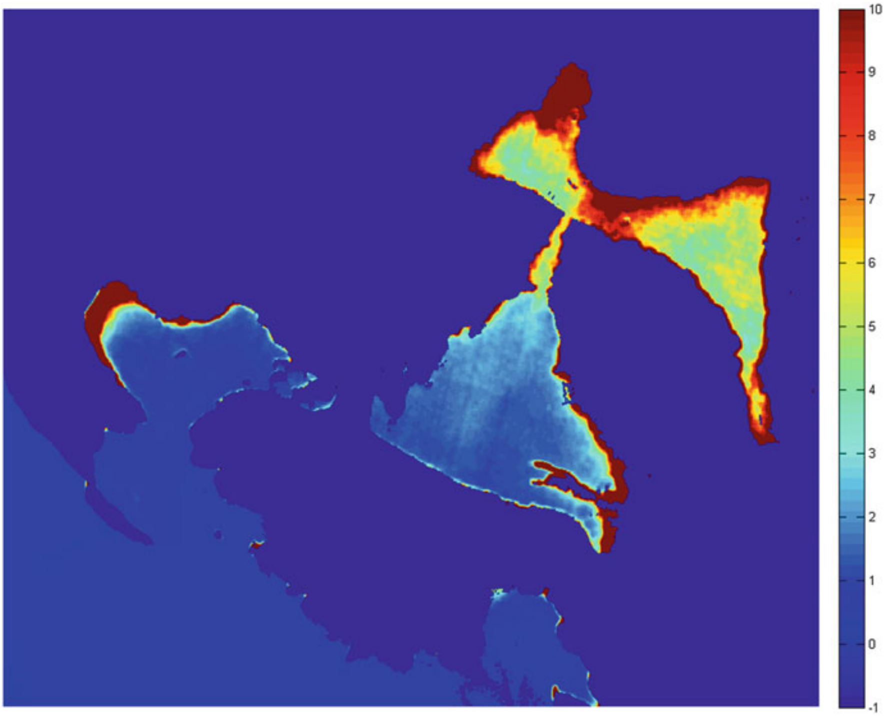

Fig. 13 Chl-a concentration [mg m^{-3}] on 15 March 2015

on [39–41] and the Sun glint removal algorithms [42] are then performed on TOA reflectances to get sea surface reflectances. The Chl-a retrieval algorithm uses band ratios, specifically the blue-green band ratio. GT data for the particular day is used to find a correlation between the L8 band ratio and Chl-a concentrations. That correlation is then applied to the band ratios of the entire Bay to acquire the map of Chl-a concentrations in the entire Bay.

Figures 13, 14, and 15 show three such maps from spring, summer, and winter of 2015, respectively. Figure 16 is a plot of Chl-a concentrations measured by taking water samples against those estimated from L8 data. The correlation between L8 Chl-a and GT Chl-a is 0.9111. One of the main issues, during 2015, was had with weather. Considering that the retrieval algorithm uses the band ratio of visible light bands, the entire process is very sensitive to atmospheric conditions. The aerosol content, high-altitude water vapor, and clouds can all cause degradation of the quality of the final product. In some cases, the conditions were so disruptive that a reasonable correlation between Chl-a and the band ratio could not be found. L8 with its long revisit time of 16 days isn't making it any better, and a couple of unfortunate cloudy days can lead to months with no remote sensing being performed. For example, the first GT campaign of 2016 was performed only on July 7 since during all of the other previous L8 overflight days the weather was not stable enough in the morning for the campaign to be given the green light.

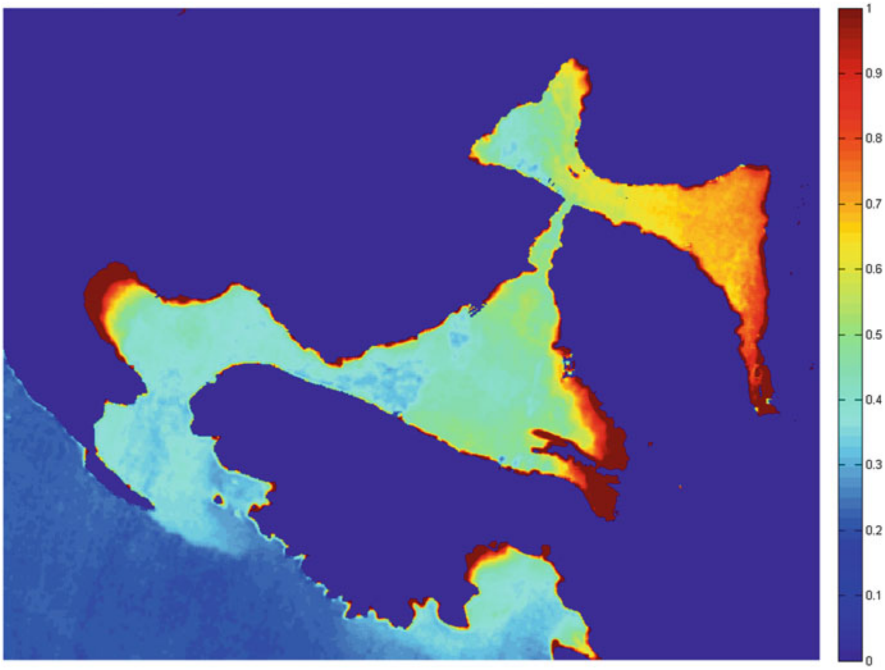

Fig. 14 Chl-a concentration [mg m^{-3}] on 19 June 2015

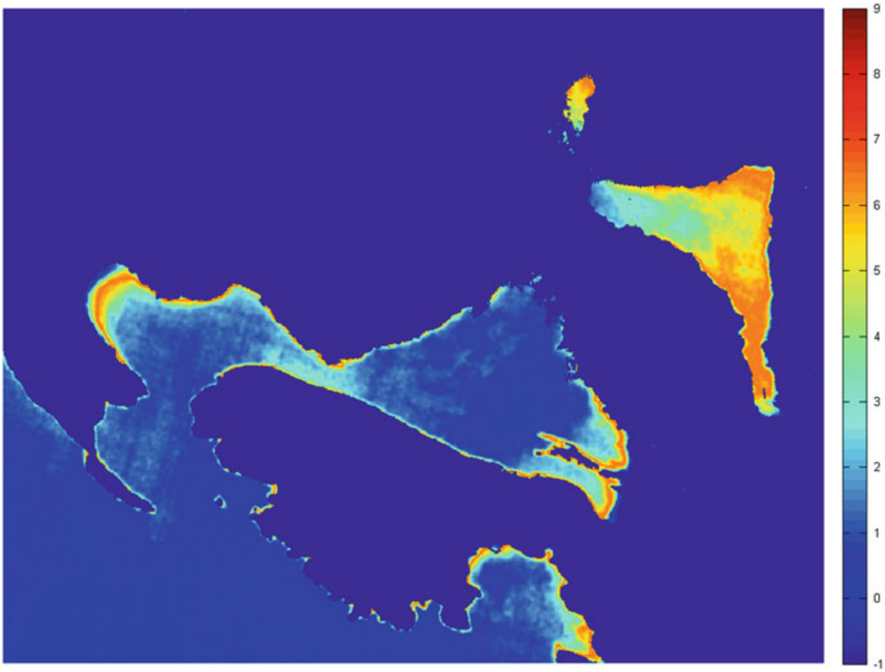

Fig. 15 Chl-a concentration [mg m^{-3}] on 28 December 2015

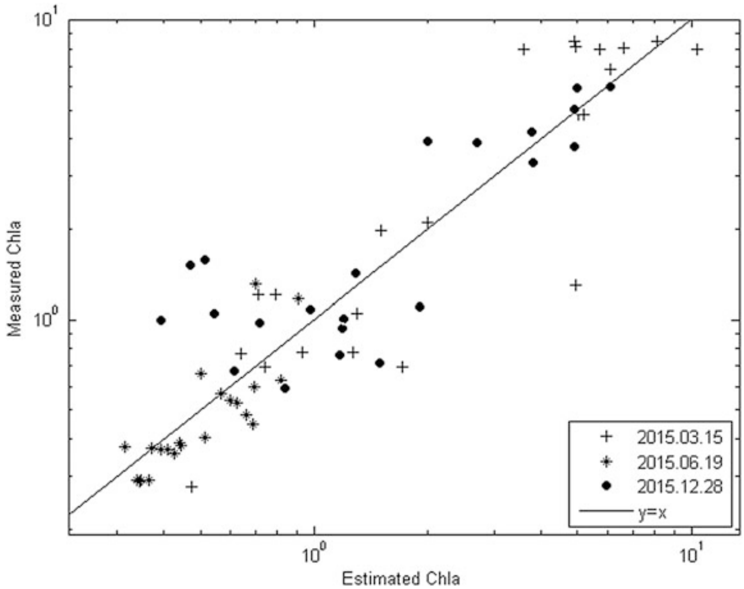

Fig. 16 Plot of Chl-a concentrations measured on the ground and estimated from L8 data

Therefore, we were unable to monitor the state of the Bay for over 6 months. Despite these shortcomings, usage of remote sensing to monitor water quality along the Montenegrin coast and in the Boka Kotorska Bay is still promising, especially as new retrieval algorithms are developed and new sensors like Sentinel-2A [43] are introduced.

5 SAR Imagery

Synthetic aperture radar (SAR) is a very important tool for environmental monitoring of the ocean, seas, and coastal zones. Since 1995 the SAR and ASAR systems installed onboard of Envisat, Radarsat-1, Radarsat-2, Sentinel-1A, TerraSAR-X, and COSMO-SkyMed-1, COSMO-SkyMed-2, COSMO-SkyMed-3, and COSMO-SkyMed-4 are effectively used for detection of oil spills on the sea surface in different parts of the World Ocean and inland seas. SAR systems are also used for detection of ships and sea ice, as well as for investigation of a series of physical processes and phenomena like fronts, upwellings, currents, mesoscale and small-scale eddies, internal waves, etc. Among advantages of this method, we can mention acquisition of data in almost all weather conditions, day and night, and spatial resolution of about 10–100 m. Among disadvantages we can list a series of look-alike phenomena on the sea surface (calm water, wind shadow, biogenic films, bloom events, ice, etc.), which make difficult correct identification of oil spills on the sea surface and a very high cost of SAR imagery. Despite all of this, SAR

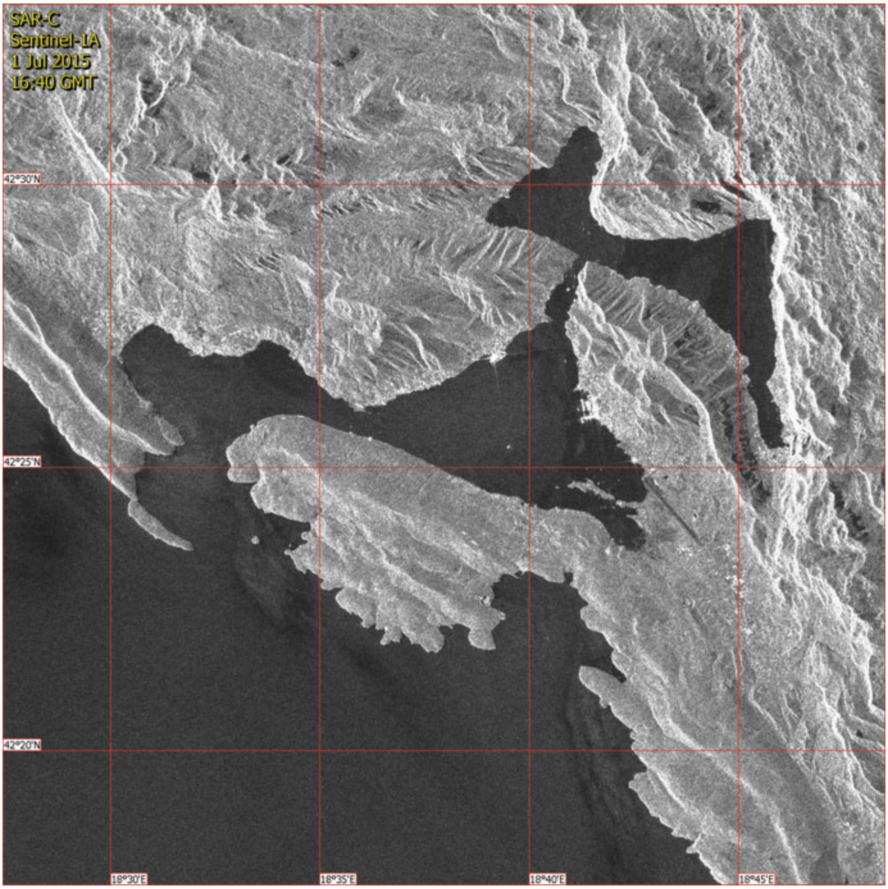

Fig. 17 Sentinel-1A SAR image of the Boka Kotorska Bay on 1 July 2015 (16:40 GMT)

imagery is a principal tool in modern industrial environmental satellite monitoring systems that was proved in our long-standing experience [2–21]. Below we show several Sentinel-1A SAR images of the Boka Kotorska Bay, which are free of charge; thus this satellite information can be incorporated in the satellite monitoring system of the Bay.

Sentinel-1 is a two-satellite constellation with the prime objectives of land and ocean monitoring. Sentinel-1A was launched on 3 April 2014 and Sentinel-1B on 25 April 2016. The goal of the mission is to provide C-Band SAR data continuity following the retirement of the European Space Agency (ESA) ERS-2 and Envisat missions. The satellites carry a C-SAR sensor, which offers medium- (25 $\times$ 100 m) and high-resolution (5 $\times$ 5 m and 5 $\times$ 20 m) imaging in all weather conditions. The swath width in different modes varies from 20 to 400 km, and it is possible to get about 15 SAR images during a month for the Boka Kotorska Bay [44].

For example, on 1 July 2015 (Fig. 17), we don't see significant contrasts in sea roughness, oil pollution, and any specific physical phenomena in the Boka Kotorska

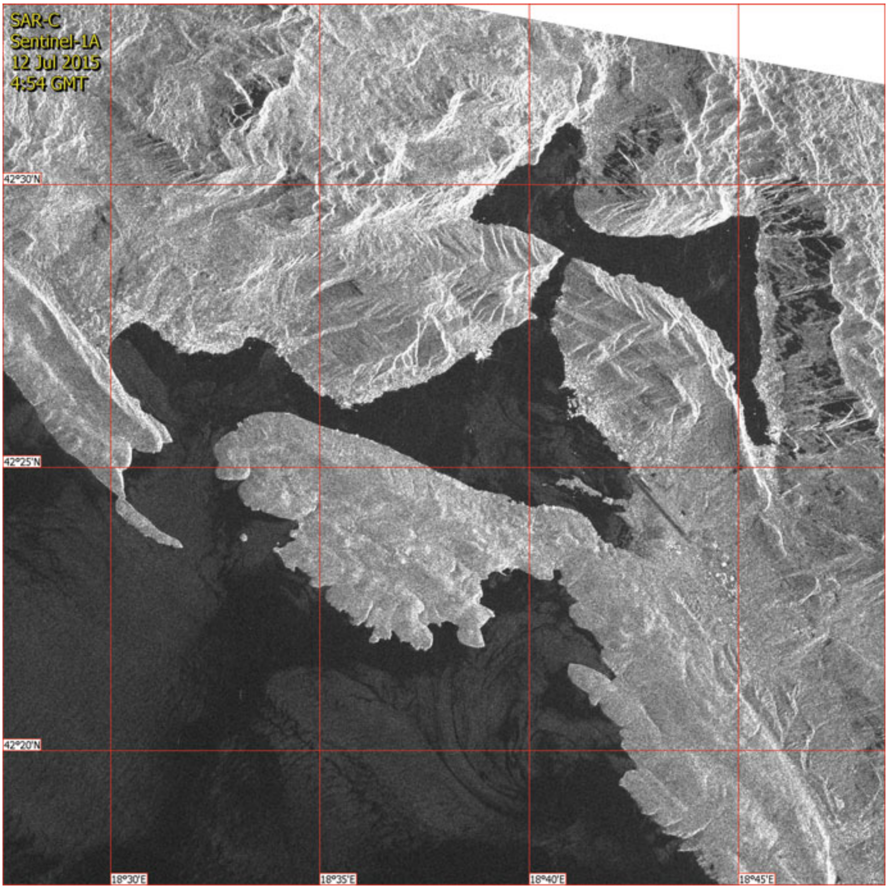

Fig. 18 Sentinel-1A SAR image of the Boka Kotorska Bay on 12 July 2015 (04:54 GMT)

Bay and in the Adriatic coastal waters. As usual ships in the sea are well visible in the Bay. Mountainous structures are very spectacularly displayed on SAR imagery. Figure 18 (12 July 2015) features numerous biogenic slicks (black narrow bands) as well as areas of calm water (large areas with a uniform black color) in the Bay and the Adriatic Sea. The most pronounced feature is a coastal cyclonic eddy in the Adriatic Sea with a center at about 42°20′N, 18°40′E, which is displayed by circular slicks of biogenic nature. Figure 19 (22 November 2015) shows uniform roughness of the sea without pronounced features, except of wind shadows behind the mountains.

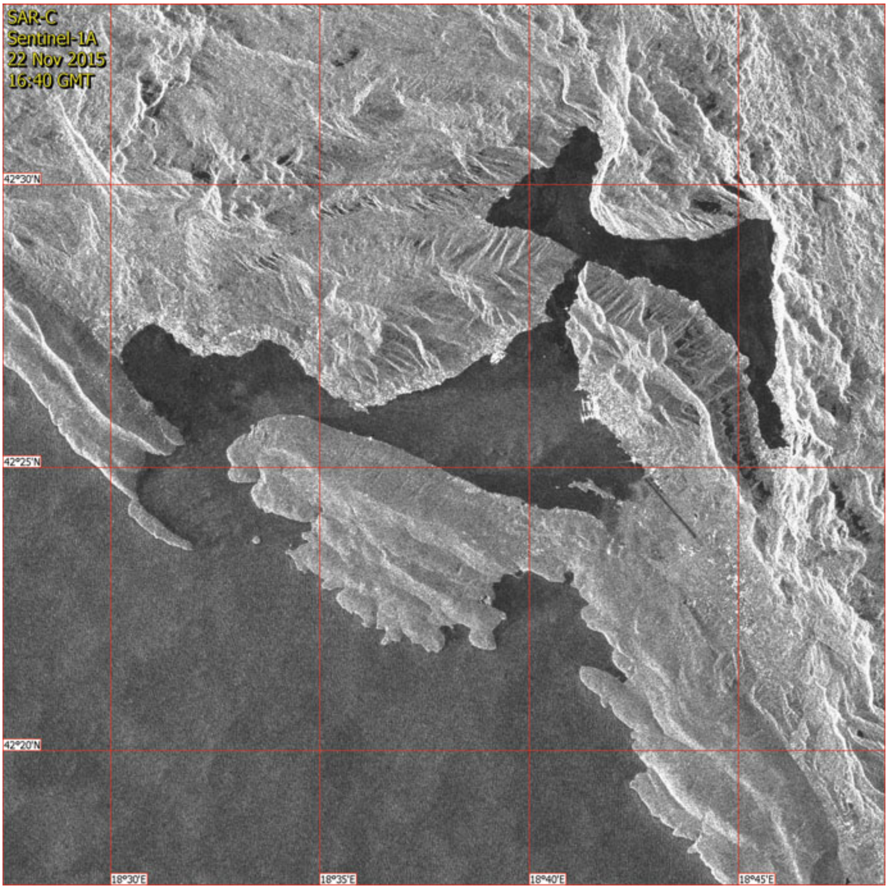

Fig. 19 Sentinel-1A SAR image of the Boka Kotorska Bay on 22 November 2015 (16:40 GMT)

6 Forest Fires

Every summer Montenegro experiences heat waves when the tropical heat with air temperature higher than 35°C lasts for several weeks. Dry and hot weather leads to forest and bush fires in the hills and mountains. According to Fire Service in Montenegro, in the first half of July 2015, 362 fires were registered in the vicinity of Podgorica City in comparison with 156 fires in July 2014. Wildfires can cause extensive damage to Montenegro and to the Boka Kotorska Bay environment, in particular, to property, tourism, agriculture, and human life. Figure 20 shows fires in the vicinity of Podgorica in July 2015, and Fig. 21 shows a satellite view of the same fire with a smoke propagating till Lake Skadar.

Fig. 20 Fires on the hills in the vicinity of Podgorica in July 2016 [45]

Fig. 21 Smoke from a fire in the vicinity of Podgorica on 11 July 2015 displayed by MODIS (Aqua) (250 m resolution)

7 Conclusions

The Boka Kotorska Bay is a pearl of the Adriatic Sea. Since 1979, the natural and cultural-historical region of Kotor has been a World Heritage Site. Nevertheless, the environment of the Bay experiences strong anthropogenic pressure from the raising tourism and shipping activities, growth of local population, problems with wastewater discharge into the Bay, construction and agriculture in the coastal zone, as well as impacts of the regional climate change. The chemical and biological characteristics of the Bay water are under control of the Institute of Marine Biology in Kotor, performed with other national and international organizations in the framework of a set of in situ monitoring programs.

Today, these monitoring programs do not comprise a satellite monitoring component, which is very important, useful, relatively cheap, and in many ways advantageous. The development of ICAMP and monitoring systems for the coastal zone of Montenegro, and for the Boka Kotorska Bay, in particular, requires establishment of permanent integrated satellite monitoring based on the multisensor and multiplatform approach. Such a system should daily observe the whole Montenegrin coast in the Adriatic Sea, the Boka Kotorska Bay, and Lake Skadar. It can be elaborated and performed in close collaboration between Montenegrin and Russian scientists, who have long-standing experience in remote sensing of the ocean and inland seas from space, as well as in conduction of operational satellite environmental monitoring for offshore industries [2–21].

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References

1. Joksimović A, Đurović M, Semenov AV, Zonn IS, Kostianoy AG (2017) The Boka Kotorska Bay environment. Springer, Heidelberg
2. Lavrova OYu, Kostianoy AG, Lebedev SA, Mityagina MI, Ginzburg AI, Sheremet NA (2011) Complex satellite monitoring of the Russian seas. IKI RAN, Moscow, 470 pp (in Russian)
3. Kostianoy AG, Bulycheva EV, Semenov AV, Krainyukov AV (2015) Satellite monitoring systems for shipping, and offshore oil and gas industry in the Baltic Sea. Transp Telecommun 16(2):117–126
4. Kostianoy AG, Lebedev SA, Soloviev DM, Pichuzhkina OE (2005) Satellite monitoring of the Southeastern Baltic Sea. Report 2004. Lukoil-Kaliningradmorneft, Kaliningrad, 36 pp (in -Russian and English)

5. Kostianoy AG, Litovchenko KTs, Lavrova OYu, Mityagina MI, Bocharova TYu, Lebedev SA, Stanichny SV, Soloviev DM, Sirota AM, Pichuzhkina OE (2006) Operational satellite monitoring of oil spill pollution in the southeastern Baltic Sea: 18 months experience. Environ Res Eng Manag 4(38):70–77
6. Kostianoy AG (2008) Satellite monitoring of oil pollution in the European Coastal Seas. OCEANIS 34(1/2):111–126
7. Kostianoy AG, Lavrova OYu, Mityagina MI (2009) Integrated satellite monitoring of oil pollution in the Russian seas. In: Izrael YuA (ed) Problems of ecological monitoring and modelling of ecosystems, vol 22. IGKE, Moscow, pp 235–266 (in Russian)
8. Lavrova OYu, Kostianoy AG (2010) A catastrophic oil spill in the Gulf of Mexico in April–May 2010. Issledovanie Zemli iz Kosmosa (Russ J Remote Sens) 6:67–72 (in Russian); (2011) Izv Atmos Oceanic Phys 47(9):1114–1118. Pleiades Publishing, Ltd., 2011
9. Kostianoy AG, Solovyov DM (2010) Operational satellite monitoring systems for marine oil and gas industry. In: Proceedings of 2010 Taiwan Water Industry conference, Tainan, 28-–29 October 2010, pp B173–B185
10. Kostianoy A, Solovyov D (2011) Operational satellite monitoring systems for marine oil and gas industry. In: Proceedings of 34th international symposium on remote sensing of environment. The GEOSS era: towards operational environmental monitoring, Sydney, 10–15 April 2011
11. Grishin N, Kostianoy A (2012) Satellite monitoring of suspended matter pollution resulted from the Nord Stream gas pipeline construction in Russian waters of the Baltic Sea in 2010–2011. Int Water Technol J 2(1):80–89
12. Grishin NN, Kostianoy AG (2012) On satellite monitoring of suspended matter transport during the construction of an offshore gas pipeline Nord Stream in Russian waters of the Baltic Sea in 2010. Mod Probl Remote Sens Earth Space 9(1):167–175 (in Russian)
13. Grishin NN, Kostianoy AG (2013) The use of satellite monitoring of suspended matter transport for the assessment of transboundary environmental impact of construction the Russian section of the offshore gas pipeline Nord Stream. Mod Probl Remote Sens Earth Space 10(1):303–319 (in Russian)
14. Kostianoy AG (2013) Oil pollution: Baltic Sea. In: Jorgensen SE (ed) Encyclopedia of environmental management, vol III. Taylor & Francis, New York, pp 1851–1866
15. Kostianoy AG, Lavrova OYu (eds) (2014) Oil pollution in the Baltic Sea, vol 27. Springer, Heidelberg. 268 pp
16. Kostianoy AG, Lavrova OYu, Mityagina MI, Solovyov DM (2014) Satellite monitoring of the Nord Stream gas pipeline construction in the Gulf of Finland. In: Kostianoy AG, Lavrova OYu (eds) Oil pollution in the Baltic Sea, vol 27. Springer, Heidelberg, pp 221–248
17. Kostianoy AG, Lavrova OYu, Solovyov DM (2014) Oil pollution in coastal waters of Nigeria. In: Barale V, Gade M (eds) Remote sensing of the African seas. Springer, Heidelberg, pp 149–165
18. Bulycheva EV, Krek AV, Kostianoy AG, Semenov AV, Joksimovich A (2016) Oil pollution in the Southeastern Baltic Sea by satellite remote sensing data in 2004–2015. Transp Telecommun 17(2):155–163
19. Kostianoy AG, Kostianaia EA, Soloviev DM (2016) Satellite monitoring of Dzhubga-Lazarevskoye-Sochi offshore gas pipeline construction. In: Zhiltsov SS, Zonn IS, Kostianoy AG (eds) Oil and gas pipelines in the Black-Caspian Seas region. Springer, Heidelberg
20. Bulycheva EV, Kostianoy AG, Krek AV (2016) Interannual variability of oil pollution of the sea surface in the Southeastern Baltic Sea in 2004–2015. Curr Probl Remote Sens Earth Space 13(4):74–84 (in Russian)
21. Kostianoy AG, Bulycheva EV, Lavrova OYu, Mityagina MI, Bocharova TYu, Soloviev DM, Sirota AM (2016) The unprecedented case of oil pollution of sea surface from a ship in the South-Eastern Baltic Sea on 23 July 2016. Curr Probl Remote Sens Earth Space 13(4):260–264 (in Russian)
22. https://lta.cr.usgs.gov/LETMP. Accessed 16 Aug 2016

23. https://lta.cr.usgs.gov/L8. Accessed 16 Aug 2016
24. Boyer JN, Kelble CR, Ortner PB, Rudnick DT (2009) Phytoplankton bloom status: chlorophyll a biomass as an indicator of water quality condition in the southern estuaries of Florida, USA. Ecol Indic 9(6):S56–S67
25. Krivokapić S, Pestorić B, Bosak S, Kušpilić G, Wexels RC (2011) Trophic state of Boka Kotorska Bay (south-eastern Adriatic Sea). Fresenius Environ Bull 20(8):1960–1969
26. Drakulović D, Pestorić B, Cvijan M, Krivokapić S, Vuksanović N (2012) Distribution of phytoplankton community in Kotor Bay (south-eastern Adriatic Sea). Open Life Sci 7 (3):470–486
27. Bosak S, Šilović T, Ljubešić Z, Kušpilić G, Pestorić B, Krivokapić S, Viličić D (2012) Phytoplankton size structure and species composition as an indicator of trophic status in transitional ecosystems: the case study of a Mediterranean fjord-like Karstic bay. Oceanologia 54(2):255–286
28. Salama M, Dekker A, Su Z, Mannaerts C, Verhoef W (2009) Deriving inherent optical properties and associated inversion-uncertainties in the Dutch Lakes. Hydrol Earth Syst Sci 13(7):1113–1121
29. Olmanson LG, Kloiber SM, Bauer ME, Brezonik PL (2001) Image processing protocol for regional assessments of lake water quality. In: Water resources center technical report, vol 14
30. Hellweger F, Schlosser P, Lall U, Weissel J (2004) Use of satellite imagery for water quality studies in New York Harbor. Estuar Coast Shelf Sci 61(3):437–448
31. Olet E (2010) Water quality monitoring of Roxo reservoir using Landsat images and in-situ measurements. MS, International Institute for Geo-Information Science and Earth Observation (ITC), Netherlands
32. Irons JR, Dwyer JL, Barsi JA (2012) The next Landsat satellite: the Landsat data continuity mission. Remote Sens Environ 122:11–21
33. EROS (2015) Landsat 8 (l8) data users handbook. Department of the Interior U.S. Geological Survey, EROS, Sioux Falls, SD [Online]. Available: http://landsat.usgs.gov//documents/Landsat8DataUsersHandbook.pdf
34. Gerace AD, Schott JR, Nevins R (2013) Increased potential to monitor water quality in the near-shore environment with Landsat's next-generation satellite. J Appl Remote Sens 7(1):073558
35. Jeffrey S, Mantoura R, Wright S (1997) Phytoplankton pigments in oceanography: guidelines to modern methods. UNESCO, Paris
36. USGS (2015) USGS Global Visualization Viewer. United States Geological Survey [Online], February. Available: http://glovis.usgs.gov/5
37. USGS (2012) Landsat Data Continuity Mission Level 1 Data Format Control Book. EROS, Sioux Falls, SD [Online], August. Available: http://landsat.usgs.gov/documents/LDCM-DFCB-004.pdf
38. USGS (2015) Using the USGS Landsat 8 Product. U.S. Geological Survey [Online], February. Available: http://landsat.usgs.gov/Landsat8_Using_Product.php
39. Gordon HR, Brown JW, Evans RH (1988) Exact Rayleigh scattering calculations for use with the Nimbus-7 coastal zone color scanner. Appl Opt 27(5):862–871
40. Bodhaine BA, Wood NB, Dutton EG, Slusser JR (1999) On Rayleigh optical depth calculations. J Atmos Ocean Technol 16(11):1854–1861
41. Hansen JE, Travis LD (1974) Light scattering in planetary atmospheres. Space Sci Rev 16 (4):527–610
42. Hedley J, Harborne A, Mumby P (2005) Technical note: simple and robust removal of sun glint for mapping shallow-water benthos. Int J Remote Sens 26(10):2107–2112
43. Drusch M, Del Bello U, Carlier S, Colin O, Fernandez V, Gascon F, Hoersch B, Isola C, Laberinti P, Martimort P et al (2012) Sentinel-2: ESA's optical high-resolution mission for GMES operational services. Remote Sens Environ 120:25–36
44. https://earth.esa.int/web/guest/missions/esa-operational-eo-missions/sentinel-1. Accessed 17 Aug 2016
45. http://balkanpro.ru/montenegro/news/15799/. Accessed 17 Aug 2016

Tourism in the Boka Kotorska Bay

Rade Ratković, Ana Tripković-Marković, and Miško Rađenović

Abstract The Boka Kotorska Bay has extraordinary natural and cultural preconditions for tourism development. The natural and cultural potential favoured early tourism development in the Boka Kotorska that dates back to the early nineteenth century. The Boka Kotorska is the first holiday and cruising destination in Montenegro.

Further intensive tourism development had a strong effect on economy and landscape of the Boka. There are three distinct stages in tourism development in the Boka Kotorska: initial development until the WW II (1939?), the period of intensive development from the WW II (1945) until 1990s and the period from 1990s until today. The Master Plan tourism development strategy of Montenegro by 2020, setting the development guidelines for the Boka Kotorska, stands out as a separate entity.

Nevertheless, in the mass tourism era, the tourism development in the Boka Kotorska Bay is burdened by a pronounced seasonal character, unfavourable structure of accommodation facilities and unsatisfactory tourism infrastructure. Analysis of the current developmental strategies and ongoing projects shows some inconsistency. The investments planned favour big mixed-purpose projects with a pronounced residential component, which is not in accordance with the tourism development plans adopted.

The Boka Kotorska Bay, UNESCO's Heritage Site, is one of the most important tourist regions in Montenegro. It is predisposed for development of specific tourism forms, such as nautical, cultural, health, sports, incentive and congress tourism, special interest tourism and others. At the same time, bathing, holiday tourism remains an important segment of the tourist offer of the Boka Kotorska Bay.

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Keywords Boka Kotorska region, Tourism, Tourism potential and development, Tourism strategy

Contents

1 Introduction

World tourism development can generally be divided into two major epochs. The first is the epoch of the so-called *privileged classes' tourism*. It is characterised by a relatively limited number of people travelling beyond the borders of their respective countries, mainly only wealthy people, members of privileged groups and classes. The first part of this period is characterised by tourism-analogous phenomena until 1845, while the second begins with Thomas Cook's opening of the first tourist agency, which is called the organised tourism period. It lasted until the outbreak of the World War I (1914–1918).

The second epoch is the epoch of the so-called *mass tourism*, i.e. the working people tourism. This period is characterised by mass tourism movement, as people began using their right to paid annual leave and had more free time. This epoch can be divided into the period between the World War I and World War II (1939) and the period after the end of the World War II (1945).

Tourism development in Montenegro, due to the specific socio-economic circumstances, is characterised by belated tourism development in comparison with most of the developed Mediterranean countries. Usually, developmental problems in tourism in Montenegro were not given particular attention which resulted in a lack of appropriate developmental policy and only minor scientific progress in this area. Despite belated tourism development, Montenegro's development path was similar to that of small coastal countries.

Tourism in the Boka Kotorska was developing along with tourism development in Montenegro in general; from working-class holiday homes to modern hotels of today, description of which is to follow in this paper.

2 Natural Attractions of the Boka Kotorska Bay

The Boka Kotorska region shows the signs of significant tourism expansion, which resulted in development of the economy of the region. Comparison of statistical data shows the development pace. Thus, for example, in 1966, the accommodation capacity in the Boka Kotorska was around 14,000 bed places, and today it is above 50,000. The number of visitors in mid-1960s was around 94,000, today it is above 400,000. The number of overnight stays was around 900,000, while today it is more than 3,500,000, etc.

The Boka Kotorska Bay is quite attractive from the viewpoint of its geographical position and climate. It is situated between the cliffs of the mountains Orjen, Lovćen and Vrmac, with both coastal and continental climate, providing extraordinary potential for health tourism development. The Boka potential has not been fully utilised in that regard. In addition to favourable climate, the Boka is characterised by natural beauties.

The Boka Kotorska Bay has the shape of two elongated sea lakes connected by the Verige Strait. The first lake spreads from Igalo to Tivat, consisting of two oval-shaped bays: the Herceg Novi Bay and the Tivat Bay connected by the Kumbor Strait. The bays communicate with the open sea through the strait. The Tivat Bay is larger than the Herceg Novi Bay and its shore is somewhat lower. In the other part of the Boka Kotorska Bay towards the continental part, there are two lakes connected by the Perast Strait: the Kotor Bay and the Risan Bay. The Verige Strait, quite narrow, connects these two bays with the large Tivat Bay and through it with the open sea, thus forming the Boka Kotorska Bay as a whole. Relief of Boka Bay is shown in Fig. 1.

When it comes to bays, most of the Boka Kotorska belongs to the Tivat Bay hinterland, around 120,025 km^2 (32.4%), followed by the Herceg Novi Bay 90,175 km^2 (24.4%), the Risan Bay 82,300 km^2 (22.2%) and the smallest to the Kotor Bay hinterland 77,125 km^2 (21.0%).

Most of the continental hinterland of the Boka Kotorska Bay belongs to the Risan Bay (21%), and the smallest part to the Herceg Novi Bay (3.8%).

The Boka Kotorska offers rest and leisure to various types of tourists in different seasons. In winter, the Orjen is covered by snow and ice. The Mt. Kopaonik (Serbia), although higher, has no traces of Pleistocene glaciers, while these are typical of the highest parts of the Mt. Orjen and Lovćen. In winter, the mountains are covered by snow, while in the coastal part palms, flowers and citruses grow. Lush vegetation comprising diverse species grows between the coast and the mountains. The major advantage of the region is the fact that in the same day, a tourist can ski in the snow-covered mountains and swim in the warm sea.

The mountainous part of the Boka Kotorska is the richest in precipitation. In rainy areas, about 5 m of water falls, while daily rainfall can reach up to half a meter. Nevertheless, the lack of water is a major problem in this region. Rainfall distribution throughout the year is uneven.

Fig. 1 Map of the Boka Kotorska Bay

The Boka Kotorska is attractive for tourists both for its natural beauties and for anthropogenous characteristics. It is characterised by unique combination of bays and straits. The hinterland is mountainous and karst, and a combination of climatic factors provide favourable conditions for growth of numerous plant species that contribute to the beauty of the landscape. Tourism development in the Boka region resulted in numerous new opportunities for establishing of a connection between the Boka coast and its mountainous hinterland, i.e. the indirect effect of the sea on the mountain and vice versa.

3 Cultural-Historical Monuments of the Boka Kotorska Region

In terms of space, the cultural-historical monuments can be divided or presented on the territories of the municipalities of Kotor, Herceg Novi and Tivat [1]. As far as tourism is concerned, the most significant are cathedrals, churches and monasteries, palaces, fortresses, citadels, fortifications and many other structures.

Most of these are located on the territory of Kotor. The Old Town of Kotor is centuries' old cultural and historical monument. One of the most beautiful and most significant cathedrals – Saint Tryphon's Cathedral – is situated in Kotor. It dates back to the ninth century, when sacred relics of the Saint Tryphon, after whom the church was named, were brought to it. Over the centuries, it was several times destroyed by fires and earthquakes, but eventually it was reconstructed to its current appearance. It has a quite rich repository, including baroque frescoes, gold plated altar and numerous ornaments of major value, etc.

Apart from the St Tryphon Cathedral, the Orthodox Church of Saint Nikola is important. As the most important Orthodox Church in Kotor, it was built in the early twentieth century. It was built by wealthy families of Kotor on the foundations of an older structure.

There are also several other churches in Kotor: Saint Luca's Church – significant since at one point, it was serving both the catholic and orthodox faith – Saint Michael's Church, Saint Ana's Church, Church of Saint Mary Collegiate, Saint Joseph's Church and Saint Paul's Church.

There are also numerous palaces in Kotor, most significant of which are: the Palace of Bisanti – built in the fifteenth century in the Romanesque style, by the Town Guards Tower. The Palace Grgurina dates back to the eighteenth century, the Palace Buca to the fourteenth century, the Palace Vrakjen – one of the most elegant – to the fourteenth century, then the Palace Pima, the Palace Drago, etc.

As far as tourism in Kotor is concerned, it is also important to mention the Town Clock Tower with the pillar of shame in front and the Town Guards Tower.

The Municipality of Tivat also has numerous cultural-historical monuments, most significant of which are: the Buca Summerhouse – in the centre of Tivat. It was built in Renaissance style with a number of late Gothic style details. Today, it hosts plays, literary nights, concerts and art exhibitions. Apart from the Palace of Buca, it is important to mention the remnants of the Saint Michael, the Archangel Monastery, on the Prevlaka Peninsula. It dates back to one of the most significant periods for Boka, the period from the ninth to fifteenth century. It was levelled in 1452 by the Republic of Venice and has not been renovated since. In terms of tourism, it is important to mention also the following: Our Lady of the Grace Island, the Church of Saint Peter, the Church of Saint Anthony of Padua, the Church of Saint Mary, the Church of Saint Roch and the Church of Saint Sava.

On the road from Dubrovnik towards Kotor, as two most important historical and touristic towns of the region, lies Herceg Novi. In addition to Monastery Savina, Herceg Novi has numerous fortresses among which the most important is the Forte Mare Fortress. It was founded by the Bosnian King Tvrtko I, as mediaeval town in 1382. Over the centuries, it survived numerous conquerors and reconstructions, and its final appearance was given by the Austro-Hungarian Empire in 1833.

The Kanli Kula Fortress (bloody tower in Turkish) is a Turkish fortress on the northern side of the old part of the town. It was mentioned for the first time in the mid-seventeenth century. It got its current appearance when Herceg Novi was under the Turkish siege in the sixteenth century. Today, it has been transformed into a modern summer stage.

The fortress commonly known as Spaniola is situated in the north-western part of the town. It was built in the sixteenth century by Spain and then rebuilt by Turks. Strategically, it dominates the entrance into the Boka Kotorska Bay, from the elevation of 170 m.

The Citadel Fortress is situated at the base of the town, dates back from the late seventeenth and early eighteenth century.

The Clock tower or the Tora is on the west gate of the town. It is a tower with a clock. At the period of Venetian rule, it was renovated and named the Tora. It is very important for tourism and is the pride of Herceg Novi.

The Monastery Savina consists of a complex of three churches, monastic quarters, cemetery and a stone paved access with a barrier, is located south of Herceg Novi and dates back to the fifteenth century. The monastery has monastic quarters with a rich collection of church books, cups and icons.

The Municipality of Herceg Novi has 99 church facilities (Orthodox as well as Roman Catholic) that form a rich cultural and historical heritage of great importance for tourism in the Boka Kotorska.

The small baroque town of Perast should be mentioned as a singular cultural and historical monument in the Boka Kotorska. Its developmental expansion took place in the seventeenth and eighteenth century, when the most renowned families built a large number of palaces, known well even today, the most famous of which are: the Palace Šestokrilović, the Palace Lučić-Kolović-Matikola, the Palace Bujović, the Palace Bronze, the Palace Balović, the Palace Smecchia, the Palace Višković and the Palace Zmajević. Island in front of Perast with the Saint George's Church is quite interesting, and the most significant is the island with the Church of Our Lady of the Rocks. Perast itself has a large number of churches, most important among which are: the Church of Saint Nicola, the Church of Our Lady of Rosary, the Church of Saint John the Baptist, the Church of Saint Marco and the Church of the Nativity of the Virgin Mary.

4 Beginning of Tourism Development in the Boka Kotorska Region

Organised tourism development in Montenegro began only after the Berlin Congress and international recognition of Montenegro (1878).[1] The preconditions for tourism development were development of economy, culture, but infrastructure as

[1]Some initial steps in organised tourism development were noted earlier. In that regard, construction of the *Hotel Lokanda* in Cetinje (1864), described in numerous relevant foreign sources, has historical significance. In terms of architecture and functionality, this hotel was a high-end facility for that period. This hotel in Cetinje had for decades been hosting renowned politicians, scientists, artists and cultural figures. By the early twentieth century, the *Grand Hotel* was the best known tourism-hospitality facility on the territory of Montenegro today. This statement does not diminish in any way the importance, quality and level of services in old, private pensions in Kotor – *Grac*

well. Two destinations in Montenegro stood out as key ones: Cetinje and surroundings, and Herceg Novi and Kotor with other sites in the Boka. Interest for Cetinje as the royal capital grew along with development of diplomatic relations. Significant contribution to popularisation of Cetinje was given by educated court and King Nikola personally, who, as Njegos had done before him, received in person not only renowned statesmen, scientists, journalists and culture emissaries, but also smaller and larger groups of tourists from a number of European countries, lending them his own ships for the Skadar Lake cruises.

The area of the Boka Kotorska, Zelenika, Herceg Novi and the Town of Kotor (included in the list of world natural and cultural heritage) were an important factor of development of Montenegro as the world tourist destination. Herceg Novi has become famous not only as attractive site with lush Mediterranean greenery, but also as a climatic spa and popular bathing site. It was also one of the reasons for which doctor Antun Magyar (from renowned Budapest family) decided to settle in Zelenika and with his own funds built in 1902 the first tourism-hospitality facility – pension *Na Zelenoj Plaži* (*On the Green Beach*), which was eventually named *Hotel Plaža*, Zelenika.

Construction of the railway in 1903 and of a contemporary quay had a positive effect on development of the region. The Hotel Plaža was at the time a unique attractive facility, as a result of its functionality and the quality of service, and also for its landscape design. Excursions around the Boka were organised for guests, as well as visits to Dubrovnik, Cetinje, Lake Skadar and Shkodra. The owner of the hotel also invested in promotion and education of staff. He financed publishing of a very interesting guide book *Round Trip from Zelenika through the Boka Kotorska, Shkodra and Montenegro in Five Days*, and he advertised some of his services in a number of newspapers, including in the guidebook for Dubrovnik. Locals employed by him were sent abroad for education to acquire new modern skills in order to perform the jobs of waiters and chefs [1].

The overall tourist offer was expanded with construction of the hotels *Europe, Ercegnovi, Balkan* and others. An important factor of tourism development was also provision of other tourist facilities and infrastructure. Kotor was the first town to be linked with regular maritime line with Adriatic towns (with Trieste in 1838) and the first excursions to Kotor and round trips of foreign tourists were organised as well. The first registered and categorised boarding houses were opened in 1850, already. In this period, no investments were made in big tourism and hospitality facilities. As late as the twentieth century, development of road transport slowly overran the railway transport, while air transport development began after the World War II.

Construction of the *Hotel Slavija* (commercially, in 1951), which was the first larger facility in this area, influenced the development of tourism in Kotor. Increase in revenues from foreign tourists was also the result of inclusion of Kotor in round

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and *Evropa* – that were pioneering the development of quality family-run hospitality and tourism services on the territory of Kotor and the Montenegrin coast as a whole.

Mediterranean trips and individual visits of foreign yachts. In addition to Kotor, other towns of the Bay, such as Prčanj, Perast and Morinj, were included in tourism industry, mainly as a result of promotional activities and investments.

Increase in turnover in Montenegro's tourism, mainly in the Boka Kotorska, in 1940s was the result of a number of factors:

- Establishing of a bus line Jadran-Express between Munich and Cetinje in 1930 that facilitated influx of tourists from Germany;
- Connecting Belgrade and Podgorica with air and bus line (1930);
- Establishing of a new air-line Belgrade–Grude (1938) as well as introduction of a motor coach Belgrade–Dubrovnik with a wagon for Herceg Novi;
- Opening of a maritime Balkan line with the ship *Lovćen*, of the *Zetska Navigation*, linking all Balkan countries and major towns in Montenegro as well as Trieste and Venice;
- Construction of new roads;
- Significant investments and minor private investments into construction of new tourism and hospitality facilities, resulting in increase in accommodation and hospitality capacities;
- Development of new tourism resorts in Montenegro, the areas of Budva, Ulcinj and Bar on the coast, and Kolašin (favourite summer resort for rich traders of Shkodra) and Žabljak, where the King's Court intended to build a mountain summerhouse.

The development cycle of Montenegro's tourism is quite similar to that of developed countries. According to a number of authors, the period of 1960s from today is of particular importance for tourism development in Montenegro, which is the period of beginning of true contemporary tourism with future development tendency [2].

5 Tourism Development in the Area of the Boka Kotorska in the Second Half of the Twentieth Century

In the second half of the twentieth century, tourism development was under the influence of economic and political measures, which was reflected in promotion of social functions of tourism. The main accommodation facilities were working-class, youth and children's holiday homes. Most of these in 1950 were situated in Herceg Novi (17), followed by Kotor (8) and Tivat (5). *Hotel Slavija* in Kotor was in commercial use as of 1951, and a year later children's holiday home of the autonomous province of Vojvodina was opened in Prčanj, Railway's Holiday Home *Glavati* (Prčanj), Pension Holiday Home *Karmel* in Prčanj, Children's Holiday Home of the Municipality of Belgrade in the Palace Ivanović in Dobrota, Holiday Home of the Road Administration of Serbia in Dobrota, Holiday Home for Children with Developmental Disorders from Jabuka near Pančevo, also in

Dobrota. Similar trend was followed by other municipalities in the Boka Kotorska. At that time, the state subsidised the transport and stay in holiday homes for employees and their families [3].

The first hotel facilities were opened in the Boka at the end of 1950s. That is when the *Hotel Mimoza* was finished with 52 bed places, which is taken as the beginning of the period of tourism commercialisation. The most intensive construction works took place in the period 1960–1970 when Montenegro adopted the *Resolution on Tourism Development*. By 1965, three hotel facilities were built on the territory of Herceg Novi and one in Tivat and Kotor, each. Nevertheless, the problem occurred as a result of insufficient infrastructure development, which limited further development. In this period, the need for further development of the education system was noted, which is why the *Tourism Department* was established at then Maritime College in Kotor and students got the title *economist in tourism*.

A number of social policy measures had a negative impact on public revenues from tourism, such as, income census, which set the right to children's allowance amount. The number of registered bed places in 1966 was 4,005, and 4 years later it was 3,460. Larger hotel facilities were built in Herceg Novi and Tivat. The accommodation facilities structure, in terms of type and purpose, was unfavourable in Herceg Novi, Tivat and Kotor compared to Budva. In the Boka Kotorska Bay, private accommodation facilities were 2.5 times higher. Share of hotel accommodation facilities in Kotor was less than 10%. According to results of the financial turnover, Budva has reached the very top of developed municipalities of SFR Yugoslavia. Even in the period of most intensive construction works, not much was built in Kotor. The reason for that is most probably the lack of capacity for mass tourism development in Kotor and particular tourism forms, such as cultural, religious and congress tourism, were not promoted.

In the period 1970–1980, the share of the Boka Kotorska Bay in overall accommodation facilities of Montenegro fell. In early 1970s, the Labourers' Council of the shipping company Jugooceanija adopted the decision on establishing of an Associated Labour Organisation as a legal person *Oceanija Turist Commerce*. This enterprise should have been involved in trade and tourism, in order to develop further the tourism in Kotor. The system of financing of accommodation facilities (bungalows) on the Cape Marko with 330 bed places and a restaurant with 800 seats was designed. Also, construction of 200 bed places in Morinj, 250 accommodation units in Risan, 1,200 in Ljuta, 400 in Orahovac, 100 vehicle units in the camp in Risan and a cable car for the Saint Ivan hill (260 m) above Kotor. However, the contractor kept changing deadlines, so investments were made years later. In 1976, OOUR[2] *Oceanija Turist Komerc* ceased its activities and Hotel Slavija became a part of the OOUR Fjord [3].

[2]T/N: OOUR – Osnovna organizacija udruženog rada: Basic Organisation of Associated Labour – one of the organisational structures in former Yugoslavia.

At the end of 1970s, on 15 April 1979, catastrophic earthquake with an epicentre immediately by the Montenegrin coast struck, inflicting enormous damage to tourism and hospitality industry and heritage monuments. The Boka Kotorska Bay suffered somewhat above 40% of the overall damage. The following decade was the period of recovery from the earthquake consequences – demolition and rehabilitation of facilities that suffered significant damage. Countries of former Yugoslavia helped financing the rebuilding of the country and new facilities were built: *Hotel Teuta* in Risan, *Fjord* in Kotor at the location of the former *Hotel Slavija, Delfin* in Bijela and Phase II of the Institute Dr Simo Milošević in Igalo. The investments were made also in infrastructure, primarily the coast and nautical infrastructure. Berth infrastructure was built for 228 vessels, of which 27 for larger lengths.

At the end of 1980s, enterprise Trecom was founded, with 90% of foreign and 10% of domestic capital. The enterprise's focal activity was exclusive tourism and complementary activities in the Kotor Bay. Reconstruction of the Ducal Palace and the Citadel fortress in Kotor began. The company Pima from Kotor leased *Hotel Fjord* and Villa Perast, but the contract was terminated after 2 years. In mid-1995, building of the Hotel Marija in Kotor was rehabilitated by private investments. In this same period, a modern section of the road Cetinje–Podgorica was built. Tourism in the Boka reached its peak at that time and its share in the overall turnover in tourism in the Republic was above one-third.

The following decade was marked with political instability caused as a result of SFR Yugoslavia disintegration, armed conflicts, economic stagnation and international sanctions, which resulted in decrease in tourism turnover in the entire region, but also in deterioration of the existing tourist facilities. Domestic tourists faced significant decrease in standard, which had a drastic impact on demand, while foreign tourists did not visit Montenegro as a result of political instability in the region.

6 Current Tourism Situation in the Boka Kotorska Region

The tourist offer of the Boka Kotorska consists of tourism infrastructure and tourism superstructure. The tourism infrastructure consists of entertainment parks, tourist information centres, access centres for tourists and visitors, lay-bys, nautical tourism facilities, golf courses, tennis courts, outdoor and indoor sports and recreation facilities, small reservoirs with bathing sites, pools, wellness facilities, entertainment and recreation paths and trails (trim tracks, health trails, overlooks, panoramic trails, cycling trails, trekking trails, snowmobile trails and similar), regulated coast, facilities for natural rarities' watching, resting facilities for tourists, facilities for adventure activities and others. There are no significant tourism infrastructure facilities on the territory of the Boka Kotorska that can be mentioned. In order to evaluate the existing tourism infrastructure, the overview, by type, is given in Table 1.

Table 1 Overview and evaluation of tourism infrastructure in the Boka Kotorska area in 2015

Infrastructure type	Description	Function
Tourist information centres	Several dispersed offices under local tourist organisations	Local information-tourism activity
Access centres for tourists	The nearest airports in Tivat and Dubrovnik, bus stations and insufficient parking places	Accept domestic guests, guests from the region and foreign guests
Lay-bys, trekking and cycling trails	Promenades along the sea and, in the initial development phase, also trekking and cycling trails	Supplementary offer for tourists in accommodation facilities
Bathing sites and pools	Urban bathing sites, beaches and public pools	Offer for residents and tourists
Sports and recreation facilities	Public sports facilities (stadiums, pools and courts)	Mainly for sports teams and citizens, with limited use by tourists
Nautical tourism facilities	There are 11 marinas on Montenegro's coast with the capacity of 508–568 commercial berths and 790–860 non-commercial berths. The new mega marina Porto Montenegro in Tivat has the capacity of around 460 berths	Existing marinas operate as the modest marinas, with elements of town ports and berths and poor accompanying facilities. Porto Montenegro is an exception, as it is a high-end marina with excellent accompanying facilities
Wellness facilities	None, except under hotels and in the medical centre Igalo	Medical facilities in Igalo are valorised, but are in the privatisation process
Natural attractions	Fascinating nature: the Bay, islands, mountains and vegetation	Insufficiently valorised in terms of tourism
Cultural attractions	A number of Austro-Hungarian fortresses, fortifications, old towns, sacral buildings, summer stages, festivals and events	Valorised in day-trip and stationary tourism

Source: own data processing

As shown in Table 1, the tourist infrastructure is relatively modest and is not sufficiently used for tourism purposes. This particularly refers to the sports and recreational facilities throughout the Boka Kotorska Bay. The exception is the new mega yacht marina Porto Montenegro with a high-quality offer.

As far as tourism superstructure is concerned, the situation is quite different. Tourism superstructure means hospitality facilities, as well as galleries, exhibition, congress and entertainment facilities directly connected with hospitality and sports-recreation facilities or together with them form a single entity. There is no doubt that hospitality facilities are the most significant and numerous segment of the tourist infrastructure and among them, the tourist accommodation facilities. Table 2 gives an overview of accommodation facilities of the Boka Kotorska, according to the statistical review of August 2014.

Table 2 Overview of accommodation facilities of the Boka Kotorska area, August 2014 [4]

Accommodation type	Herceg Novi		Kotor		Tivat		Total	
	No. of facilities	No. of bed places	No. of facilities	No. of bed places	No. of facilities	No. of bed places	No. of facilities	No. of bed places
Hotel	12	2,757	4	670	7	1,068	23	4,495
Garni hotel	2	104	3	72			5	176
Small hotel	13	459	15	373	8	214	36	1,046
Apart hotels	1	56			1	80	2	136
Boutique hotel			1	18			1	18
Houses for rent in households		25,674		5,870		188	0	31,732
Tourist apartments in households		83		280		76	0	439
Rooms for rent in households		1,138		3,992		5,360	0	10,490
Camp	2	385	3	82	1	4	6	471
Holiday homes	3	489	1	141	1	108	5	738
Hostel	1	180	4	350	1	30	6	560
Medical facility	1	1,457					1	1,457
Total	35	32,782	31	11,848	19	7,128	85	51,758

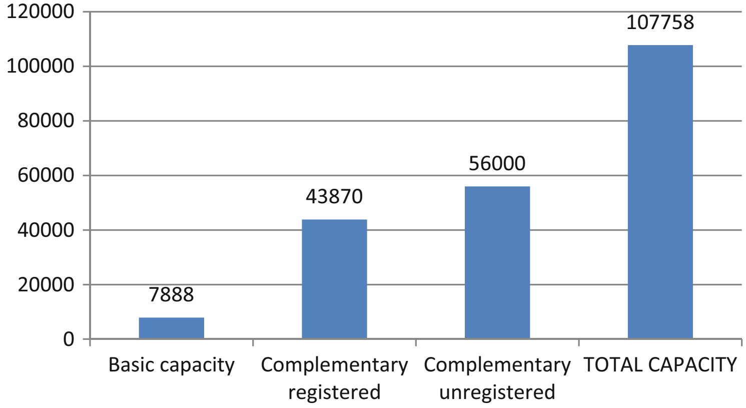

Fig. 2 Overview of accommodation facilities (both registered and unregistered)

Data from Table 2 were derived on the basis of official statistics that does not cover completely the secondary housing. Figure 2 gives an overview of both registered and unregistered (estimated) accommodation facilities [2].

Basic accommodation facilities include all hotel types as well as hotels and medical facilities, while complementary facilities include accommodation in households, holiday homes and camps. As shown in Fig. 2, the basic accommodation facilities account for only around 8% of the total facilities, or around 16% of registered accommodation facilities. Unregistered accommodation facilities include secondary housing facilities, in line with the assessment from the abovementioned review for 2007. It is estimated that the number of these facilities is currently higher by about 30%; however, accommodation structure is quite unfavourable even without the inclusion of the estimated facilities after 2007.

Hotels are, beyond any doubt, the most important segment of the accommodation sector. The overview of the hotel facilities on the territory of the Boka Kotorska Bay is shown in Fig. 3.

As shown, Herceg Novi is the leader in Boka in terms of hotel facilities, with a share of around 58%; the share of Tivat is around 23%, while Kotor is the smallest with 19% share in overall hotel facilities of the Boka Kotorska Bay. Overall, hotel facilities of the Boka Kotorska account for around 16% of the hotel facilities of Montenegro. The standard of hotels in the Boka Kotorska Bay, according to the statistical review of 2014, is the following: five-star 3.5%, four-star 37.62%, three-star 9.50%, two-star 33.97% and one-star 15.41%. The area of the Boka Kotorska Bay registers around 417,000 tourist arrivals, of which 5.5% are domestic, and 94.5% foreign tourists, which makes approximately 24% of the overall tourist arrivals in Montenegro in 2015. The distribution of arrivals by municipalities is shown in Fig. 4.

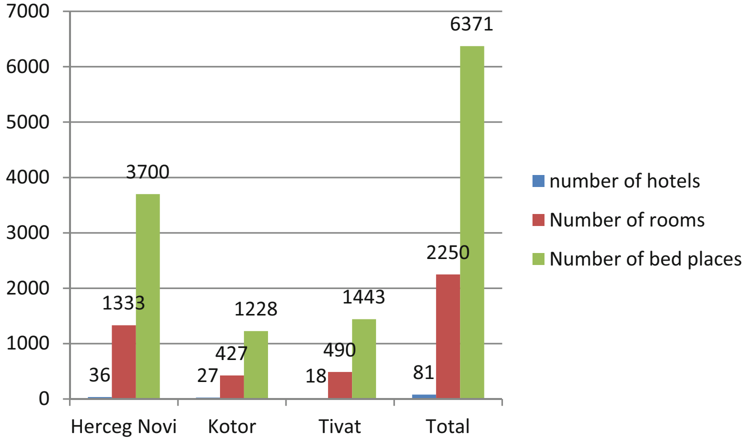

Fig. 3 Overview of hotel facilities of the Boka Kotorska Bay in 2015

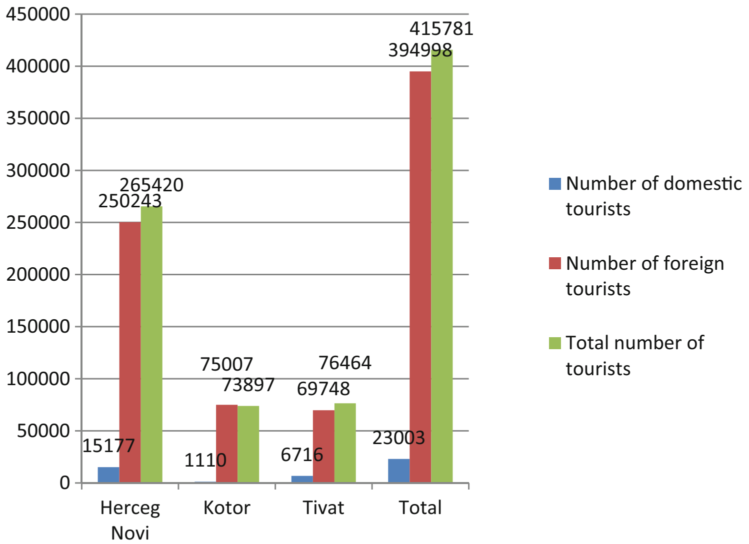

Fig. 4 Distribution of tourist arrivals in the Boka Kotorska area in 2015

By number of arrivals, Herceg Novi is the leader with a share of around 64%, followed by Kotor and Tivat with almost equal shares. Overnight stays have similar characteristics, as shown in Fig. 5.

The total tourist turnover according to data for 2015 is around 3.2 million overnight stays, accounting for around 29% of the tourist turnover of Montenegro, with the share of domestic tourist turnover of about 5.5%, and foreign of 94.5%. The average length of stay of a guest is 7.7 days, which is by 18% above the average for Montenegro. Occupancy rate for overall accommodation facilities in the Boka

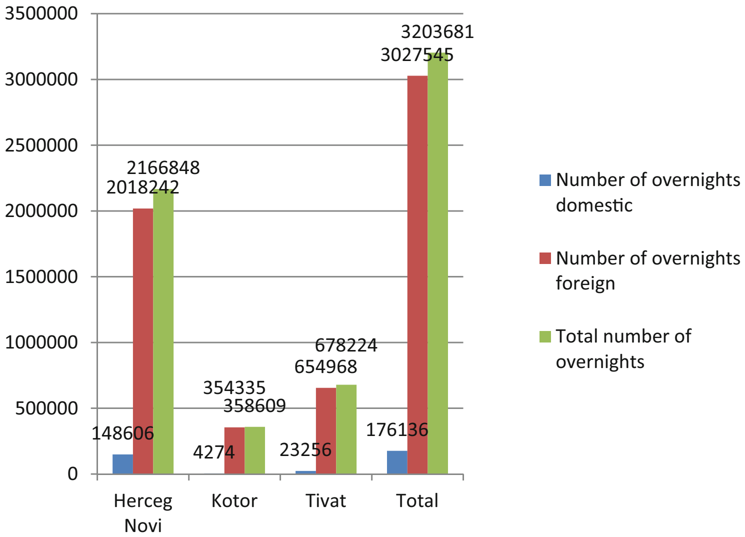

Fig. 5 Distribution of the number of overnight stays in the Boka Kotorska in 2015

Kotorska Bay is 62 days of full occupancy, or 17% annually. These parameters show that the Boka Kotorska Bay is a distinct holiday tourist destination with a pronounced seasonal character.

6.1 Tourism Development Prospects in the Boka Kotorska Region

Prospects and projections of the tourism development in the Boka Kotorska are laid down by tourism development strategies of Montenegro of 2001 [5] and 2007 [6]. The vision of tourism development, according to the Master Plan of 2001, is presented in Table 3.

The Boka Kotorska Bay is not taken as a single tourism cluster, as Tivat was separated from it and attached to the Rocky Coast cluster, along with Budva, Sutomore and Bar. The Master Plan of 2007 (2008) paid more attention to Montenegro's tourism development planning, and thus of the tourism in the Boka Kotorska as well. The planners take the Boka Kotorska as a single cluster (Cluster 3), out of three on the territory of the Montenegrin coast (Cluster 1: Budva–Bar; Cluster 2: Ulcinj). Positioning of the Cluster 3 is expressed by the following determinants: *Cluster 3 Boka Kotorska, Luštica – Bathing, cultural tourism and sports-health tourism.*

Table 3 Vision of tourism development for the Boka Kotorska [2, 5]

Characteristics: Unique nature, culture and small town environment	
Boka Kotorska	Environment: peaceful, expensive and exclusive
Herceg Novi Kotor Perast	Small, well-maintained hotels, pensions, restaurants, taverns, cafés, dancing terraces, swimming in the bay, green areas, cycling and trekking trails, promenades, golf, casino, fitness, health, marinas, boat trips, excursions, museums, music, folklore, galleries, etc. Congresses, meetings and incentives.
Characteristics: gravel beaches and coves, younger audience and lively holidays	
Rocky coast	Environment: family, sports and natural.
Tivat Budva Sutomore Bar	Big and small hotels, private rooms and camping, fast food restaurants, beer gardens, discotheques, modern sports, diving, jet skiing, sports competitions and outdoor celebrations and thematic park Old Bar. Public but clean beaches.

Fig. 6 Perspectives of sustainable tourism in the Boka Kotorska Bay – special interest tours [9]

Sustainable tourism development of the Boka Kotorska can be encouraged by stimulation of ecologically and sociologically "friendly" forms of tourism as shown in Fig. 6 (e.g. special interest tours – speleological, diving, sailing, culinary, kayaking, hiking, biking, photo – and other similar tours).

6.2 Current State of Affairs

The Boka Kotorska Bay is among the most beautiful bays worldwide. It is a unique bay in the Mediterranean, predestined for high-quality individual tourism. Its cultural resources and landscape values are extremely favourable for different tourism types – bathing and sports tourism – regattas of all kinds, competitive rowing training in winter, diving, trekking, hiking, etc. – nautical tourism, health and cultural tourism. With the planned marina, the region takes the shape of an exciting lighthouse project. Other first-class developmental opportunities are Župa near Tivat, military grounds in Kumbor, Saint Marko and the Island of Flowers, healing mud in the bay near Igalo and in particular the Luštica Peninsula.

However, there are still a number of major obstacles to full utilisation of those opportunities in tourism: hazardous, quite distressing road traffic in Herceg Novi and around the Bay, shipyard and industrial ports located in the Bay (Zelenika, Risan), untreated waters burdening the seawater quality (Table 4).

Illegal construction of secondary residence facilities (and planned construction based on poor urban plans) poses a serious threat to tourism development. It represents a major load on environment and infrastructure, so that it sets serious limitations on tourism suprastructure and infrastructure. High concentration of seasonal residents creates unproductive overcrowding of public spaces and bathing sites, and numerous vehicles produce harmful exhaust gasses that pose threat to the environment, air and sea.

Cruise tourism expansion in the Boka Bay, i.e. the increased concentration of large cruise ships, has the same effect as they pose a major threat to maintenance of the cleanliness of the sea and coastal area. Cruise tourism in the Boka Kotorska has

Table 4 Market positioning of the Cluster 3 Boka Kotorska region

SWOT analysis	
Strengths Beauties of the fjord and the mountains connected with the Adriatic, area for water sports in Tivat – Saint Marko, cultural heritage from the times of the Republic of Venice with Kotor (UNESCO's World Cultural Heritage) and Perast, the ring of Habsburg fortresses around the Bay – unique worldwide – almost intact Mediterranean character of the Luštica. Landscape park and touristic park could be made in Luštica	*Weaknesses* Distressing road traffic, environment burdened by industry and ports, insufficient infrastructure, unplanned destruction of the bay with illegal building, regardless of the cultural monuments and the inherited building tradition, generally poor hotel industry
Opportunities For year-round tourism, Cluster 3 probably has the best and multiple opportunities, strengthened further by the vicinity of Dubrovnik, opportunities for cross-border cooperation and the best air connection due to vicinity of the airport Čilipi	*Threats* Further unplanned construction in Herceg Novi, Kotor, Perast and the Luštica Peninsula

shown negative effects on the destination, reflected in obstructing the visual experiences of the town and its surroundings, where enormous dimensions of the ships (docking by the very Town of Kotor) hamper the aesthetic experience of the surroundings, particularly the Old Town of Kotor. High concentration and inflow of tourists from large ships, able to receive several thousand passengers, cause frequent vehicle and pedestrian traffic jams in the central coastal area, causing great dissatisfaction both for residing guests and local population. This adverse effect of cruise tourism definitely results in destination's reduced attractiveness for residing tourists. This is particularly notable in smaller destinations, where adverse effect is more visible. It is beyond doubt that the area of the Boka Kotorska is one of such sensitive destinations. Similar negative experiences of the cruise tourism have been recorded in other destinations. For example, we would like to note that the adverse effect of cruise passengers is the greatest where the number of such passengers is the biggest, which is the case with Dubrovnik. According to an analysis of the Institute for Tourism,[3] almost one in four hotel guests in Dubrovnik (23%) assessed as negative the effect of cruise tourists on attractiveness of their stay in the destination.

For the time being, there are no surveys in Montenegro, but also in Croatia, on effects of cruise tourism on the environment (sea, coast and air). However, there are numerous estimates. It is beyond doubt that cruise ships pollute the air through exhaust gasses and waste incineration. In cities, like Vancouver, studies have shown that air pollution originating from ships in just one day has the negative effect equivalent to 2,000 cars and trucks per annum (Institute for Tourism). Wastewaters from vessels pose a major threat to marine ecosystems, and also for humans who depend on them. Three major wastewater groups are identified: black and grey waters and bilge water. The cruise ship waste composition is very similar to municipal waste (food waste, paper, cardboard, bottles, cans, etc.). Daily accumulation per passenger is estimated at around 3–4 kg. Taking into account that the number of cruise tourists in Kotor in 2013 was around 315,000, the accumulated waste was around 1,260 t.

The National Strategy of Sustainable Development of Montenegro by 2030[4] (Draft document currently in public discussion process) insists, among others, on preservation of the natural resources and introduction of the green economy. In that regard, stopping further degradation of values of renewable natural resources is proposed: biodiversity (water, air and soil), resolution for the problem of unsustainable spatial development generated by unrealistic demands in terms of quantity and quality of constructed environment, along with alleviation of effects of natural and anthropogenic hazards. In the field of green economy, strong support is given to low-carbon economy, improvement of the resources efficiency in key

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[3]Study on Sustainable Development of Cruise Tourism in Croatia, Institute for Tourism Zagreb, 2007.

[4]National Strategy of Sustainable Development by 2030, Ministry of Sustainable Development and Tourism, 2016.

economic sectors, improvement of waste management in transition to circular economy, valorisation and preservation of marine resources, fostering blue economy, support to greening the economy through the promotion and implementation of sustainable forms of production and consumption and greening the public acquisitions. For that reason, in further development, strong support has to be given to development of low-carbon tourism, landscape-friendly construction, preservation of natural resources, revitalisation of rural areas and rural development and all that is in accordance with the strategic guidelines for tourism development in the Boka Kotorska Cluster from the Tourism Development Master Plan of Montenegro by 2020.

Objective of the new positioning:

Vision:	Top offer of the hotel industry and experience in historical Mediterranean environment
Orientation:	Region is focused exclusively on tourist demands and needs in line with the Regional Development Concept for the Boka Kotorska. From Herceg Novi, Kotor, Tivat and Budva, the hinterland as well as the Luštica Peninsula with cycling and hiking trails will be included in the extension of the season
Emphasis:	Emphasis is placed on health with light fitness activities, demanding and challenging sports, such as sailing, diving, competitive rowing, alpine cycling, hiking, cultural programs, events and festivals
Standards:	Top-class hotels and small family hotels of the 3–5-star standard are the backbone of the tourist offer

Future projections for hotel development in the Boka Kotorska are shown in Table 5.

The Master Plan provides for intensified hotel facilities development of the Cluster 3, which is shown also in Fig. 7.

As shown in Fig. 6, significant hotel development is planned, capacity of which in 2020 would be 3.6 times higher than in 2014.

Tourism development strategies of Montenegro [7] paid attention to development of the maritime tourism, and under it the nautical tourism in particular. Marina development projections are given in Table 6.

As shown, out of nine marinas projected, five are on the territory of the Boka Kotorska, share of which in the projected capacity ranges from 55 to 56%. The marina development projection did not include the ongoing project of the mega

Table 5 Hotel development projection for the Boka Kotorska area, 2020 [2]

Hotel facilities development projection, 2020				
Standard	Herceg Novi	Kotor	Tivat	Total
5*****	2,000	500	500	3,000
4****	6,500	2,500	3,000	12,000
3***	4,500	3,500	2,500	10,500
2**	2,000	500	500	3,000
1*				
Total	15,000	7,000	6,500	28,500

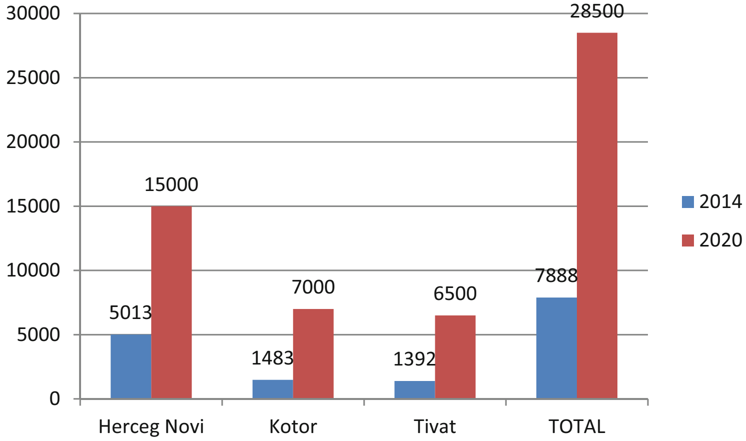

Fig. 7 Hotel development dynamics on the territory of the Boka Kotorska Bay

Table 6 Marina development projections

Marina type	Location	Number	Probability
1 Big service marina	Bar	400–500	High
2 Big service marina	Tivat	400–500	High
3 Standard marina	Ulcinj-Liman	250–300	Low
4 Standard marina	Kumbor	200–250	Medium
5 Standard marina	Cape Kobila	100–150	Low
6 Standard marina	Bigovo	100–150	Low
7 Special (VIP) marina	Kotor	80–150	Low
8 Special (eco) marina	Buljarica	50–100	Very low
9 Special (eco) marina	The Bojana mouth	20–50	Very low
Total		1,600–2,150	

yacht marina, known as Porto Montenegro, whose projected capacity is around 800 berths.

The new Spatial Plan for the coastal zone of Montenegro [8] included also the strategic aspects of tourism development. The projection of development of accommodation facilities is given in Table 7.

The dynamics of the structure of the basic accommodation according to the Spatial Plan are shown in Fig. 8.

As it can be seen, the emphasis is placed on tourist villages (resorts), in difference to the Master Plan that lays emphasis on the hotels, whereby tourist villages are not mentioned as a separate accommodation type. Investors interested in the area of the Boka Kotorska Bay have shown greater interest in development of mega properties than in making hotel investments that are, according to tourism development strategies, given absolute priority. The overview of ongoing mega projects of residential settlements on the territory of the Boka Kotorska are given in Table 8.

Table 7 Projection of accommodation facilities development in line with the Special Purpose Spatial Plan for the coastal zone of Montenegro [3]

Accommodation type	Herceg Novi		Kotor		Tivat		Total	
	2020	2030	2020	2030	2020	2030	2020	2030
Hotels	6,247	7,531	2,440	3,097	5,219	6,568	13,906	17,196
Tourist villages	6,991	9,987	3,577	5,110	7,345	10,492	17,913	25,589
Basic sub-total	13,238	17,518	6,017	8,207	12,564	17,060	31,819	42,785
Camps	385	385	82	82	14	14	481	481
Private accomm.	27,431	25,791	7,498	7,050	5,251	4,937	40,180	37,778
Other	2,462	2,462	367	367	108	108	2,937	2,937
Sub-total complementary	30,278	28,638	7,947	7,499	5,373	5,059	43,598	41,196
Total	43,516	46,156	13,964	15,706	17,937	22,119	75,417	83,981

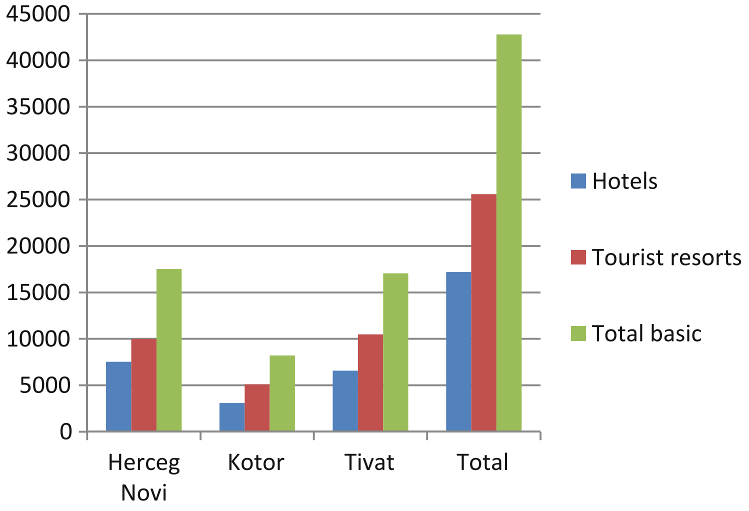

Fig. 8 Projection of development of basic capacities on the territory of the Boka Kotorska area in line with the Special Purpose Spatial Plan by 2030

The previous analysis of developmental strategies and initiated projects shows some strategic wandering. Both Master Plans of tourism development push for sustainable development, controlled and landscape-friendly building and minimizing the construction of residential facilities almost to their exclusion. On the other side, the offered mega investment projects favour mixed agglomerations with pronounced residential component, thus encouraging a far higher degree of construction on the coast than given by the sustainability limit set by the Master Plans of tourism development. The Special Purpose Spatial Plan for the coastal zone of Montenegro, although significantly reducing the construction planning zone,

Table 8 Overview of mega residential projects for the area of the Boka Kotorska

Project	Facilities planned	Investor
Porto Montenegro	Mixed purpose (tourism + residential) Mega marina, hotel, vile, kondo hotel	Adriatic Marinas D.O. O Brand Regent Hotels, 600 mio. €
Lustica Bay	Mixed purpose (tourism + residential) + golf course, 275 residential villas, 271 houses, 1,158 housing units, 8 hotels with 1,260 rooms, golf, wellness, marina...	Luštica Development Brand unknown EUR 1,100 million
Kumbor, One&Only Resort, Kumbor/working title	Tourism (T2) + mixed purpose (residential + tourism) + nautical tourism	Azmont Investments Brand One&Only, 500 mio. €
Saint Marko island	Top-class luxury resort (6 stars) with 93,000 m^2 of gross floor area of various facilities of which 240 are private villas, apartments and houses of lux-class, a hotel	Metropol Group, brand Banyan Tree Hotels and Resorts, 450 mio. €, dormant
Plavi Horizonti	Hotel complex with 170 luxury 5-star apartments and accompanying commercial facilities, spa centre, beach club, restaurant, sports grounds...	Qatari Diar 250 mio. €

Source: own data processing

nevertheless supports the mixed-purpose projects with residential component and thus actually supports the obstruction of the sustainable development in line with the Master Plan of 2007–2008.

7 Conclusion

Tourism industry is the priority branch of Montenegro's economy and the Boka Kotorska Bay is one of its most significant tourist regions. The Boka Kotorska has extraordinary natural, cultural and anthropogenous tourist potential so it is no surprise that this region pioneered many areas of tourism in Montenegro, such as: (a) ***In the field of economy***: This region is where the first Montenegrin *holiday* (pension On the Green Beach, 1902), *organised day-trip* (excursion guidebook *Round Trip from Zelenika through the Boka Kotorska, Shkodra and Montenegro in Five Days*, 1904) and *cruising tourism* began (maritime line with Trieste and Adriatic towns, 1838); (b) ***In the field of tourism development management:*** The first *documented private-public partnership in tourism development* is the Resolution from the big tourism conference called at the Adriatic fjord initiative, held in Kotor on 17 May 1936 with participation of representatives of municipalities, tourism organisations and business associations; the Resolution included a set of progressive provisions aimed at increasing the quality of tourism and transport, need for cooperation among municipalities, drawing up of a single regulation plan, importance of fair and harmonious cooperation of all local authorities and private initiatives, diversification of tourist offer, development of tourism in the hinterland, accurate statistical records, etc and (c) ***In the field of education in tourism:*** The first *Tourism Department* was established at then Maritime College in Kotor and students got the title *economist in tourism.*

On the other hand, despite undisputable opportunities, the tourism in the Boka Kotorska is burdened, first of all by the following: (a) ***Insufficient and unfavourable accommodation structure*** – hotel capacity of the Boka Kotorska accounts for just one-sixth of the hotel capacity of Montenegro and their share in the overall accommodation facilities of the Boka Kotorska is also quite low; (b) ***Pronounced seasonal character*** – although average length of stay is somewhat longer than Montenegrin average, the occupancy rate of accommodation facilities shows that the Boka Kotorska is a distinct holiday tourist destination with a pronounced seasonal character and (c) One of the causes to the two burdens mentioned above can be found in a ***relatively modest tourist infrastructure*** that is not even sufficiently utilised for tourism purposes.

One of main causes of the discrepancy between the opportunities and actual tourism development can be found in the mass tourism era, where different tourist destinations were developed and promoted, although the Boka Kotorska Bay is predisposed for development of specific tourism forms, such as nautical, cultural, health, sports, incentive and congress tourism, special interest tourism and others. At the same time, bathing, holiday tourism remains an important segment of the tourist offer of the Boka Kotorska Bay.

The Boka Kotorska Bay, UNESCO's heritage site, is a unique area and is among the most beautiful destinations in the Mediterranean and beyond. Further development requires adequate planning and implementation, along with the targeted investments into the hotel, tourism and transport infrastructure – investments that paved the way of all successful tourist epochs.

References

1. Bukvić U (2011) Korišćenje prirodnih i kulturnih resursa Boke Kotorske u skladu sa održivim razvojem turizma. Univerzitet Singidunum, Beograd, str 11–27
2. Radović M (1997) Jedan pogled na inicijalnu fazu razvoja turizma u Crnoj Gori. Zbornik radova, Razvoj turizma u Crnoj Gori u XIX i u prvoj polovini XX vijeka, Cetinje. str 113
3. Ratković R (2009) Razvoj hotelijerstva u Crnoj Gori-geneza, stanje i perspektive, IVPE, Cetinje. str. 12-117; 174–175
4. Pasinović M (2002) Neke karakteristike globalnih turističkih kretanja u Boki Kotorskoj u drugoj polovini XX vijeka s posebnim osvrtom na opštinu Kotor. Zbornik radova, Razvoj turizma u Crnoj Gori u XIX i u prvoj polovini XX vijeka, Cetinje. str. 232–236
5. Monstat (2014) Turizam, Smještaj. http://www.monstat.org/cg/. [17.04.2016]
6. Vlada RCG, Ministarstvo turizma (2001) MASTER PLAN: Strategija razvoja turizma do 2020, DEG, Podgorica
7. DEG (2007) MASTER PLAN ZA TURIZAM – Revizija Masterplana iz 2001

8. Grupa autora (2005) Tržišno pozicioniranje, sadržaji i finansijski efekti razvoja nautičkog turizma u Crnoj Gori, GTZ i Ministarstvo turizma CG, Podgorica
9. Vlada CG, Horwath HTL, RZUP, MonteCEP (2015) Nacrt: Prostorni plan posebne namjene za Obalno područje Crne Gore, Podgorica

Agriculture in the Boka Kotorska Bay

Miomir Jovanović, Miljan Joksimović, and Aleksandra Despotović

Abstract The Boka Kotorska covers an area of 616 km^2 and belongs to the coastal region, and it is a large bay on the Adriatic coast. In administrative terms, the Boka Kotorska is divided into three municipalities: Herceg Novi, Kotor and Tivat. By 1960s, agriculture was dominant in the Boka Kotorska, while tourism was in its infancy, as well as other industries. The population engaged in livestock and crop farming and growing maize, barley, rye and wheat. Olive growing was quite developed in the coastal zone. It used to be the most important industry in this area, generating significant income. After the 1960s, with further development of nonagricultural economy, Municipalities of Herceg Novi, Tivat and Kotor experienced population influx and sudden economic prosperity. After urbanization, rural areas became areas with low population density and agriculture as predominant activity referred mainly to households with elderly owners. Since 1970s, shipping industry, tourism, ship building and chemical industry were pillars of the Boka's economic development, while agriculture was neglected, although natural conditions for its development existed.

Based on socio-economic analysis in three Municipalities of the Boka Kotorska, it can be concluded that agriculture was gradually becoming more a symbol of keeping the tradition and culture of this region alive, with its economic importance becoming almost negligible. Analysis of statistical data in the period 1965–2011 points to the fact that agriculture had not been the primary activity of the population of the Boka Kotorska, either at the beginning or the end of the period observed. The reasons for such situation are multiple and complex. They are caused not only by natural but also by social factors.

In the upcoming period, it is necessary to use the favourable climatic conditions, as an important factor of increasing the volume of agricultural production. It is very

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important to put the existing natural resources into the function of agricultural development. It is particularly important to provide support to the production of healthy food and so-called organic farming and processing of Mediterranean crops.

Keywords Agriculture, Development, Livestock farming, Plant production, Rural areas, Socio-economic analysis

Contents

1 Introduction

Montenegro is situated in South-eastern Europe, in the Balkan Peninsula. Its total area is 13,812 km^2 with population of 620,029. Population density of 46 inhabitants per km^2 places Montenegro in the group of countries with the lowest population density. Compared to other countries of the region, its population density is lower than that of Bosnia and Herzegovina (75), Croatia (56.5), Serbia (88.4), Slovenia (102) and Macedonia (83) [1]. Length of Montenegro's coastline is 294 km, and territorial sea covers the area of 2,089 km^2. According to the European Commission Regulation, Montenegro is defined as a single region, with 41% of the EU-28 average, measured by GDP per capita in PPS for 2012. Montenegro is below the EU average development level, and one of key reasons is imbalanced regional development of its three geographical regions: northern, central and coastal [2]. Northern region, covering 52.8% of Montenegro's territory and accounting for 1/3 of its population, is the least developed region in the country. On the other hand, this region disposes the most of the country's natural resources.

Fig. 1 The Boka Kotorska Bay

The Boka Kotorska belongs to the coastal region, and it is a large bay on the Adriatic coast, penetrating into the karst hinterland about 15 km in depth (Fig. 1). The Boka Kotorska Bay covers an area of 616 km^2. It is divided from the open sea with a string of peninsulas (reaching up to 789 m in height) – Vrmac, Luštica and Devesil – with its inner part rising steeply into the mountains Orjen (1,895 m) and Lovćen (1,749 m). In administrative terms, the Boka Kotorska is divided into three municipalities: Herceg Novi, Kotor and Tivat.

The Boka consists of four bays: Herceg Novi Bay and Tivat Bay (outer) and Risan Bay and Kotor Bay (inner) (Fig. 1). Outer and inner bays are connected with the Verige Strait, 340 m in width. The bays of Boka Kotorska were formed during glaciation, by fluvial erosion in soft flysch rocks, while higher slopes of the bay consist of more resistant rocks, mainly Triassic limestone and dolomites. When in postglacial era the sea surface rose by about 100 m, valleys created previously by erosion were flooded and turned into bays. The relief was further modified with karst processes and in higher slopes in the base of the Orjen also by ice tongues descending down the mountain. The slopes around the Boka are very steep, and just one-third of the Bay's terrestrial sides are up to 200 m above sea level. Connection between the Boka Kotorska Bay and the inner part of Montenegro was quite difficult until the early twentieth century. While it was a part of the Austro-Hungarian Empire, the Boka got the road to Njeguši and Cetinje (in 1870s), with 25 hairpin turns. The road was intended for vehicle traffic and had passing places to allow two carriages to pass one another, which are today used by cars. This was the only proper road that connected the Boka Kotorska with the hinterland.

Since 1970s, shipping industry, tourism, ship building and chemical industry were pillars of the Boka's economic development, while agriculture was neglected, although natural conditions for its development existed [3].

2 Overview of Agricultural Development in Montenegro and the Boka Kotorska Bay

In general, agricultural production in Montenegro has a long tradition. However, limiting factors for Montenegro's rural development are agricultural land fragmentation and utilization structure. When at the Congress of Berlin (1878), Montenegro acquired definite international recognition and significant territorial expansion, which included fertile plains, towns and settlements, as well as access to the sea, and thus had preconditions for a faster economic and overall social development. Significant increase in arable area enabled cultivation of more crops than it used to be the case before, but still the main problem of Montenegro's agriculture was its extensive character [4]. During the entire twentieth century, Montenegro was a typical emigration area. Poor economic development, as well as wartime destructions, was the cause to massive emigration of Montenegro's population. After World War II, the net migration balance was negative in all intercensal periods [5]. Economic development after World War II had to a large extent paved the path for further agricultural development. The accelerated industrialization process resulted in decrease in agricultural population, which caused lack of workforce as the main development engine. Intensive industrialization effects in Montenegro resulted in an increasing share of nonagricultural population in general population; reduction in agricultural overpopulation, which was notable before the war; and decline in economic power of rural areas.

Table 1 Agricultural area by land use category, agricultural census 1960 and 2010

	1960	2010	2010/1960
Agricultural area	615,019	516,798	84.03
Arable area	192,903	188,703	97.82

Source: Statistical Bureau – Statistical overview 1947–1965, Statistical Yearbook 2012

2.1 Overview of Agricultural Development in Montenegro

The specific character of Montenegro's agriculture results from available area on one side and multiple diversity in terms of relief, climate, land and water on the other. The soil, as the most important natural resource, is quite diverse, with heterogeneous systematic units, resulting from the conditions of creation. Soils of modest fertility, acid reaction and lighter mechanical composition, often skeletal and shallow, prevail. The total area of agricultural land in Montenegro is 515,740 ha, accounting for 37.4% of Montenegro's territory. Arable land area is 189,075 ha and accounts for 36.66% of the total agricultural area, while the share of nonarable land is 63.33%. Over the past several decades, Montenegro has been undertaking numerous measures at the national level, aimed at further agricultural improvement and development (crop farming, livestock production, fruit growing). These included adopting legislation, establishing public organizations, educational institutions and education of human resources; hiring international experts and financial aid from the budget development, providing incentives for leading producers in agricultural production, etc.

According to the data presented in Table 1, the total agricultural area was reduced by 15.97%. The total arable area was reduced by 2.18%. In the arable area structure, the major decline is recorded in arable fields and gardens (32%), with the major increase recorded in areas under vineyards (244.12%). Area under orchards rose by approximately 40%, meadows by about 9.99%. Area under pastureland decreased by 22.65%, while ponds, fishponds and reeds by 1.24% [6, 7]. Today, Montenegro belongs to the group of European countries with favourable land resources, taking into account that it disposes of 0.83 ha of agricultural land per capita and 0.31 ha of arable land per capita. Despite significant land resources, it is not adequately structured.[1] In the coastal region, the farm structure is the least favourable, while the northern region has the highest percentage of holdings using larger areas of agricultural land. A large area of nonarable land is the result of a large share of pastures in the total agricultural area. One of the main characteristics of the agricultural land structure is fragmentation, resulting both from geographical characteristics of the area and poor utilization of the areas available.

[1] 31.6% of the total agricultural land are plots of up to 0.50 ha. More than half of households (oko 54%) use just 0.10–1 ha of agricultural land. Only 0.9% of family households have land plots larger than 100 ha. Average agricultural household disposes of 4.6 ha of used agricultural land.

Table 2 Regional population structure in Montenegro (1961–2003) – share (%)

	1961	1971	1981	1991	2003
Northern region	46.19	43.44	39.19	37.17	33.01
Central region	36.13	38.28	41.00	42.56	43.30
Coastal region	17.68	18.28	19.81	20.27	23.69
Total	100.00	100.00	100.00	100.00	100.00

Source: Sectoral Study, Spatial Plan of Montenegro by 2020

Table 3 The share of agricultural population in the general population of Montenegro (%)

	1948	1961	1971	1981	1991	2003
Agricultural population	75.40	48.0	42.60	13.00	7.10	5.3

Source: Ž. Andrijašević, Š. Rastoder: The history of Montenegro from ancient times to 2003 [9]

2.2 Regional Population Structure in Montenegro

Abrupt economic prosperity of Montenegro's coast resulted in intensive increase in population, with the most intensive growth in towns and settlements along the coastline. In 1961, 60% of the total population of Montenegro's coastal region lived in the coastal zone of up to 100 m above sea level; in 1991, it was 80%, which shows how attractive the coastal zone is [8]. In rural settlements, population trends vary. In settlements on the very coast or in its immediate vicinity, population growth is recorded; in settlements further inland, particularly in the hilly and mountainous parts, depopulation process is notable.

Table 2 provides an overview of the regional structure of Montenegro's population in the period 1961–2003. In this period, population growth was recorded in the coastal region, while in the northern region, the population decreased as well as their share in the total population of Montenegro.

The rise in population in settlements along the coast is the result of a general migratory wave, from the north to south and with local migrations from the hinterland towards the coast. According to the population census 2011, only 9.1% of the population of the coastal region lived in the settlements in the hinterland, while the migration from the north to south is illustrated with the fact that less than one-third of the population lives on more than 50% of the territory of the state. The main feature of Montenegro's rural areas after World War II was migration. In this period, rural areas were depopulated with migrations towards urban settlements. Table 3 gives an overview of the share of agricultural population in the general population of Montenegro in the period 1948–2003.

The data on trends of agricultural population's share in the general population of Montenegro show its significant decrease over the period reviewed. Compared to other republics of former Yugoslavia, Montenegro experienced the fastest and the most intensive transformation in this regard [10]. The process of increase in nonagricultural and decrease in agricultural population was accompanied by growth in urban and decrease in rural population. Urban population accounts for

Table 4 Montenegro's regions, main indicators

Region	Population	Area (km^2)	Population density	Population	Territory (%)
Northern	177,837	7,304	24.35	28.7	52.9
Central	293,509	4,917	59.69	47.3	35.6
Coastal	148,683	1,591	93.45	24.0	11.5

Source: MONSTAT, Population census 2011

63% of the general population of Montenegro. According to the population census 2011, majority lives in the central region, 293,509 (47.3%), followed by the northern region, 177,837 (28.7%), while the coastal region has the lowest population of 148,683 (24.0%). In the intercensal period, decrease in northern region population was notable, while in the central and the coastal regions, the population rose. Changes occurring as a result of migrations from the north to the coastal region of the country caused also changes in the population age structure, having a negative effect on agricultural development [11]. Average population age in Montenegro is 34. Rural settlements in all municipalities have an age structure[2] different from that in urban settlements, which contributed to imbalanced regional development. Northern region (dominantly rural) accounts for more than 50% of the territory of the state, but it is populated by less than one-third of the population. In the coastal region, 25% of the total population lives on 11.5% of the territory of the state (Table 4).

2.3 *Demographic and Economic Aspect of Agricultural Development in the Boka Kotorska Bay*

By 1960s, agriculture was dominant in the Boka Kotorska, while tourism was in its infancy, as well as other industries. Thus, for example, by 1930s, the Municipality of Herceg Novi covered 18 villages, and hamlets had the population of about 8,000 and approximately 1,900 households [12]. The population engaged in livestock and crop farming and growing maize, barley, rye and wheat. Olive growing was quite developed in the coastal zone. It used to be the most important industry in this area, generating significant income. Quality of the olive oil was good and it was exported in large quantities. In the mountainous hinterland of the Boka, sheep, goats and pigs were bred. According to data from 1936, the Municipality of Luštica, which functioned as an independent municipality in the period 1826–1944, disposed 2,612 ha of land under forests, 602 ha under olive trees, 240 ha under arable fields, 194 ha under pastureland, 55 ha under vineyards, 32 ha under gardens and around 28 ha of barren land. According to the soil structure given, it can be seen that yields could not have met even the half of the needs. There were 98,700 olive trees in

[2]In almost 260 rural settlements, average population age is above 50.

Table 5 Areas, population and population density in the Boka Kotorska in 1900

Tax district	Total area		Arable area – total (ha)				Other areas (ha)	
	I.	II.	a	b	c	d	e	f
Herceg Novi	132,59	127,35	932	23	1.501	521	5.192	4.556
Kotor	102,77	99,06	1.050	7	1.032	386	4.743	2.706
Risan	191,77	189,83	614	265	280	33	10.052	7.739
Total	427,13	416,14	2.596	295	2.813	940	19.987	15.002

Source: Crkvenčić, I., Schaller, A. "Boka Kotorska: društveno-političke promjene i razvoj etničkog sastava do 1918.godine", Hrvatski geografski glasnik 67/2, 2005 [14]

Table 6 Population and population density in the Boka Kotorska in 1900

Tax district	Population	Density (inhabitants/km^2)	
		General	Agricultural
Herceg Novi	9,615	72.3	320.5
Kotor	11,127	108.0	445.1
Risan	5,441	28.3	454.4
Total	26,183	61.3	396.7

Note: I. = total area, II. = taxable land; arable area: a = fields, b = meadows, c = gardens, d = vineyards; other areas: e = pastureland, f = forest

Luštica, and in the highest yielding year, 1928, 36 wagons of oil were exported [13]. Income from fisheries was negligible, as well as income from the famous smoked ham from Luštica. Crop farming was practised in the contact area with the coastline and at the edges of the slopes, where flysch zones were formed.[3] Nevertheless, the arable zone in the Boka was too small to be able to provide living for the large population of this area.

In the period where agricultural production was dominant in the Boka, almost all areas suitable for farming were used (Table 5). Remnants of terraces in the landscape of once farmed areas illustrate former agricultural activities. The possibility to utilize the land was one of conditions for settling in the area.

The data given in Table 6 show that the general population density in the Boka was low, but agricultural (total population per arable land unit) was quite high. Scattered settlements prevailed in the Boka, as a single rural settlement had, on average, 8 settlement parts, with 57 inhabitants on average. This settlement form, with small rural settlements comprising a large number of parts, is the result of differences in lithostratigraphic structure of the area. Settlements along the coast had zones of softer soil – flysch, which is more favourable for cultivation, and for the most part, it was present along the contact zone of the coast and surrounding, higher terrain. These settlements have higher population than the average for the entire area studied. Settlements farther from the coast were more scattered, and some of their parts were connected with smaller and spatially separate areas of

[3]Flysch sequence of sedimentary rocks where marl, sandstone, clayey shale and limestone.

arable land. These settlements were formed in higher elevations, and such position is a result of differences in pedological structure of the soil. These differences influenced the possibility for land cultivation and utilization. Such position of the settlements is also the result of social circumstances of the times in which they were formed. Scattered distribution of settlements was the result of their dependence on arable areas that were separated in space that the population depended on in the period when they engaged in traditional crop and livestock farming. Since coastal areas had more favourable living conditions, migration of population from settlements in higher elevations to coastal settlements was notable. That process caused abandoning of traditional agriculture and engaging in maritime transport and trade [14]. Descent of the population from higher slopes towards the coast resulted in forming new settlement Tivat, where Austrians built an arsenal. Significant part of the population from the hinterland of the Vrmac moved to Tivat, and its total population by 1910 rose to 1,882. During the Austrian rule, Tivat maintained the status of a village.

After 1960s, with further development of nonagricultural economy, Municipalities of Herceg Novi, Tivat and Kotor experienced population influx and sudden economic prosperity. After urbanization, rural areas became areas with low population density and agriculture as predominant activity referred mainly to households with elderly owners. Significant part of the younger rural population lives and works in urban areas, but also takes care of their rural households.

2.4 Geographical and Climatic Conditions in the Boka Kotorska Bay

The framework of the Boka Kotorska Bay is formed by steep slopes of the mountains Orjen and Lovćen as well as ridges that connect them. The terrain and coast of the Boka Kotorska Bay formed of limestone are steep, while flysch slopes are much milder, and in some places they develop into small basin-like and plain-like parts (Fig. 2) [15, 17].

As regards the soil layer in the coastal zone, the narrow plains and coastal fields are characterized by alluvial soils, with terra rossa and limestone chernozem on limestone and cambisol and brown anthropogenic soils on flysch and terraced terrain. Grape vine, olives and tobacco grow well on terra rossa, vegetables in gardens and clover in arable fields. The flysch zone along the northern coast is covered by luxuriant evergreen vegetation (oak, laurel, etc.).

The Boka Kotorska has a mild Mediterranean climate. Average annual temperature is around 16°C. Bora is most common in winter, sirocco in spring and autumn and mistral in summer. Precipitation follows the distribution of winds throughout the year, and it is mainly in the form of rain, rarely snow. Vegetation is lush, giving subtropical appearance to the area. Of cultivated plants, olives, grape vine and figs grow well. In places protected from bora gusts, lemons, oranges and mandarins can

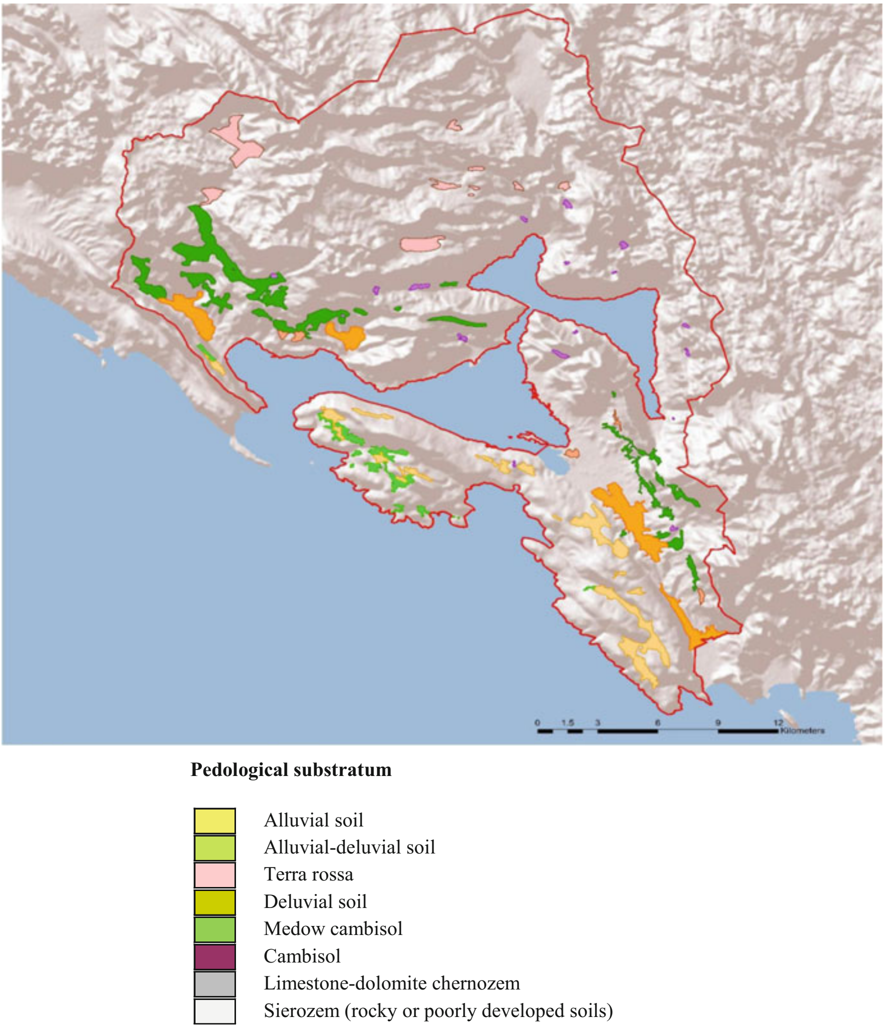

Fig. 2 Graphic overview of rural settlement types and subtypes in the Boka Kotorska Bay

grow. Furthermore, pomegranate, cactuses, cypresses, oleanders, etc. grow in this area as well. Abundant precipitation is typical of the Boka Kotorska, resulting from its relief. Mean annual precipitation is 1,990 mm. Rainfall in the coastal zone varies from around 1,830 mm (near Herceg Novi) to 2,930 mm (near Risan) [14]. Abundant precipitation enhances growth of plankton – fish food – so the bay has rich fish stocks, though limited sea surface [16].

Table 7 Overview of urban and rural population by regions, according to the population census 2011

Region	Population	Urban population		Rural population	
		Number	%	Number	%
Coastal	148,683	86,707	58.30	61,976	41.70
Central	293,509	293,509	79.60	59,869	20.40
Northern	177,837	71,673	40.30	106,164	59.70
Montenegro	620,029	392,020	63.20	228,009	36.80

Source: MONSTAT, Population census 2011

2.5 Rural Area

According to OECD, rural area is an area with population density below 150 inhabitants per m^2. At the regional level, geographical units are classified into three types: predominantly rural (50%), significantly rural (15–50%) and predominantly urban regions (15%). According to this methodology, almost entire territory of Montenegro can be considered rural. The largest share of urban population in the total population is in the central region (79.60%), followed by the coastal (58.30%), and the smallest share is in the northern region – 40.30% (Table 7).

Montenegro's agriculture is characterized by ageing of the rural population and significantly lower education level.[4] In comparison with the EU member states, it should be noted that they, too, have unfavourable age structure: 33% of workforce in agriculture is below 40, 57% between 40 and 65 and 10% 65 and above. According to the Law on Territorial Organization of Montenegro (Official Gazette of Montenegro No. 54/11, 27/13, 62/13 and 12/14), Montenegro is divided into 23 local self-governance units. Coastal region comprises the following municipalities: Bar, Budva, Herceg Novi, Kotor, Tivat and Ulcinj. There is a wide discrepancy in area, population and population density among municipalities. Tivat is the smallest municipality by area (46 km^2), while Nikšić is the biggest (2,065 km^2). According to the settlement size typology, most of the villages in the hinterland of the Boka Kotorska belong to small villages (0–100 and 100–500 inhabitants). Just a small number of settlements fall under the category of medium-sized villages from 500 to 1000 inhabitants (Fig. 3) [15, 17].

2.6 Agricultural Holding

Agricultural holdings are the key entities in agricultural development, and they play an important role in the development of rural areas. Over the past 50 years,

[4]More than 44% of the population is above 55, and 65% above 45. More than half – 55.3% – of employees in agriculture have secondary education, but only 9.1% graduated from college or faculty.

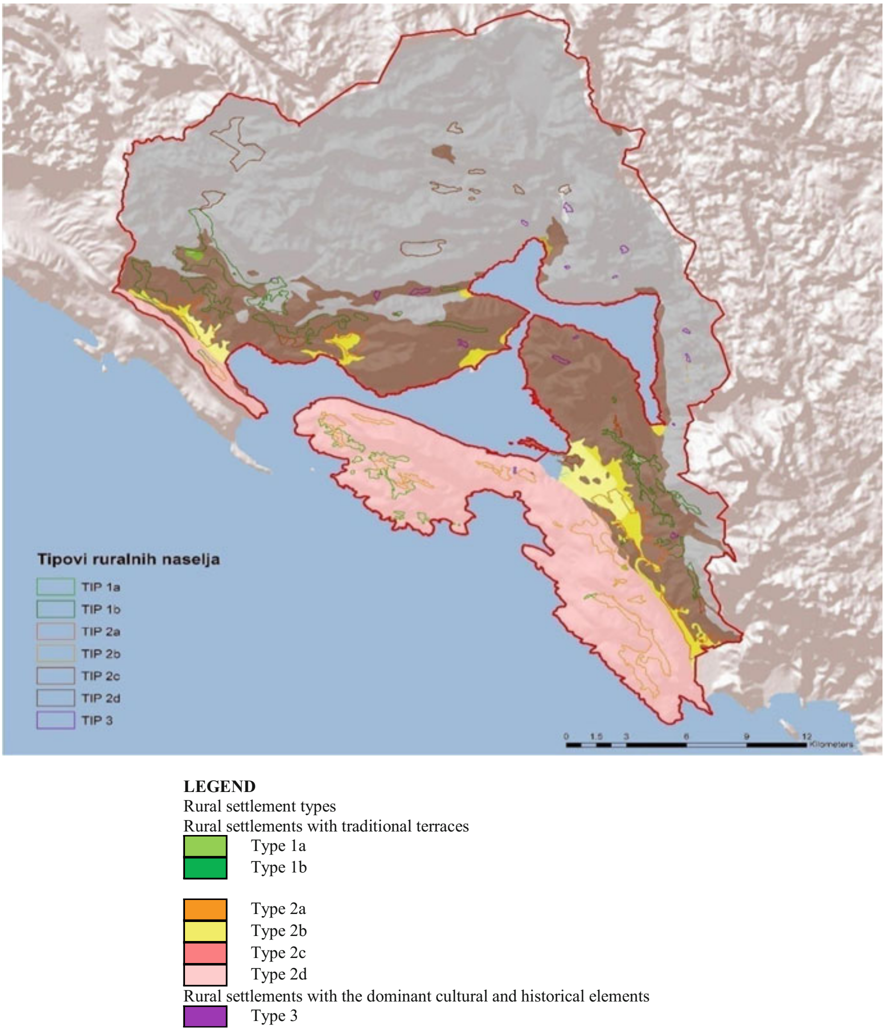

Fig. 3 Soil map overlapped with settlement types

agricultural structure has changed in Montenegro. According to the agricultural census 1960, the total number of agricultural holdings in Montenegro was 64,918, while according to the census 2010, there were 48,824 holdings. Therefore, over the past 50 years, the number of agricultural holdings fell by about 25%. According to the agricultural census 1960, holdings of 1–2 ha have the largest share (18.39%), while according to the census 2010, holdings of 0.1–0.5 ha have the largest share (31.6%). Today in Montenegro, family agricultural holdings make the majority of all agricultural holdings,[5] around 99%, or 48,824, with only 46 enterprises engaged in agriculture. The share of agricultural population in the general population has decreased several times – from approximately 75% immediately after World War II to approximately 6% according to the most recent estimates in the majority of Montenegrin municipalities. The municipality with the lowest number of family agricultural holdings is Tivat, with 169, which is 0.35% of the total number of family agricultural holdings, while the municipality with the largest number is Podgorica, with 7,276 which accounts for 14.89% of the total number of family agricultural holdings [18, 19]. According to the class type by size of utilized agricultural land, 15,418 of family agricultural holdings in Montenegro fall under the class from 0.1 to 0.5 ha or 31.6%. Very few holdings belong to the size class of 100 ha and above, only 425 or 0.87% of the total available land. These data point to the fact that small land plots still prevail in Montenegro. Table 8 provides an overview of family agricultural holdings by class type by size of utilized land in the Municipalities of Herceg Novi, Kotor and Tivat, according to [7, 9].

In the 50-year period analysed, the total number of agricultural holdings has significantly decreased in three Municipalities of the Boka Kotorska, by about 73.34%.[6] According to the latest agricultural census 2010, data on holdings above 5 ha have not been presented, while the census from 1960 shows that the Municipality of Herceg Novi had more holdings of 1–10 ha – 77, compared to the other two municipalities (Kotor and Tivat) [6, 20]. Majority of the holdings above 10 ha in size was in the Municipality of Kotor, compared to Herceg Novi and Tivat. According to the latest census 2010, majority of family agricultural holdings were in the Municipality of Herceg Novi (522) and the lowest in the Municipality of Tivat (169). These data show that over the period analysed, significant changes occurred in the area of the Boka Kotorska. The reduction in total number of agricultural holdings and changes in the structure of utilized land classes are the result of demographic age of settlements surrounding the towns. In this period, the so-called "elderly settlements" were formed, facing the risk of complete depopulation (Fig. 3).

[5] Average agricultural holding in Montenegro disposes of 6 ha of total available land, 4.3 ha of utilized agricultural land, 0.4 ha of other uncultivated agricultural land, 0.2 ha of unutilized agricultural land, 0.8 ha of forest land, 0.20 ha of infertile land and 3.6 livestock units.

[6] According to the census 1960, the total number of agricultural holdings was 3,963, while in 2010 it was 1,053. According to the census 2010, the share of holdings of 0.10–0.50 ha in the holdings structure has risen significantly compared to 1960, by 475 index points.

Table 8 Family agricultural holdings by class type by size of utilized agricultural land, by Municipalities of Herceg Novi, Tivat and Kotor (agricultural census 1960 and 2010)

	Herceg Novi			Kotor			Tivat			Total		
	1960	2010		1960	2010		1960	2010		1960	2010	
	1	2	2/1	1	2	2/1	1	2	2/1	1	2	2/1
Total number of agricultural holdings	1,792	522	29.12	1,621	362	22.33	550	169	30.72	3,963	1053	26.57
LANDLESS	–	31	–	–	6	–	–	6	–	–	43	–
<1.00 ha	658	402		518	306		290	145		1,466	853	
1.00–<10.00	1,069	77		997	30		253	9		2,319	116	
10 and above	65			106			7			178		356

Source: Statistical Bureau – Statistical overview 1947–1965, Statistical Yearbook 2012

3 Natural Conditions and Production Resources of Agriculture in the Boka Kotorska Bay

3.1 Natural Conditions

The territory of the Municipality of **Herceg Novi** which, as a part of the Boka Kotorska, belongs to the south-eastern part of the Adriatic coast is situated between 18°25 and 18°42 longitude and 42°32 latitude. The north-eastern part of the area is surrounded by the Orjen massif (1,895 m above sea level), while to the west it borders Konavle. The territory of the Municipality of Herceg Novi is divided from the Vrmac massif (768 m above sea level) by the Verige Strait, narrowest part which is 300 m in width. The widest part of the Boka Kotorska Bay is in the vicinity of Tivat, 6.5 km [20].

Two international airports (Dubrovnik and Tivat) that receive about 50% of tourist arrivals to the Boka from abroad have a major importance for the development of tourism in the Boka. Population density is 132 inhabitants per km^2.

Specific natural and geographical characteristics, in particular its indented relief and terrain configuration with dominant hilly mountainous environment of the pronounced south-Adriatic and Boka Kotorska identity combined with the bay, have a direct effect on the development of the area of Herceg Novi. Indented relief with steep slopes over the narrow coastal strip is characterized by relatively large strips in higher elevations and limited opportunities for human settlement and their activities.

Herceg Novi has a Mediterranean climate with warm and long summers and short and mild winters. Air temperatures rarely drop below 0 and the number of frost days is very low. The minimum mean temperature occurs in January, of approximately 8–9°C, while the highest is in August, 24–25°C. Herceg Novi, on average, has 105 days with temperatures of above 25°C and 33 days with temperatures above 30°C, with only 3.3 days on average per annum with temperature dropping below 0°C. Average annual cloud cover is quite high, so that means monthly and annual cloud cover in 1/10 of the celestial dome covered is 5.0/10. Most of cloudy days are in November and the least in August. Duration of isolation is around 2,430 h on average per year, or 6.6 h per day. July has the highest average of 11.5 h, and December and January the lowest with 3.1 h.

Abundant precipitation is typical of this municipality as well as the bay as a whole, resulting from high relief conditions. The number of days with precipitation above 1 mm in Herceg Novi is 128 per annum, with its maximum in November and minimum in July. Mean annual precipitation is 1,990 mm. Snow is rare.

Terrain of the Municipality of Herceg Novi has a very complicated geological structure – it is one of the most complex areas in south-eastern part of the Outer Dinarides. Layers of quite variable lithologic composition are present, and their structural position is intensively distorted by tectonic movements. Various Triassic, Jurassic, Cretaceous, Tertiary and Quaternary sediments are present in this area, and a part of the terrain is covered by anthropogenic deposits. Lithostratigraphic units are characterized by different biostratigraphic, fractional and lithologic properties. Both vertical and horizontal changes are quite frequent within them, which shows different sedimentation conditions. Morphological terrain forms are quite pronounced. From the coast towards the mountains, different soil types can be found (Mediterranean terra rossa, mountain terra rossa of the buavica type, shallow skeletal terra rossa or buavica), while in depressions, depositing of the material from the higher terrains resulted in the formation of medium-depth and deep soils. In the zone under the influence of the Adriatic climate, brown coastal soil is formed on flysch, and in the mountain zone, brown humus soil. Activity of rivers and torrential streams along the coastal part formed younger, genetically undeveloped soils, duvium and alluvial-deluvial soils.

In the existing relief, the share of agricultural land is small, the share of forest land is considerable, and the share of infertile land is relatively larger. The ratio of agricultural and forest land had been distorted long ago with expansion of agricultural land, but now, the process is taking place in the opposite direction. Utilization of agricultural areas in Herceg Novi has been marginalized, mainly as an auxiliary or ancillary activity.

Kotor has a specific position in the Adriatic Sea, and it is the most indented part of the south-eastern part of the Dinaric coast. At the south-eastern end of the Kotor Bay, where the sea penetrated the land 29.6 km in depth, the Town of Kotor has settled – the centre of the municipality and cultural, educational and scientific centre. On the territory of the Municipality of Kotor, natural characteristics, notable in the area of the Kotor-Risan Bay, give particular value as they, along with the natural and cultural-historical area of Kotor, are included in the UNESCO's World Heritage list. This area covers the innermost and narrowest part (340 m), cut deeply into the Boka Kotorska Bay. Its formation and morphological characteristics make it the unique bay in the Mediterranean. Population density is 67.5 inhabitants per km^2.

The area of the bay is surrounded by vertical dinaric-coastal limestone slopes, extremely high and thick, one of rare holokarst areas in the world with pronounced karst morphology and hydrology. It is a typical area of the karst hydrology: the highest precipitation in Europe (Crkvice), water sinking, making the slopes waterless and reoccurrence of water in the form of springs on the surface and submarine springs on the sea bottom. The hydrological factor of freshwater and seawater mixing resulted in rich marine flora and fauna.

All climatic types, from the Mediterranean to Alpine, can be differentiated in this small area. This phenomenon results in a diverse vegetation cover. The northern part of the municipality, by the border with the Municipalities of Herceg Novi and Nikšić, has particular natural values. It is characterized by differences in elevation, forests, pasturelands and fertile land. Although with abundant precipitation, the area is waterless and the zone depopulated.

High-quality land on the territory of the municipality is quite scarce and needs to be protected. Agriculture used to be the traditional activity of the rural population of Kotor. However, nowadays, only 0.6% of Kotor's population is engaged in agriculture as primary activity, while for majority of holdings, agriculture is just an auxiliary income source. Most of holdings have less than 3 ha of land, so the current structure does not provide for cost-effective agricultural production. Production of citruses, early vegetables, olives, medicinal herbs and planting material of subtropical crops, as well as greenhouse production, prevails.

Tivat presents borders of Municipalities of Herceg Novi and Kotor and has the smallest area of all municipalities in Montenegro. It covers the area of 4,631.6 ha. Coastal zone area belonging to this municipality covers 746.3 ha. Tivat is the municipality with the highest population density in Montenegro, of 307 inhabitants per km^2 [21].

Tivat has Mediterranean climate with mild and rainy winters and clear and warm summers. Mean annual maximum air temperature in the warmest months (July and August) is around 30°C, while in the coldest (January and February) it is 12–13°C. The number of summer days, with air temperature reaching 25°C and above, is approximately 113 per annum, with most of these days in July and August. Precipitations take exclusively the form of rain, most of which occurring in winter, with minimum of rainfall during summer months. Mean annual precipitation is 1,755 mm. According to morphological characteristics and geological structure, three spatial microunits are distinct on the territory of the Municipality of Tivat as follows: Vrmac massif, the Tivat field and Krtola. Krtola is a typical karst area of elevation of up to 200 m, without any surface watercourses. This is where the karst processes are most prominent, with their main characteristics being water sinking and diverse karst relief forms. Although the area of the Boka Kotorska belongs to the dinaric karst, which induces water supply issues, the broader area of Tivat in geological and hydrological terms has a number of specific properties. The Tivat field is made of impermeable flysch and alluvial sediments, enabling normal surface drainage of watercourses. Terra rossa, brown acid soil, alluvial saline soil and alluvial clayey soil can be found on the territory of the Municipality of Tivat. Taking into account soil types, it can be said that the Municipality of Tivat has favourable conditions for organic farming.

3.2 Agriculture on the Territory of the Municipality of Herceg Novi, Kotor and Tivat

In the Middle Ages, the population engaged in crop farming, mainly viticulture, while livestock farming was rare. In the mid-eighteenth century, under the influence of the Venetian Republic, more intensive olive growing began. In current circumstances, land for intensive agricultural production is provided in the Tivat field, while in rural areas, agricultural production is mainly extensive.

3.3 Agricultural Production Potential by Municipalities

One of the natural resources most important for agricultural development is soil. Table 9 gives an overview of agricultural soil by utilization category in Montenegro and in Municipalities of Herceg Novi, Kotor and Tivat, in the period 1965–2010.

In the period 1965–2010, significant changes happened in the structure of agricultural areas in Montenegro,[7] as well as in the coastal municipalities under survey. Total agricultural areas have also decreased in the Municipalities of Herceg Novi, Kotor and Tivat. The largest decrease in total areas in 2010 compared to 1965 was recorded in the Municipality of Kotor, where it was 63.08%, followed by the Municipality of Herceg Novi 41.47%, and in Tivat the reduction was 32.42%. Total arable area, at the level of Crne Gore, has not varied significantly in the period 1965–2010, but in all three coastal municipalities, their area has decreased – particularly in the Municipality of Herceg Novi – by 19.23%. Area under arable fields and gardens decreased both at the level of Montenegro (30.70%) and the Municipalities of Herceg Novi, Kotor and Tivat. The major decrease was recorded in the Municipality of Kotor – 64.83%. Area under vineyards in Montenegro have significantly increased (211%); by municipalities, it can be seen that they rose most in the Municipality of Herceg Novi by 9.19%, while in the Municipality of Kotor, the area under orchards rose by 17.43%. Taking into account the dynamics of trends of total agricultural area, as well as arable area in all three municipalities, it can be seen clearly that in the period 1960–2010, agriculture has slowly becoming a negligible activity of the population. Today, agricultural areas of the Municipality of Tivat account for 0.33% of the total agricultural area of Montenegro. Total arable area of the Municipality of Herceg Novi in 2011 accounts for 0.62% of the total arable area of Montenegro.

3.3.1 Plant Production

Table 10 gives an overview of utilization of arable fields in the Municipalities of Herceg Novi, Kotor and Tivat as well as in Montenegro in general in the period 1965–2010.

According to the data on the manner of use of arable land in Montenegro and Municipalities of Herceg Novi, Kotor and Tivat in the period 1965–2010, it can be seen that the area under arable fields and gardens has decreased,[8] with the major decrease in the Municipality of Kotor, of 64.83%. As a result of favourable climate

[7] At the level of Montenegro, total agricultural area was decreased by approximately 11.80%, while the major drop is recorded in areas under arable fields and gardens, of 30.67%. In the period observed, area under vineyards has significantly grown by about 211 index points, and increase is noted also in areas under orchards by about 34% and meadows by about 12%.

[8] Sowed areas have been decreasing, both at the level of Montenegro and at the level of municipalities. The most notable decrease in total sowed areas was recorded in Kotor and Tivat, by around 83%. In the structure of sowed areas, areas under vegetables are growing, at the level of Montenegro by 80%, while in Tivat it is higher, at about 245 index points. In the municipality of Kotor, in the period observed, decrease in areas under vegetables by 23.43% has been recorded. Area under uncultivated arable fields is growing, mostly in the Municipality of Kotor – 388%. In the three observed municipalities of the Boka Kotorska Bay, potato production is most significant of all vegetable crops.

Table 9 Structure of agricultural areas in Municipalities of Herceg Novi, Kotor and Tivat, 1965–2010

		Total	Total arable areas	Arable fields and gardens	Orchards	Vineyards	Meadows	Pastureland	Ponds, fishponds and reeds
Montenegro	1965	584,673	188,562	65,580	8,880	1,409	112,693	393,621	2,490
	2010	515,798	188,703	45,472	11,970	4,391	126,870	324,447	2,648
	2/1	88.22	100.0	69.3	134.8	311.6	112.5	82.4	106.3
Herceg Novi	1965	14,420	2,387	726	822	174	665	12,031	2
	2010	8,441	1,928	388	694	190	656	6,510	3
	2/1	58.5	80.7	53.4	84.4	109.2	98.6	54.1	150.0
Kotor	1965	15,916	3,059	1,808	545	66	640	12,857	–
	2010	5,877	2,801	636	640	70	1,455	3,073	3
	2/1	36.9	91.5	35.1	117.4	106.0	227.3	23.9	
Tivat	1965	2,533	1,182	420	570	113	79	1,350	1
	2010	1,712	1,166	368	510	100	188	545	1
	2/1	67.5	98.6	87.6	89.4	88.5	237.9	40.3	100.0

Source: Statistical Bureau – Statistical overview 1947–1965, Statistical Yearbook 2012

Table 10 Utilization of arable areas in Montenegro and Municipalities of Herceg Novi, Kotor and Tivat 1965–2010 (ha)

		Arable fields and gardens	Sowed area					Flowers and nurseries	Fallow land and uncultivated arable fields
			Total	Cereals	Industr. crops	Vegetables	Forage crops		
Montenegro	1965	65,582	58,940	41,855	723	10,137	6,225	–	6,642
	2010	45,472	31,025	5,012	125	18,268	7,620	18	14,429
	2/1	69.33	52.63	11.97	17.28	180.21	122.40	–	217.38
H. Novi	1965	2,387	304	44	–	120	140	–	–
	2010	388	175	–	–	132	43	–	213
	2/1	16.25	57.65	–	–	110	30.71	–	–
Kotor	1965	1,808	861	449	6	111	295	–	–
	2010	636	146	11	–	85	50	–	488
	2/1	35.17	16.95	2.44	–	76.57	16.94	–	–
Tivat	1965	420	325	8	–	11	315	–	–
	2010	368	55	10	–	38	7	–	313
	2/1	87.61	16.92	125	–	345	2.22	–	–

Source: Statistical Bureau – Statistical overview 1947–1965, Statistical Yearbook 2012

and other agro-environmental conditions, the Municipalities of the Bay of Boka Kotorska take an important place in terms of number of olive and citrus trees. Olive growing has a long tradition in the Municipality of Kotor.

At the end of the eighteenth century, about one million of olive trees were grown, producing from 2 to 4 thousand tons of quality olive oil, which was then exported to European courts.

Table 11 gives an overview of trends regarding the number of olive and citrus trees and grape vine plants in the period 1965–2010.

On the basis of the analysis of number of productive grape vine plants, it can be seen that the number has been decreasing in all three municipalities, with the sharpest decline in the Municipality of Tivat, by 73%, while the mildest decrease was in the Municipality of Kotor, 11%. Total yield in vineyards has decreased across all municipalities, with yield per vine plant increasing in Herceg Novi by about 66%.

The number of olive trees has increased in the Municipality of Tivat by about 3.43%, while in the other two municipalities, it has decreased. The total yield of olives has grown, most in the Municipality of Tivat, by 314%. Furthermore, yield per vine plant has grown, notably in Tivat and Kotor.

The number of productive orange and mandarin trees is growing, mainly in the Municipality of Kotor, the whole 17 times more than in 1965. Furthermore, the total yield and yield per tree have been increasing, most in the Municipality of Kotor. Today, the number of the citrus trees is the highest in Kotor, accounting for 6.36% of the total number of trees in Montenegro.

3.3.2 Livestock Farming

The analysis of livestock numbers in the Municipalities of Herceg Novi, Kotor and Tivat shows significant decrease in number of animals. The data in Table 12 show that livestock is not the primary agricultural production branch in the observed Municipalities of the Boka Kotorska, which is in concordance with the historical heritage of the area, because livestock farming was present only in the hinterland.

Nowadays, the average share of cattle in the Municipality of Herceg Novi in the total cattle number in Montenegro ranges from 0.71%, in the Municipality of Kotor 0.7%, and in the Municipality of Tivat 0.06%. These shares are similar in sheep breeding as well. The average share of sheep numbers in Herceg Novi in the total sheep number in Montenegro is at the level of 0.48%, in the Municipality of Kotor at the level of 0.52% and in the Municipality of Tivat at the level of 0.09%.

3.3.3 Demographic Indicators by Municipalities

Based on data given in Table 13, it can be seen that the population in Montenegro was continuously growing in the period 1948–2011. Likewise, the population was growing also in the Municipalities of Herceg Novi, Kotor and Tivat.

Table 11 Production of grapes, olives and citruses in Municipalities of Herceg Novi, Kotor and Tivat, 1965–2010

		Vineyards			Olives			Oranges and mandarins		
		Number of productive grape vine plants	Yield (t)	Per vine plant (kg)	Number of productive trees	Yield (t)	Per tree (kg)	Number of productive trees	Yield (t)	Per tree (kg)
Herceg Novi	1965	574,070	438.9	0.6	120,746	229.8	1.9	8,080	77.60	9.6
	2010	322,734	336.0	1.0	71,390	343.0	4.8	10,960	198	18.1
	2/1	56.2	76.5	166	59.1	149.7	252.6	135.6	257	188
Kotor	1965	292,600	350.7	1.2	61,866	62.1	1	1,653	3.8	2.4
	2010	261,000	183.0	0.7	40,000	172	4,3	28,000	268	9.6
	2/1	89.2	52.28	58.33	64.6	277	430	1,693	7,052	400
Tivat	1965	460,600	324.2	0.7	62,842	62.7	1	6,529	11.2	1.7
	2010	124,500	88	0.7	65,000	260	4.0	11,000	106	9.6
	2/1	27.0	27.1	100	103.4	414.6	400	168.4	946	564

Source: Statistical Bureau – Statistical overview 1947–1965, Statistical Yearbook 2012

Table 12 Livestock numbers in Municipalities of Herceg Novi, Kotor and Tivat, 1965–2010

		Cattle		Pigs		Sheep		Horses			
Montenegro		Total	Cows and Heifers	Total	Sows and sows of the first farrow	Total	Breeding ewes and dairy ewes	Total	Mares and In-foal yearling mares	Poultry	Bee hives
Herceg Novi	1965	2,362	1,654	1,095	11	5,207	1,237	234	114	–	–
	2010	631	470	–	–	1,036	585	49	–	2469	–
	2/1	26.71	28.41	–	–	19.89	47.29	20.94	–	–	–
Kotor	1965	2,074	1,384	652	–	3,843	2,909	256	81	–	–
	2010	653	653	–	–	1,120	1,100	16	–	201	239
	2/1	31.32	47.18	–	–	29.14	37.81	6.25	–	–	–
Tivat	1965.	374	313	–	–	162	136	102	30	–	–
	2010	49	30	60	10	227	227	–	–	1,022	–
	2/1	13.10	9.58	–	–	140	166.91	–	–	–	–

Source: Statistical Bureau – Statistical overview 1947–1965, Statistical Yearbook 2012

Table 13 Population by municipalities, by censuses

	1948		1971		2003		2011	
	Number of households	% share	Number of households	% share	Number of households	% share	Number of households	% share
Montenegro	377,189	100	529,604	100	620,145	100	620,029	100
Herceg Novi	12,482	3.31	18,368	3.50	33,034	5.30	30,864	4.98
Kotor	14,124	3.70	18,917	3.60	22,947	3.70	22,601	3.65
Tivat	5,030	1.33	6,925	1.30	13,630	2.20	14,031	2.26

Source: Statistical Bureau – Statistical overview 1947–1965, Statistical Yearbook 2012

Table 14 Households by municipalities, by censuses

	1948		1971		2003		2011	
	Number of households	% share	Number of households	% share	Number of households	% share	Number of households	% share
Montenegro	83,639	100	121,911	100	180,517	100	194,795	100
Herceg Novi	3,485	4.2	5,373	4.4	11,076	6.1	11,133	5.7
Kotor	3,940	4.7	5,317	4.4	7,290	4.0	7,649	3.9
Tivat	1,484	1.8	1,997	1.6	4,502	2.5	4,862	2.5

Source: Statistical Bureau – Statistical overview 1947–1965, Statistical Yearbook 2012

According to the latest population census 2011, Municipalities of Herceg Novi and Kotor have recorded population decrease compared to 2003. The population index in Kotor is 73.2. In rural areas, population trends vary. In settlements closer to the coast or immediately behind, the population is growing, while in settlements in the hinterland, particularly in the remote hilly and mountainous terrain, depopulation process continues. According to the census 2003, the share of agricultural population of Montenegro was 5.3%. The share of agricultural population of the Municipality of Herceg Novi in Montenegro is 0.64%, Kotor 0.44% and Tivat 0.18%. When it comes to the share of the agricultural population in the total population of these municipalities, these are the figures: in Municipality of Herceg Novi at the level of approximately 0.64%, in Kotor at the level of 0.63% and in Tivat at the level of 0.44% (Table 14).

The number of households has been growing from one census to another, so that the number of households in the Municipality of Herceg Novi is higher by 219% in 2011 than in 1948, in Kotor by 94% and in Tivat by 227%. According to the latest population census 2011, Herceg Novi had the highest share of households in Montenegro (5.7%). In the period observed, the Municipality of Tivat has experienced the biggest changes. These concern both the population and share of agricultural resources of the Municipality of Tivat in the total agricultural resources of the Boka Kotorska and Montenegro.

4 Possible Agricultural Development Directions for the Boka Kotorska Bay

The analysis of available resources highlights as main characteristics of rural areas on the territory of the Boka Kotorska, first of all, the fragmented plots, non-commercialized agricultural production of the holdings, not sufficiently developed rural infrastructure and negative demographic trends. One of the main limitations is also the change of purpose of agricultural land and its transformation into urban, construction land.

In the process of designing possible directions for agriculture and food production development on the territory of the Boka Kotorska, in addition to relief, climatic, soil and other specific characteristics, the strategic documents adopted as well as major internal factors need to be taken into account [22–24]. In general, the sustainable development concept, as the only acceptable model for future development of Montenegro's agriculture, has to be a logical framework to agricultural development also in the area analysed. This concept lays emphasis on support defined by the rural development policy, as follows: strengthening competitiveness, sustainable management of resources and a comprehensive rural development programme. Encouraging the production of healthy food and so-called organic farming is very important, in particular the production and processing of Mediterranean crops.

Objectives and principles at the local level are set in accordance with the spatial plan of Montenegro. Development on the territory of the Municipalities of the Boka Kotorska should be based, above all, on comparative advantages of the area, in accordance with objective implementation which is feasible in the upcoming period. The analysed area should be dominated by agricultural activities and orientation focused on production of citruses, early fruit, olives, medicinal herbs and planting materials of subtropical plants as well as greenhouse production. The market logic imposes also modified production orientation, where necessary. In the upcoming period, it would be necessary also to work on improvement of the system of innovations, standards, food safety, product quality, etc.

Regardless of the pronounced shortcomings, the hinterland of the Boka Kotorska provides extraordinary opportunities for connecting rural tourism development with agricultural development. The process of enhancing agricultural development in the forthcoming period has to be based on an improved interaction between rural development and development of agricultural holding in the municipalities analysed. Favourable climate, preserved nature, soil and others provide significant advantage for breeding and production of various plant species. The emphasis in development and advancement of agricultural production in the forthcoming period should be laid on optimal utilization of available agricultural resources in plant and livestock production and on improvement of the quality of agricultural products and their better market valorization. Development of agricultural activities as the main or auxiliary income source for rural population is also one of the most important instruments in curbing the negative trend of hinterland depopulation. Furthermore, it is necessary to work on improvement of regional marketing of agricultural products by strengthening the link between agricultural production and tourism. It is particularly important to protect the existing potential of agricultural land, and further transformation of agricultural land into development land should be done in strictly controlled procedures. Construction of the Porto Montenegro and announcements of further investments in the high-end tourism imply technological improvement of agricultural holdings with supply of equipment necessary for animal farming, as well as land cultivation machinery, orchard equipment, etc. Protection of geographical origin of the products specific for this area entails more intensive professional training for producers through delivery of various specialization trainings and organization of promotional activities for specific products in local events and through participation in exhibitions and fairs in the country and abroad.

5 Conclusion

By the 1960s, agriculture was a dominant activity in the Boka Kotorska, while other industries were at their infancy. In this period, almost all available area was used for agricultural production. After the 1960s, the beginning of nonagricultural economic development resulted in influx of population in Municipalities of Herceg Novi, Tivat and Kotor, as well as their sudden economic prosperity. Following the urbanization, rural areas become areas with low population density and employment in agriculture mainly referred to senior households. Population grew in settlements in the hinterland, while the population in hilly and mountainous areas decreased considerably.

In the period analysed, demographic system was distorted, which also resulted in changes within agricultural activities, particularly in terms of decrease in available workforce, etc. Based on socio-economic analysis in three Municipalities of the Boka Kotorska, it can be concluded that agriculture was gradually becoming more a symbol of keeping the tradition and culture of this region alive, with its economic importance becoming almost negligible.

Analysis of statistical data in the period 1965–2011 points to the fact that agriculture had not been the primary activity of the population of the Boka Kotorska, either at the beginning or the end of the period observed. The reasons for such situation are multiple and complex. They are caused not only by natural but also by social factors. From decade to decade, agriculture has been increasingly marginalized due to numerous factors that can be divided into two groups. The first group includes natural factors, i.e. climatic geographic, while the other includes elements from the socio-economic development that naturally includes both sociological and culturological ones. Analysis of their effect provides an inspiring field for future multidisciplinary research activities. The Municipality of Tivat is the best example of dynamics of agricultural development and changes typical of the entire area of the Boka Kotorska.

In the upcoming period, it is necessary to use the favourable climatic conditions, as an important factor of increasing the volume of agricultural production. It is very important to put the existing natural resources into the function of agricultural development. It is particularly important to provide support to the production of healthy food and so-called organic farming and processing of Mediterranean crops.

References

1. World Development Indicators 2014. World Bank, Washington, doi:10.1596/978
2. Spatial Plan of the Republic of Montenegro by 2020 (2008) Ministry of Environmental Protection, pp 1–180
3. Maritime Encyclopedia (1972) Tom 1-8, Yugoslav Lexicographic Institute, Zagreb, 1972–1989
4. Knežević S, Jovanović M (2016) Economic development of agriculture in Montenegro in the period from 1878–1914. Agric For 62(1):275–289, Podgorica
5. Despotović A, Joksimović M, Jovanović M (2016) Regional demographic problems and their impact on the development of agriculture in Montenegro. Agric For 62(1):275–289, Podgorica
6. Statistical Bureau – Statistical Review (1947–1965), Titograd, pp 10–60
7. Statistical yearbook of Montenegro 2012. http://www.monstat.org/userfiles/file/publikacije/godisnjak%202012/GODISNJAK%202012-
8. Doderović M, Ivanović Z (2015) Demografski profil crnogorskog primorja. Matica crnogorska 63:449
9. Andrijašević Ž, Rastoder W (2006) History of Montenegro from the ancient times to 2003, the Center for Emigrants from Montenegro. Podgorica 1–302
10. Vujošević N (1990) Promjene u seoskoj porodici Crne Gore, Beograd, SANU, 1990:92–95
11. Statistical Bureau (2008) Demographic Trends and Projections in Montenegro, Podgorica
12. Crnic M (1972) Iščezava još jedno zanimanje-Maslinarstvo, "Boka", 4, Zbornik radova iz nauke, kulture i umjetnosti, Herceg Novi, p 173
13. Crnic M (1976) Prilog o ekonomsko-migracionim kretanjima iz luštičke opštine, "Boka", 8, Zbornik radova iz nauke, kulture i umjetnosti, Herceg Novi, pp 233, 234
14. Crkvenčić I, Schaller A (2005) Boka Kotorska: društveno-političke promjene i razvoj etničkog sastava do 1918.godine. Hrvatski geografski glasnik 67/2:115–116
15. Fuštić B, Djuretić G (2000) Soils of Montenegro. Biotechnical Institute, University of Montenegro, pp 1–626
16. Radojičić D (1984) Ribarstvo u Boki Kotorskoj od XIX do naših dana, "Boka" (15-16), Zbornik radova iz nauke, kulture i umjetnosti, Herceg Novi, pp 194–195
17. Čurovic Ž, Popović SG (2014) Typological classification of settlements in the rural hinterland of the Bay of Boka Kotorska. Agric For 60(4):275–289, Podgoric
18. Statistical Bureau (2011) Agriculture Census 2010, Structure of agricultural holdings, topics of special interest, Podgorica. http://monstat.org/eng/page.php?id=185&pageid=58
19. Statistical Bureau (2012) Agriculture Census 2010, Structure of agricultural holdings – We know what we have, Podgorica 2012, p 17. http://monstat.org/eng/page.php?id=185&pageid=58
20. Spatial plan of municipality Herceg Novi till 2020, Herceg Novi, pp 1–239. www.hercegnovi.me/files/PPOHN.pdf
21. Strategy for the Development of municipality Tivat - 2020 (2014), Tivat, pp 1–59
22. Strategy for the Development of Agriculture and Rural Areas 2015–2020 (2015) Ministry of Agriculture and Rural Development, Podgotrica, pp 21–67. file:///C:/Users/User/Downloads/25%20VI%2015%20Strategy%20ch11.pdf

23. Montenegro's Tourism Development Strategy by 2020 (2008) Ministry of Tourism and Environment, pp 1–105. file:///C:/Users/User/Downloads/01%20Montenegro%20Tourism%20Development%20Strategy%20To%202020.pdf
24. National Strategy of Sustainable Development of Montenegro (2007) Ministry of Tourism and Environmental Protection, Podgorica, pp 1–126. http://www.kor.gov.me/files/1207655097.pdf

Integrated Coastal Zone Management in Boka Kotorska Bay

Jelena Knežević and Slavica Petović

Abstract Boka Kotorska Bay is one of the most renowned stretches of the Montenegrin coast and it is the Mediterranean's only fjord. It is a relatively closed ecosystem, which is very sensitive and requires special measures to maintain its environmental as well as developmental status. The specific geographical position and the combination of environmental factors create ecological conditions which are different in many ways from those at the open sea, thus making it a special biotype. At the same time it is area of high interest for tourism development thus being under pronounced pressures by tourism and related urban development. It does not create negative impacts only on marine and coastal ecosystems and natural resources, especially fish stocks, agricultural land, and ecosystem services, but to local economy and sustainability of tourism development. Taking into account the fragility of coastal ecosystems and diversity of activities and uses and their interactions, the Integrated Coastal Zone Management (ICZM) has to be applied in order to provide sustainable management of the coastal zone of Boka Kotorska which includes protection, preservation, and improvement of the environmental status. The application of the vulnerability assessment in determining optimal land uses for the terrestrial part of the coastal zone and marine spatial planning that includes the application of the ecosystem approach in analyzing the status of marine environment and determining the objectives of good environmental status provides comprehensive set of tools to support effective coastal zone management of Boka Kotorska. Therefore further urgent actions are necessary as to enforce

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implementation of ICZM and Marine Spatial Planning instruments and tools in Boka Kotorska.

Keywords Boka Kotorska Bay, Good environmental status, Integrated Coastal Zone Management, Marine spatial planning, Vulnerability assessment

Contents

1 Introduction

Boka Kotorska Bay is one of the most renowned stretches of the Montenegrin coast and it is the Mediterranean's only fjord (Fig. 1). It was inhabited since antiquity and it is rich in biodiversity. Its unique beauty and cultural value have led to Boka Kotorska Bay being added to the list of the twenty-five most beautiful bays in the world. From the physical point of view, the Bay's length is about 28 km from the open sea to the harbor of the city of Kotor, it is surrounded by mountains of Orjen on the west and Lovćen on the east and its narrowest section, Verige Strait, is only 300 m wide. Its shoreline length is 107.3 km [1].

The specific geographical position and the combination of environmental factors create ecological conditions which are different in many ways from those at the open sea, thus making it a special biotype. Certain still preserved parts of the Boka Kotorska Bay are among coastal zone sites where greatest number of habitats of international importance occurs (including marshy habitats). The existing protected natural assets include special nature reserve (Tivat Salinas), as well as the area of Kotor–Risan Bay with the town of Kotor (which is protected under a municipal regulation and is on the UNESCO list of natural and cultural heritage) [2].

Three municipalities are part of Boka Kotorska: Kotor, Tivat, and Herceg Novi. Boka Kotorska Bay coastal and marine environment provides the local population with the live hoods necessary for their well-being and the local economy is mainly based on tourism and other services (primarily trade), maritime activities, and to a smaller extent on industry, aquaculture, fisheries, and agriculture. Thanks to tourist activities it is one of the richest areas in Montenegro and a further expansion of

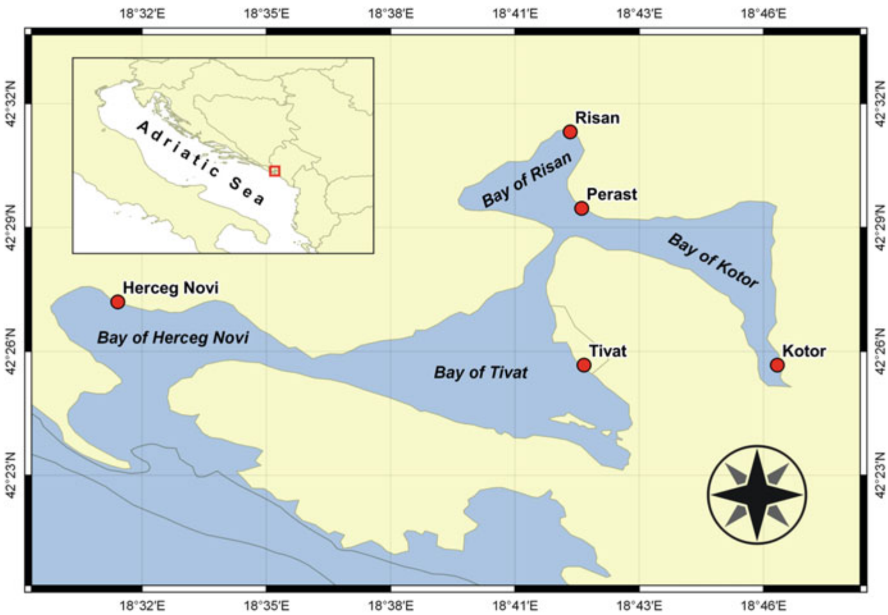

Fig. 1 Boka Kotorska Bay

tourism is expected [3]. However the pressure generated by urban development has already damaged natural resources and constitutes a risk for its ecosystems and consequently for the local economy as a whole.

2 Integrated Coastal Zone Management in Boka Kotorska

The Integrated Coastal Zone Management (ICZM) is dynamic process for the sustainable management and use of coastal zones, taking into account at the same time the fragility of coastal ecosystems and landscapes, the diversity of activities and uses, their interactions, the maritime orientation of certain activities and uses, and their impact on both the marine and land parts [1]. As the key component of the Coastal Area Management Programme of Montenegro that was realized in cooperation of the Government of Montenegro and UNEP/MAP, the vulnerability assessment was applied in the coastal area of Montenegro as the methodological approach that supports implementation of the core set of ICZM instruments and tools. It was primarily conducted with the objective to contribute to protection, preservation, and improvement of the environmental status of the coastal area of Montenegro in line with national legislation and commitments accepted at ratification of the Barcelona Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean and its protocols. Boka Kotorska Bay was selected as the geographic area for vulnerability assessment with application of

Ecosystem Approach (EcAp) as a relatively closed ecosystem, which is very sensitive and requires special measures to maintain its environmental as well as developmental status. Mediterranean Action Plan states that EcAp recognizes the linkages between various habitats, and between the environment and the biota it supports, and the economies and human well-being of coastal communities [4]. It allows priorities for management to emerge, and at the same time, creates efficiency in addressing management and conservation needs. In addition, the UN Convention on Biological Diversity defines the EcAp as a strategy for the integrated management of land, water, and living resources that promotes conservation and sustainable use in an equitable way.

In general terms, vulnerability is defined as a state of the environment, space, soil, or phenomena that can cause negative impacts on the environment in case certain interventions are implemented. Vulnerability assessment, i.e., determination of sensitivity or susceptibility of space is a method (a mechanism, task or process) that determines more vulnerable spatial segments for a given intervention or activity [5]. The purpose of vulnerability assessment is to determine those parts of space where it is less suitable or unsuitable to plan certain activities or interventions. In the context of preparing analyses needed for spatial planning and environmental protection and in the spirit of the Protocol of Barcelona Convention on ICZM in the Mediterranean, Assessment of General Vulnerability was prepared within CAMP MNE based on vulnerability of individual environmental segments. Degree of spatial vulnerability derived from the assessment of general vulnerability does not depend on potential impacts of individual activities or interventions but on (individual) characteristics, i.e., value of space.

Detailed Vulnerability Assessment of the Narrow Coastal Zone represents an amendment to the Assessment of General Vulnerability [6]. The purpose of this analysis was primarily to prepare expert baselines for identification of areas where conditions exist for expansion of the coastal set back, i.e., of the zone where construction along the shore is limited or prohibited in line with the ICZM Protocol. Therefore for the purpose of assessing vulnerability of the narrow coastal zone detailed analyses have been realized as follows:

– habitats mapping for selected locations (Velika plaza in Ulcinj, Buljarica, Platamuni, and Tivat Saltpans) and assessment of their vulnerability;
– erosion map of the immediate coastline;
– study of seismic categorization of space in coastal municipalities of Montenegro;
– study of storms in the Montenegrin coastal region; and
– sea level rise study.

3 The Vulnerability Assessment of the Boka Kotorska

Understanding the complementary of application of ICZM concept that includes the vulnerability assessment in determining optimal land uses for the terrestrial part of the coastal zone to the application of marine spatial planning that includes the application of the ecosystem approach in the analysis of marine environment provides the instruments and tools for optimizing various planned uses of the land and the sea. Limitations and possibilities in the application of the vulnerability assessment with EcAp were shown for the Boka Kotorska Bay in the framework of the Coastal Area Management Programme – CAMP activities. As marine and coastal functions and the good environmental status of marine and coastal ecosystems are important for the well-being of the population, the vulnerability assessment with application of EcAp recognizes that development of an area and the health of its environment are linked. Because marine and coastal ecosystems provide valuable natural services, or "ecosystem services," enhancing and protecting their good environmental status is important to make sure that they provide their services sustainably in a long term.

Concentration of different activities in this part of the coast is very high, and pollution problems (due to communal wastewater, maritime activities, and industry) are expressed, exacerbated by the enclosed nature of the Bay and slow exchange of water with the open sea. Pressures from urbanization and tourism development are substantial. A number of major infrastructure projects are planned or being considered, which may have an impact on the area. These first of all include a bridge over the Bay of Boka (Verige bridge) and Adriatic speedway. Areas for intensive agriculture and an industrial zone are also being planned. There is also a pressure to increase volume of maritime transport within the Bay and its port capacities [3].

Taking into account complexity of nature and human interactions, the Coastal Area Management Programme (CAMP) of Montenegro analyses shows high sea vulnerability in the Bay of Boka and at open sea. Marine ecosystems in the Bay of Boka are highly vulnerable, especially in the Bay's narrow part, in the section between Bijela Shipyard and Porto Montenegro Harbor, as well as in Igalo Bay. It should also be pointed out that the entire narrow coastal belt of the open sea and the Bay of Boka is highly vulnerable in case of accidental pollution (such as oil spills due to maritime accidents). Water quality in the Bay of Boka is intermediate [5]. The reason is high content of nutrients and chlorophyll *a*. Level of pollution at the open sea is lower due to relatively big depth and good mixing of waters [5]. Pollution assessment indicates urgent remediation measures are needed for *hot spot* location and for regulating sewage systems in Kotor and Tivat Bays.

Applying the MEDPOL criteria (depending on the value which is calculated for each individual hot spot, they are classified into four categories: A, B, C, or D) for

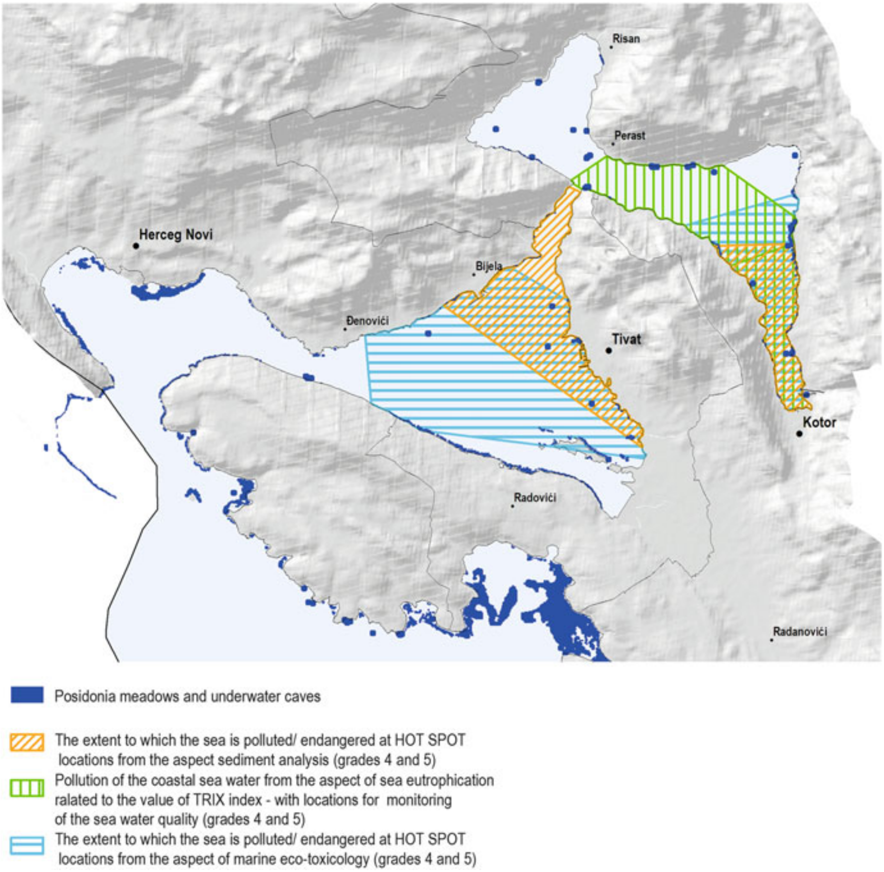

Fig. 2 Integrated overview of the most important biodiversity components and of the most polluted areas (*source* – the National Strategy for Integrated Coastal Zone Management of Montenegro-MSDT)

scoring potential hotspots in the Boka Bay: Port of Kotor, Port of Herceg Novi, Kotor Bay near the Institute of Marine Biology – IMB, Port of Tivat, Port of Risan, Bijela Shipyard, and the site of the former Overhaul Institute – Arsenal in Tivat, generated the results according to which Shipyard Bijela is hot spot type B, while all other locations belong to sensitive area type C [7]. The locations with high pollution levels of seawater, soil, and sediments with priority pollutants, such as Shipyard Bijela, belong to hot spot type B.

Figure 2 shows the most important biodiversity sites and the most polluted areas (hot spots) (Fig. 3). High concentration of hot spots with high level of pollution in a relatively small area indicates that internal waters of the Bay are the most endangered ones.

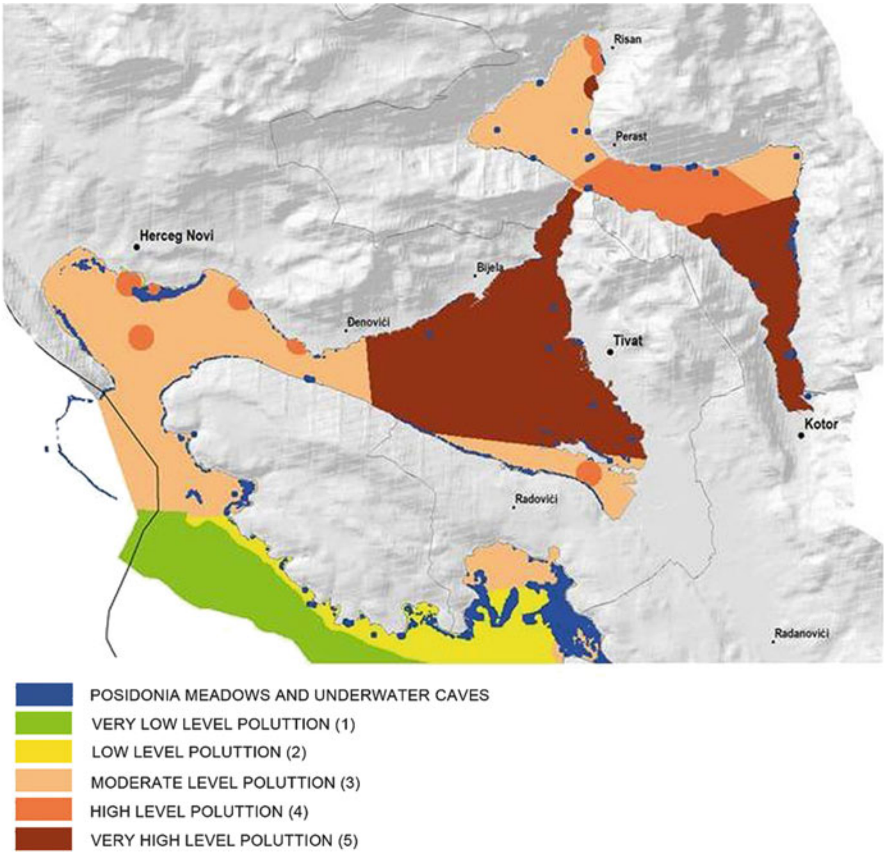

Fig. 3 Ranking of pollution impacts and distribution of biodiversity components (*source*: the National Strategy for Integrated Coastal Zone Management of Montenegro-MSDT)

Under conditions of A2/2071–2100 scenario, the entire coastal region is an area where the most significant impacts of droughts, forest fires, and strong rains during a year are likely to occur. It indicated that strong rains would have the highest impact in the Bay of Boka hinterland. Montenegrin coast towards the open sea does not have natural wave protection in the form of a chain of islands or reefs. That is why the coast is exposed to destructive waves and highly vulnerable to them. Impact of waves in the most of Boka Bay is moderate, with the exception of Herceg Novi Bay and some locations where there are larger fetches. A common feature for these locations is that they have a low shore and are thus more vulnerable to flooding caused by storm waves [6]. Having in mind intensity of storms, their movements, and consequences they can cause, as well as geometry of Montenegrin coast (at some points, slope of the shore is low, there are semi-enclosed coves and bays, and river mouths), a number of areas were singled out and assessed as moderately to highly vulnerable to storms. A major part of Boka Bay has moderate vulnerability level to the storm impacts [6].

Sea level rise is a problem that is being researched in numerous scientific circles, therefore a large number of various projections that can substantially differ among themselves are available. Projections derived from climate models recommended by the Intergovernmental Panel on Climate Change (IPCC) as well as projections based on semi-empiric methods of certain authors have been taken into account in the analysis of the sea level rise in the Montenegrin coastal zone. Transference of the projected sea level rise for the Montenegrin coastal zone into space was done only through application of the digital terrain model, without using techniques to downscale global models to regional level and by taking into account changes of the sea level in the Adriatic basin [6]. Effects caused by strong winds and waves have not been considered in the assessment of the sea level rise for Montenegro's coast. In line with chosen method of work and by taking sea level rise projections, the following vulnerable areas in Boka Kotorska Bay have been assessed in order to determine locations where conditions for expanding the coastal set back exist: mouth of Sutorina River (Fig. 4), Kostajnica–Risan (Fig. 5), north-western part of Vrmac (Fig. 6), and Tivat Saltpans (Fig. 7). Analysis of individual areas assessed as vulnerable in terms of formulating proposal for the coastal set back expansion is presented in the tables in subsequent sections [6]. One of the key requirements of the ICZM Protocol refers to introduction of the construction setback line at a minimum of 100 m from the shore. The Protocol requires that public services and activities are given priority, whereas projects of public interest are also important when adaptation cases (less than 100 m) in applying the coastal setback are determined. The tables include the most significant vulnerability aspects that have been covered in detail in the Assessment of General Vulnerability of the Coastal Zone and in individual analyses and studies prepared for the Vulnerability Assessment of the Narrow Coastal Zone.

3.1 Sutorina River Mouth

Coastal ecosystem:	No
Nature protected area:	No
Erosion:	No
Seismic vulnerability:	Yes, very high seismic vulnerability
Groundwater:	No
Impact of storms and sea level rise:	Yes, area of flooding due to impacts of storm waves, and a probable impact of sea level rise upstream Sutorina: mouth of Sutorina river, even though located in the Bay of Boka, is exposed to the activity of high waves coming from southern direction through the Bay's entrance; coast at river mouth is low, partly flooded, whereas larger areas can be flooded in case of cumulative impact of sea level rise.
Non-built areas:	Area between the coastline and walking corridor is partly developed (built); a small non-built area designated for development is located along the very river
Location specificity:	Yes, zone of peloid deposits in the hinterland
Proposal for expanding coastal set back:	Yes, expansion of the coastal set back is proposed – it is sensible to limit construction in order to preserve peloid deposits (area's surface is 32.17 ha)

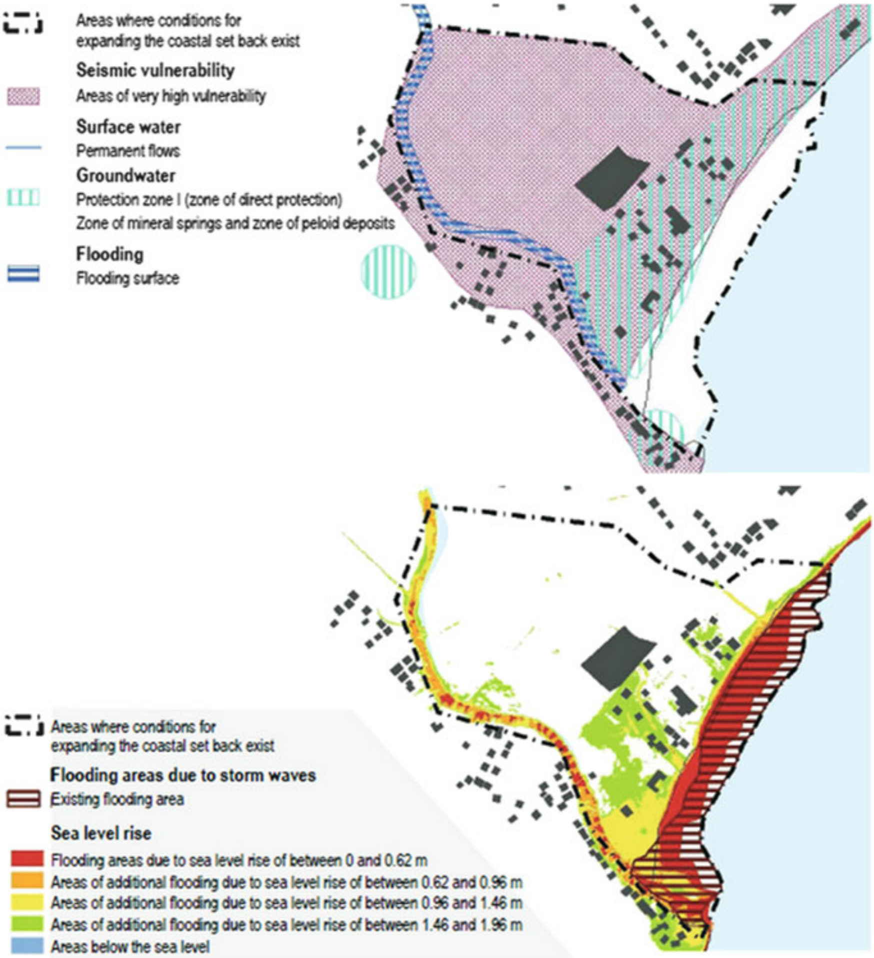

Fig. 4 Integrated assessment of the Sutorina River Mouth (*source*: the Vulnerability Assessment of the Narrow Coastal Zone-MSDT)

3.2 Kostanjica–Risan

Coastal ecosystem:	Yes, coastal holm oak forest – black oak (Orno-Quercetum Ilicis) community especially important for biodiversity of the Mediterranean coastal zones
Nature protected area:	Yes, Kotor-Risan Bay is protected under municipal decision and also an area listed as UNESCO's natural and cultural heritage
Erosion:	Yes, from place to place moderate to strong erosion (illustration 2)
Seismic vulnerability:	Yes, from place to place very high seismic vulnerability
Groundwater:	No
Impact of storms and sea level rise:	Yes, sea level rise impact at the mouth of Morinjska river
Non-built areas:	Partly developed area, with smaller settlements located along the shore
Proposal for expanding coastal set back:	No, due to steep slopes, expansion of the coastal set back is not sensible – construction should be directed towards completion of the existing settlements; expansion is proposed at the mouth of Morinjska river where significant impact of the sea level rise is expected (surface of the area: 3.61 ha)

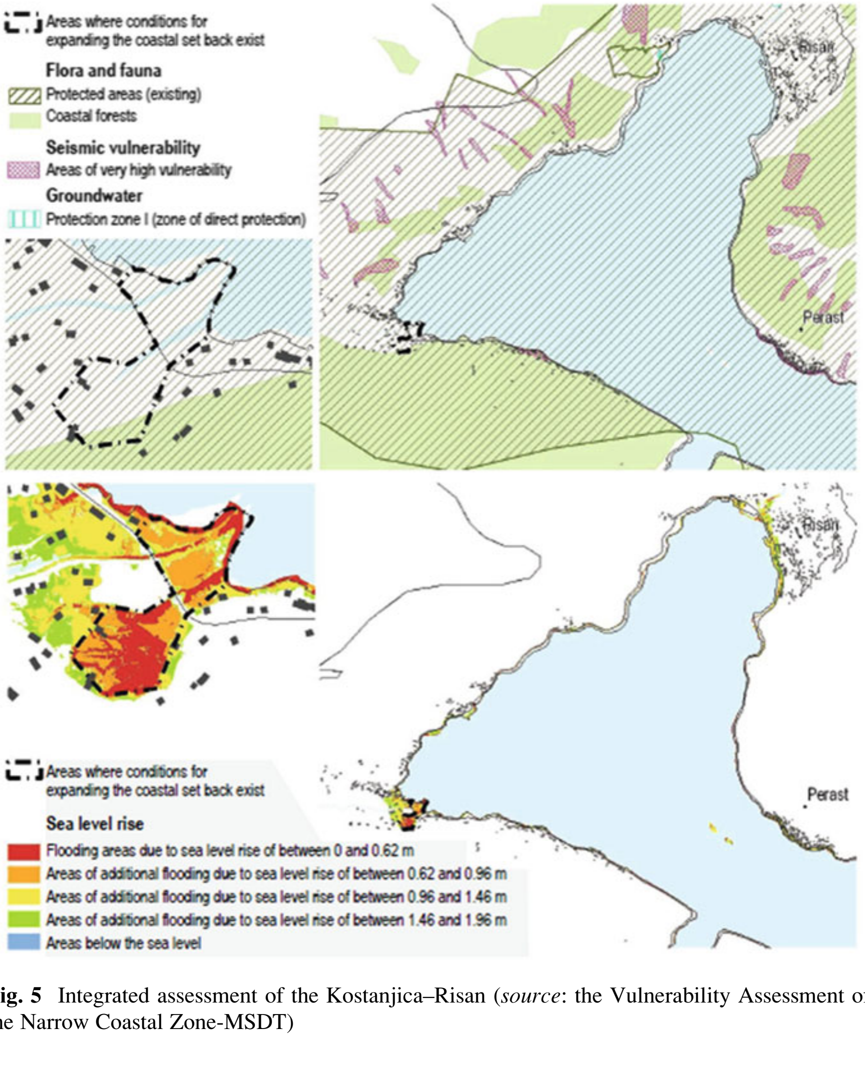

Fig. 5 Integrated assessment of the Kostanjica–Risan (*source*: the Vulnerability Assessment of the Narrow Coastal Zone-MSDT)

3.3 North-Western Part of Vrmac

Coastal ecosystem:	Yes, coastal holm oak forest – black oak (Orno-Quercetum Ilicis) community is present, especially important for biodiversity of the Mediterranean coastal zones
Nature protected area:	Yes, Kotor-Risan Bay is protected under municipal decision and also an area listed as UNESCO's natural and cultural heritage
Erosion:	Yes, from place to place moderate erosion (illustration 2)
Seismic vulnerability:	Yes, from place to place very high seismic vulnerability
Groundwater:	Yes, protection zone I (Lepetane)
Impact of storms and sea level rise:	No
Non-built areas:	Partly developed area, with smaller settlements located along the shore
Proposal for expanding coastal set back:	No, due to steep slopes, expansion of the coastal set back is not sensible – construction should be directed towards completion of the existing settlements

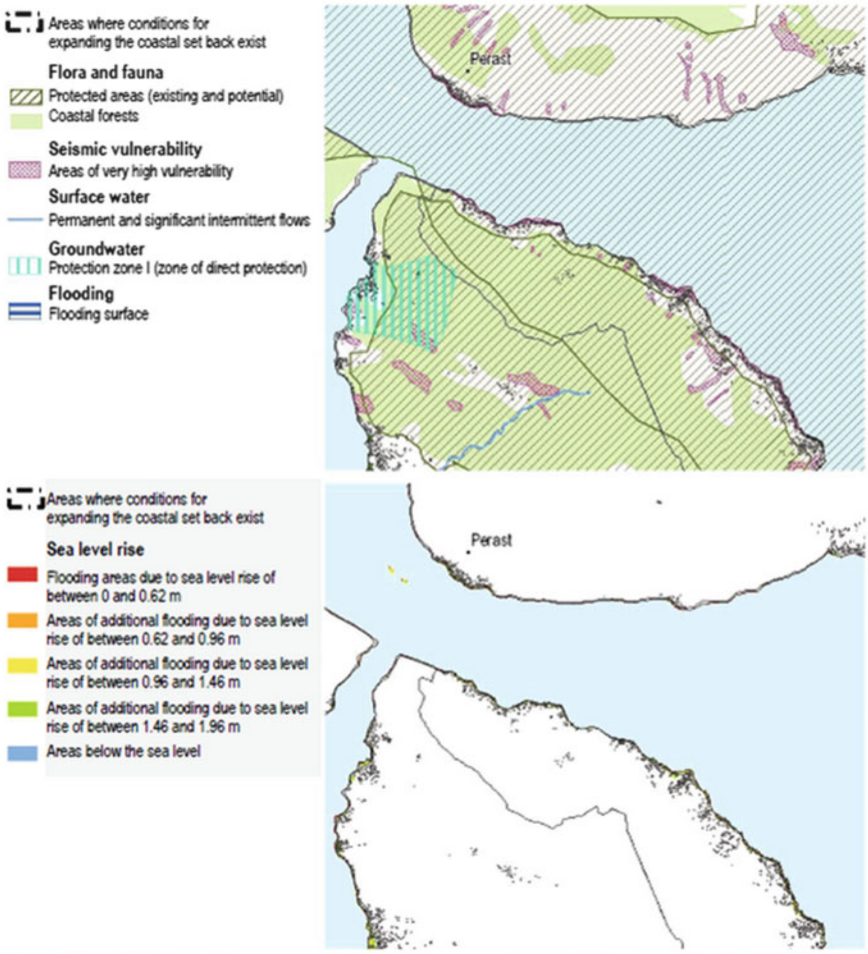

Fig. 6 Integrated assessment of the north-western part of Vrmac (*source*: the Vulnerability Assessment of the Narrow Coastal Zone-MSDT)

3.4 Tivat Saltpans

Coastal ecosystem:	Yes, wetland area and at the same time mouth of Kološun stream
Nature protected area:	Yes, special nature reserve
Erosion:	No
Seismic vulnerability:	Yes, very high seismic vulnerability
Groundwater:	No
Impact of storms and sea level rise:	Yes, flooding area due to a small difference between the sea and saltpans' level; high impact of the sea level rise is expected – Saltpans are saline, occasionally flooded wetland area. Even though the cove itself is in the protected Bay of Boka, it has a fetch in the north-western direction of 9.5 km so a strong and long-lasting wind from that direction causes waves that flood coastal belt in the cove
Non-built areas:	Partly developed area, with smaller settlements located along the shore
Proposal for expanding coastal set back:	Yes, expansion of the set back is proposed. Tivat Saltpans are typical area protected under the ICZM Protocol (surface of the area: 161.20 ha)

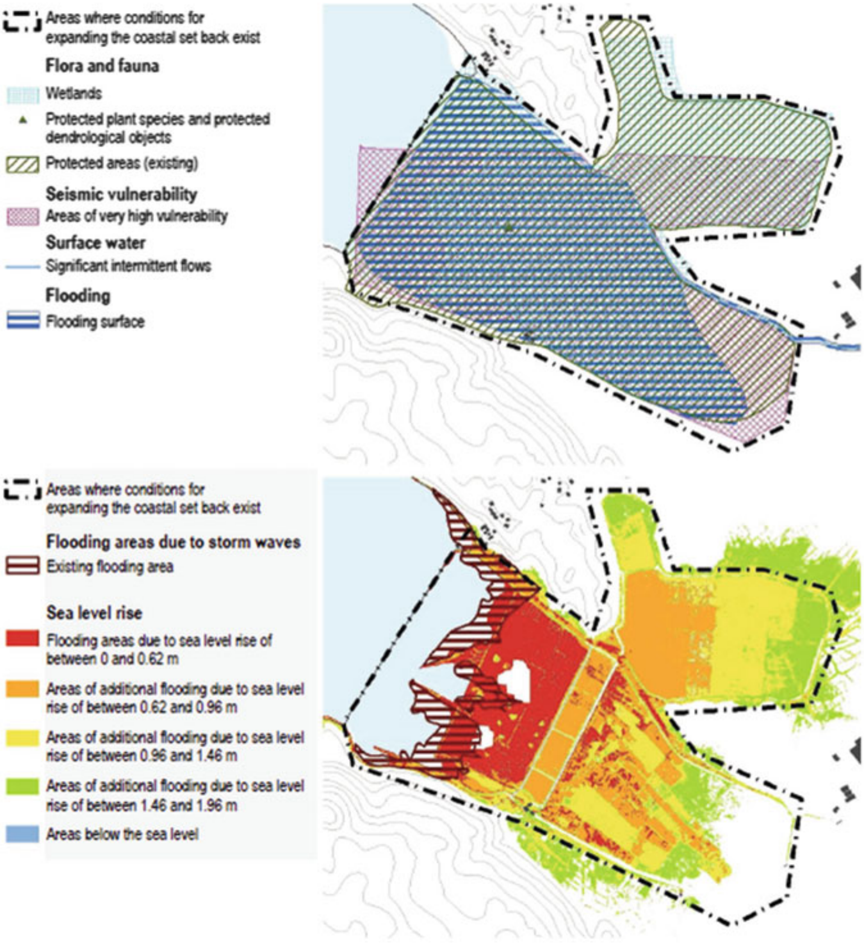

Fig. 7 Integrated assessment of the Tivat Saltpans (*source*: the Vulnerability Assessment of the Narrow Coastal Zone-MSDT)

In line with above results, the following areas in Boka Kotorska where expansion of the coastal set back zone were defined, i.e., where construction along the shore should be restricted or prohibited, in accordance with the Barcelona Convention Protocol on ICZM in the Mediterranean (ICZM Protocol): mouth of Sutorina river, mouth of Morinjska river, and Tivat Saltpans.

4 Establishment of a Basis for Maritime Spatial Planning

Complementary to the application of vulnerability assessment in determining optimal land uses for the terrestrial part of the coastal zone, application of the ecosystem approach in the analysis of marine environment serves as a basis for optimizing various planned uses of the sea. Limitations and possibilities in the application of ecosystem approach in the context of future maritime spatial planning in Montenegro were shown for the Boka Kotorska Bay in the framework of CAMP activities [1]. That pilot application of the ecosystem approach in development of the Maritime Spatial Plan for the Boka Kotorska Bay was tested in order to enable protection of its particularly sensitive parts and rational use of its economic potentials.

Even though an optimal coverage of the maritime spatial plan would be entire marine part of the Montenegrin coastal zone, complementary to the coverage of the CASP, a pragmatic approach would be to develop a plan for a pilot area prior to establishing the overall system of maritime spatial planning. In this way, it would be possible to gain a more detailed understanding about necessary data and its availability, barriers, and existing capacities for introduction of the maritime spatial planning. At the same time, a demonstration project could considerably improve planners' knowledge on the principles, measures, methods, and other specialized knowledge important for maritime spatial planning. Taking into account relative availability of data on the Boka Kotorska Bay, the first demonstration maritime spatial plan could in fact be developed for the Bay and related part of the open sea. Close attention should be paid to bio-geographic zones, which requires a comprehensive database. In this context, it is important to note that outer parts of the Montenegrin marine area have not been researched to the extent to which Boka Kotorska Bay has been. At the same time, the open sea is in economic terms significant for potential exploitation of hydrocarbons as well as an area with important fishing zones, maritime transport routes, and underwater installations. That is why decision on the scope of the maritime spatial plan should be made through a coordination mechanism for ICZM.

5 Conclusions

Above presented results that indicate the high vulnerability of the fragile marine ecosystem of Boka Kotorska Bay imply necessity of EcAp application and transposition of the Marine Strategy Framework Directive into national legislation. It would provide control and reduction of human pressures as to enable achievement of the objectives of good environmental status of marine ecosystem of Boka Kotorska Bay. EcAp application which stems from the decisions of the Contracting Parties to the Barcelona Convention is to a significant extent compatible with reaching good environmental status of marine environment that is required within the mandatory transposition of the Marine Strategy Framework Directive into national legislation. Hence it is important to apply the ecological objectives and related operational objectives and indicators in the framework of EcAp application simultaneously with application of qualitative descriptors of the state of the environment of the marine part of the coastal zone, and criteria and methodological standards for defining good environmental status in accordance with the Marine Strategy Framework Directive. Therefore it is necessary to realize the following activities:

- Initial assessment of the state of marine environment based on the application of EcAp by taking into account state of the terrestrial part of the coastal zone, comprising the following analyses:
- Analysis of the characteristics and components of the existing state of marine environment: hydrographic, physical and chemical characteristics, geological characteristics, biological characteristics, habitat types, etc.
- Analysis of main pressures and impacts on the state of marine environment, including human activities: physical loss of space, e.g., urbanization/making the coastal line artificial; physical damages, e.g., abrasion and other physical disturbances – e.g., marine litter, noise; impacts on hydrological processes, e.g., changes of heat regime, changes in the sea salinity regime; pollution with hazardous substances such as heavy metals, synthetic compounds, and radionuclides; continuous inputs of matters the discharges of which are regulated by the law; inputs of nutrients and organic matter, e.g., input of matters rich in N and P from point and diffuse pollution sources; biologic disturbances, e.g., introduction of non-indigenous (alien) species, invasive species, pathogens, as well as selective extraction of species; this analysis will include qualitative and quantitative characteristics of pressures and trends in their impacts, as well as the main cumulative and synergetic effects;
- Analysis of the state and main pressures and impacts on the state of terrestrial environment of the coastal zone;
- Economic and social analysis of the use of sea resources and the costs of degradation of marine and terrestrial environment of the coastal zone.
- After completing the initial assessment of the overall state of the environment, good environmental status of the marine environment and of the land part of the coastal zone in the Boka Kotorska Bay will be established. Good environmental status will be defined as a set of characteristics on the good environmental status of the sea and land parts of the coastal zone. This will be done based on qualitative descriptors, i.e., ecological objectives and related operational objectives and indicators as listed within the decisions of the Contracting Parties to the Barcelona Convention on EcAp application (e.g., they can include: location and

extent of habitats impacted directly by hydrographic alterations (EO7; 7.2.2); length of the coastline subject to physical disturbances due to the influence of manmade structures (EO8; 8.1.4); land use changes (EO8/8.2.1), and others). Methodological differences in the application of EcAp should be established thereby, and good environmental status of marine environment in accordance with the Marine Strategy Framework Directive defined. The amendments in relation to the requirements of the Marine Strategy Framework Directive should be made.
– Determining the objectives of good environmental status of the marine environment based on the initial assessment and a set of characteristics of good environmental status of the marine and terrestrial environment of the coastal zone.
– In accordance with the established baseline and objectives of good environmental status, proposal of the amendments to the existing marine environment monitoring programme and proposal of protection and management measures for the marine and land parts of the coastal zone will be defined.

In order to control pronounced conflicts in marine areas uses point to the need to manage pressures on marine ecosystem, as the next step it is necessary to establish a framework for maritime spatial planning. Maritime spatial planning has to enable sustainable use of maritime resources while protecting valuable parts of the marine ecosystem of Boka Kotorska Bay. In developing maritime spatial plan in order to optimize marine area uses, application of EcAp, as presented above, is significant element which will result with determination of the state and pressures on marine environment. It creates preconditions to achieve good environmental status and to reduce to the lowest possible extent conflicting interests among potential users of the marine environment while maximizing economic effects.

References

1. Ministry for Sustainable Development and Tourism, 2015, the National Strategy on Integrated Coastal Zone Management (NS ICZM)
2. Ministry for Sustainable Development and Tourism, 2013, the Study on Biodiversity and Nature Protection of Coastal Area of Montenegro
3. Ministry for Sustainable Development and Tourism, 2014, ECAP Implementation in Montenegro, (Draft of) the Master Plan and Pilot Actions for the Promotion of Green and Blue Economy in the Boka Kotorska Bay
4. UNEP/MAP, 2016, the Integrated Monitoring and Assessment Guidance
5. Ministry for Sustainable Development and Tourism, 2014, the Assessment of General Vulnerability of the Coastal Area of Montenegro
6. Ministry for Sustainable Development and Tourism, 2014, the Vulnerability Assessment of the Narrow Coastal Zone
7. Ministry for Sustaianble Development and Tourism, 2016, National Action Plan For the implementation of the LBS Protocol and its Regional Plans in the framework of the SAP-MED with the aim to achieve good environmental status for the pollution related EcAp objectives

Conclusions

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Abstract This paper is the first attempt to combine interdisciplinary studies of Boka Kotorska Bay of the Adriatic Sea with the aim of improving its presentation in terms of functioning and limits of the use of its natural potential. It collects and highlights the geographical and oceanographic characteristics, climate, history and development, biology, fisheries, agriculture, coastal zones, shipping, marine tourism and pollution. In the recent decades, there has been an increased awareness worldwide of the very important role of the coastal regions along with their assessment of them as sites with unique properties, priceless and non-renewable natural resources. The distinctive characteristic of the Boka Kotorska Bay is that its

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whole "life" has been connected with the seasonal tourism; although seasonal in character and uneven, it largely provides economic development of its coastal zone.

In the process of development of the coastal zone of the Bay, there is an inevitable conflict between the types of business activities, fishing and tourism, the growth in housing and infrastructure (port complex), and we are taking account of the interaction and collision of industrial, social and natural processes that lead to the emergence of environmental conflicts.

Keywords Adriatic Sea, Boka Kotorska Bay, Coastal zone, Fishery, Marine biology, Tourism

The introduction into this monograph demonstrates why it has been chosen for highlighting the oceanographic, ecologic-biological and socio-economic issues of the Boka Kotorska Bay. Summing up the results of the research performed and analysed under this endeavour, its timeliness, importance and practical value should be mentioned. This is due to the sudden development of tourism industry over the recent decades – marine tourism on the Adriatic coast and accompanying use of the coast, sailing, scuba diving, sport fishing, etc. and their effects on marine, coastal and shoreline areas.

The history of the Boka Kotorska Bay is closely linked with the rich maritime history of the Adriatic Sea. In the eighth century BC in the southern part of the Adriatic, Greek colonies appear. Fight for the Kerkyra (Corfu) Island served as one of the reasons for the Panhellenic Peloponnesus wars of the fifth century BC to the end of the third century BC when Romans begin to conquer the entire coast of the Adriatic Sea. In 395 Eastern and Western Adriatic coast was divided along with the entire Roman Empire. At the beginning of the sixth century, Byzantium seized the whole coast of the Adriatic Sea, but with the invasion of the Lombardy in 568 Italy deprived Byzantium of this monopoly. In the sixth and seventh centuries, Slavs came to the northern and eastern coasts of the Adriatic Sea. On the other side, Venice was on the rise. In the eighth century, Arabs came to the Adriatic Sea and in the tenth century Normans. In the eleventh century, Venice and Dubrovnik fought for dominance over the Adriatic Sea.

When Venice conquered Dubrovnik, it became the strongest state in the Adriatic. In the ninth century, a part of the Adriatic coast was conquered by Hungary and in the eighth century by Austria. In the fifteenth century, Turks threatened the Venetian dominance. The end of the fifteenth and early sixteenth centuries was marked by Venetian-Turkish wars. In the eighteenth century, the influence of Austria rose, and it conquered the Balkan part of the Adriatic coast and in 1797 the Republic of Venice itself. In 1806, the French Emperor Napoleon conquered practically the entire Adriatic coast, which led to the establishing of a Russian naval squadron in these waters. After Napoleon, the Adriatic was seized by Austria. In 1866, the coast held by Austria was challenged by Italy, but the Italian fleet was defeated. During the World War I, there was a naval war between Italy and Austria-Hungary over the Adriatic. Using their supremacy, the Entente locked the Austro-Hungarian Navy in the Adriatic. After 1918, Italy's aspirations to seize the Adriatic rose. In April 1939, Italy annexed Albania. In October 1940, Italy attacked Greece, and this part of the Adriatic became a new battle area of the World War II. In April 1941, Axis countries, Berlin-Rome-Tokyo, seized the entire Adriatic coast. In autumn 1943, Britain began an offensive along the Adriatic coast in Italy. In autumn 1944, the liberation of the Balkan part of the Adriatic coast began. In May 1945, the war in the Adriatic ended. After the breakup of Yugoslavia in 1991, and in a series of interethnic conflicts in the period 1991–2001, hostilities occurred again in the Adriatic.

The long and rich history has left its distinctive mark on the shores of the Boka Kotorska Bay. Advancement of natural sciences has given us the ability to link a series of historical cycles and review their impact on the nature.

The physical and oceanographic features of the Adriatic Sea provide the basis for describing these characteristics of the Boka Kotorska Bay.

The Boka Kotorska Bay is one of the largest in the Adriatic Sea and the largest in Montenegro – tourist country – whose main asset, the magnificent nature and people, assists in establishing of tourist industry in all of its forms. Montenegro is the first country in the world that adopted in 1991 the constitution proclaiming it the ecological state, according to which economic development provides a balance with the surrounding environment through sustainable development.

The Boka Kotorska Bay is an enclosed water body with a narrow and shallow connection to the Adriatic Sea; the shallowest part is only 37.6 m deep at present, limiting the exchange of water with the Adriatic. The Boka kotorska Bay has an area of 87.3 km^2, the volume of 2.4 km^3 and the length of 28.13 km. The maximum depth is 65 m, average 27.3 m, coastline 105.7 km and indented coastline 3.07, and the width of the entrance to the Bay is 2.961 m. The Bay is officially listed as one of the most beautiful bays of the world (1997), and even earlier in 1979, it was included in the UNESCO cultural heritage list.

The Bay is one of the most important transitional areas of the Adriatic from both an environmental and socio-economic viewpoint. Multibeam bathymetry combined with seismic reflection images suggests that the observed morphologies are due to the interaction at different timescales of climate, water circulation, sea level change, erosion, sedimentation and tectonics constrained by the geological and structural setting of the area. The Bay is composed by three major basins (Herceg Novi, Tivat and Morinj-Risan-Kotor), connected by two narrow straits (Kumbor and Verige) with a maximum depth of 60 m. It shows steep upper slopes and flat subbasin central sectors lying at depths ranging from 35 to 45 m. Among the several morphological features shaping the seafloor, we noted deeply incised valleys and delta fans related to past sea level falls, slope failures and mass wasting triggered by strong earthquakes, channels bounding the steep slopes of Kumbor and Verige narrow passages and sediment wave fields in Verige strait formed by strong bottom currents, and karst morphologies developing at the seafloor with submarine siphons, springs and resurgences (pockmarks) fed by karst hydrology of Boka Kotorska Bay's surroundings.

Human settlements were formed on the shores of the Boka Kotorska Bay long time ago; the first town was established in 229 BC, at the site of present-day Risan. When founded, it soon became a major town and centre of the whole region of Boka Kotorska Bay. The coast of the town and the Bay were under the influence of all eras: they were built by the Illyrians and Romans and Byzantines, settled by Slavs and Venetians and conquered by Ottoman Turks and various European countries (from France to Austria, at one time, even the Russian Fleet was based there) until all of its territory became permanently Yugoslav and eventually, as of 2006, Montenegrin.

So an active historical process is simple – the Bay has always been bustling, with developed economy and seafaring, built towns, temples and houses. This part of the coast had been under numerous empires and military actions. Frequent change of rulers has left in many towns unique architectural monuments of different styles and eras. The modern towns of Kotor, Risan, Perast and Herceg Novi are popular tourist destinations, attracting numerous visitors with its sights and spiritual pilgrims – ancient Orthodox and Catholic churches.

There are nine interesting small islands in this Bay – Mamula, Prevlaka, Vavedenje, Gospa od Škrpjela, Gospa od Milosti, Sveti Marko, Ostrvo Cvijeća, Sveti Đorđe and Zanovjetni Skoljic – as well as interesting underwater caves and ships of different periods lying on the bottom that are available for diving enthusiasts.

Fishing, since ancient times, as one of the major sources of human sustenance, has always been dependent on the natural environment, the determinants and the species composition of the raw material base for fisheries and, on the other hand, on the socio-historical-economic structure, the degree of occupation of the coasts, socio-environmental conditions, etc.

The Adriatic Sea, forming part of a unified Mediterranean aquatic ecosystem, including the river discharge, shares the same modern problems, existing in all Adriatic states. Most of these issues are a consequence of the negative developments which had taken place under the influence of human activities. This and environmental degradation, reduced stocks of most fishing resources caused by excessive fishing pressure, and much more, have led to a decrease in fishing activities in the Adriatic Sea and the Boka Kotorska Bay.

Apart from its economic significance, the fishing with traditional gear in the Boka Kotorska Bay also has a strong culturological and sociological importance for the local population, and as such, it should be preserved and protected at the times of industrialization and development of the coastal areas. Activities aimed to preserve the traditional fishery types in the Boka Kotorska Bay should be implemented also in order to diversify further the tourist offer of Montenegro since in addition to provision of fresh, wholesale food from the sea, the use of traditional gear is also a tourist attraction.

Analysis of phases and features of the development of fishing activities allows for a deeper understanding of contemporary problems and their origins, which will help identify the most optimal solutions in the problems of conservation of fish populations. Historically, the Bay has developed its traditional fishing culture, which includes almost all of the production stages for the extraction of fish (fishing boats, fishing gear) to implement it. Today fishing centres in the Boka Kotorska Bay remain in ancient cities – Kotor, Risan, Perast and Herceg Novi.

Human influences on marine plant communities are grouped into direct impacts including mechanical damage, pollution and biological damage and indirect effects such as global/regional warming and changes in the sea level. Regression of seagrass meadows is high.

The book includes a review of recently published results regarding zooplankton in the Boka Kotorska Bay (since 2009) and comparison of these results with earlier investigations. Non-loricate ciliates were the most numerous microzooplankton in spring 2013 (37%). *Loricate ciliates* (*tintinnids*) values were low and similar to those recorded in the open Adriatic Sea. However, their diversity was quite high: 20 estuarine-neritic and 26 species typical of the open sea were identified. *Copepod nauplii* were dominant metazoan microzooplankton component (32%). Seven phyla and 81 mesozooplankton taxa were determined. Copepods were the most dominant groups. Among them, *Oncaea* cyclopoids and *Oithona nana* were the dominant copepod taxa at all stations. Heterotrophic dinoflagellate *Noctiluca scintillans* and cladocera *Penilia avirostris* were often extremely numerous during warm seasons. Changes in the zooplankton community noted during recent investigations can be linked with the observed climate changes identified in the Adriatic and Mediterranean Sea since the 1990s, which are reflected in: (1) zooplankton high densities in the winter period with a lack of spring peak; (2) domination of small-sized cyclopoid copepods, and decreasing of contribution of neritic calanoid species; (3) prolongation of high *Penilia avirostris* abundance in the autumn period; (4) spreading of invasive Siphonophorae *Muggiaea atlantica* in the inner part of the Bay; (5) frequent outbreaks of gelatinous zooplankton; and (6) the first registered bloom of the ctenophore *Bolinopsis vitrea* in the Mediterranean in spring 2014 having a major impact on the regular planktonic food web system.

Description of the basic characteristics of the zoobenthos assemblages at the seafloor of the Boka Kotorska Bay was created by compiling available data from the scientific and grey literature, and they are a result of research of this area during the last 55 years. With the establishment of the Institute of Marine Biology in Kotor, more intensive research of marine biodiversity of this particular area had started.

Available data indicate the presence of a large number of species of seabed fauna which has adapted to specific environmental conditions. Among the identified taxonomy, there are many species protected by national and international regulations. Most of these species are builders of coralligenous biocenosis that make this space unique. These communities are particularly distributed in the inner part of the Boka Kotorska Bay (the Bay of Kotor and Risan) where they are distributed to the relatively shallow depths (12–30 m).

Since the area of the Boka Kotorska Bay is abundant with underground springs, many species have adapted to life in the brackish environment with reduced salinity. From the species that inhabit the sea bottom of this area, there is a large number of endemic species of the Mediterranean, especially from the group of molluscs and echinoderms.

That the area of the Boka Kotorska Bay has not been spared of the trend following the development of modern society speaks the fact that the presence of invasive species has been reported, some of which become domesticated. This number is certainly not final and has the tendency to increase.

This book provides an overview of all the data available on qualitative composition and distribution of ichthyoplankton in the area of the Boka Kotorska Bay. Although the research activities were not conducted continuously, the results showed a high level of diversity and abundance of certain species and proved that the Boka Kotorska Bay is one of the most important spawning areas and feeding grounds for juveniles of a number of pelagic fish species. Analysis of the plankton material resulted in identification of spawning of 40 different species from 7 genera and 20 families.

Marine invertebrates from the Boka Kotorska Bay represent a gold mine for both marine pharmacology and biotechnology as well as for bio-inspired materials science. Especially sponges are highly prospective organisms due to their ability to grow under marine farming conditions and to synthesize biologically active secondary metabolites as well as diverse biopolymers. Their skeletal structures contain unique biocomposites made of organic templates and calcium carbonate, or silica phases. Studies on structural biopolymers like amino polysaccharide chitin, or proteinaceous keratin-like sponging, are current topics of scientific interest today. Chitinous scaffolds of poriferan origin are discussed as unique templates for application in extreme biomimetic and tissue engineering.

On the basis of population distribution on the shore of the Boka Kotorska Bay, the use of biological and recreational resources can be followed (fishermen's historical settlements). Structure of the tourist flow has remained constant over the recent years: about three-fourths are organized tourists (cruises, amateur tourists) and a quarter are the unorganized (amateur) tourists who are difficult to track. Many amateur tourists use individual accommodation facilities (apartments, rooms and houses for rent); seasonal campsites are rarely used. Services of privately owned accommodation are used by citizens of Russia, Ukraine and Serbia and foreign tourists from Germany, Italy, Austria, Hungary, Norway, etc.

Seasonal character of the tourism industry creates some difficulties. The income of households in the off-season, the so-called "dead" winter season, is significantly reduced. Owners who earn money in the summer months invest it mainly in repairs and construction (residential areas for rent are expanding). Seasonality increases industrial and anthropogenic load on the nature of the coastal zone and infrastructure. It creates a problem of retention of qualified staff and maintaining the necessary level of competence.

There is an extensive coastal marine area for scuba diving provided by underwater landscapes, most of which are poorly developed and practically do not change business activities.

What is very relevant is the data collection on natural rational capacities of the Bay (rational underwater tourism). Diving and recreational bathing can damage the marine vegetation.

It is important to identify coastal areas with water parameters favourable for the future setting up of mussels' farms (at depths greater than 4–5 m), plantations and artificial reefs.

The structure of the economic development of the Boka Kotorska Bay is determined, above all, by tourism and service sectors, as well as the share of the agricultural sector. The Bay's total population, according to the national statistics report, grows quite slowly. It rises significantly during the summer months compared with "normal", which is due to the inflow of tourists. This anthropogenic load resulted in further expansion of already urbanized coastal areas along the waterline at the expense of the slopes of the mountains, descending to the water. Existing houses by the sea, with a view to attracting tourists, usually are but only up to the permitted number of storeys of the detailed spatial urban plan.

By the 1960s, agriculture was dominant in the Boka Kotorska Bay, while tourism was in its infancy, as well as other industries. The population engaged in livestock and crop farming, growing maize, barley, rye and wheat. Olive growing was quite developed in the coastal zone. It used to be the most important industry in this area, generating significant income. After 1960s, with further development of nonagricultural economy, municipalities in Herceg Novi, Tivat and Kotor experienced population influx and sudden economic prosperity. After urbanization, rural areas became areas with low population density and agriculture as predominant activity referred mainly to households with elderly owners. Since 1970s, shipping industry, tourism, ship building and chemical industry were pillars of the Boka's economic development, while agriculture was neglected, although natural conditions for its development existed.

Based on socio-economic analysis in three municipalities of the Boka Kotorska Bay, it can be concluded that agriculture was gradually becoming more a symbol of keeping the tradition and culture of this region alive, with its economic importance becoming almost negligible. Analysis of statistical data in the period 1965–2011 points to the fact that agriculture had not been the primary activity of the population of the Boka Kotorska Bay, either at the beginning or the end of the period observed. The reasons for such situation are multiple and complex. They are caused not only by natural but also social factors.

In the upcoming period, it is necessary to use the favourable climatic conditions, as an important factor of increasing the volume of agricultural production. It is very important to put the existing natural resources into the function of development of agriculture. It is particularly important to provide support to the production of healthy food and so-called organic farming and processing of Mediterranean crops.

The effect of reduction of industrial activities in the Bay of pollution emissions into the atmosphere from stationary sources is practically non-existent. But the emissions from transport, including the increasing number of tourist vehicles and large cruise ships serving tourist lines, and use of the Boka Kotorska Bay (as well as harbour berth for ships) are growing. Poor quality fuel, dilapidating vehicles and maintenance behind the required level require further efforts to improve air quality.

Total emissions from cruise ships in the Boka Kotorska Bay area in 2015 were estimated as follows: 258.50 t y^{-1} of NOx, 578.80 t y^{-1} of CO, 24,996.74 t y^{-1} of CO_2, 126.87 t y^{-1} of VOC, 9.42 t y^{-1} of PM and 7.84 t y^{-1} of SOx in the case when assumed that cruise ships burn low sulphur fuels and 418.95 t y^{-1} of Sox in the case of high sulphur fuels.

Mariculture development in Montenegro began after the completion of initial explorations on the possibilities of farming edible bivalves on the area of the Boka Kotorska Bay, which were conducted in 1960s. After this period, the first commercial farming of mussels (*Mytilus galloprovincialis*) began, while the first commercial farming of oysters (*Ostrea edulis*) began in 2009 in the Boka Kotorska Bay. Today, there are around 20 active shell farms as well as two fish farms using the multi-trophic aquaculture system. Bivalve farming is done using the traditional method of floating parks system (longlines), while fish farming is done in floating cages.

Based on data presented for the Boka Kotorska Bay, phytoplankton abundance reaches up to 10^7 cells/L. Diatoms are the phytoplankton group present throughout the year. In some research conducted in the Boka Kotorska Bay, diatom abundance reaching up to 10^7 cells/L was recorded. Dominant species are typical of areas with higher eutrophication that prefer nutrient-rich areas and are very good indicators of ecosystem conditions. Dinoflagellates are the second important group of microplankton, frequently found in the aquatorium of the Boka Kotorska Bay, generally less represented than diatoms, both quantitatively and qualitatively.

Coastal Boka Kotorska Bay area has a unique natural and significant cultural heritage; it is a single coastal zone and can be considered as a tourist and recreational complex. It has great ecological, cultural, aesthetic and historical significance. According to the definition of the European Commission, "coastal zone sea is an area of contact of land with sea, including natural systems, as Bank and adjacent sea borders, allowing environmentally balanced development for coastal areas, the preservation of coastal and marine landscapes and ecosystems from pollution and destruction is the territory with the regime limited and regulated economic and other activities".[1]

In spite of the ecological and political instability in the world, the tourism demonstrates resistance to limiting development factors and has a general tendency to growth. Europe continues to be the largest international tourism region, and its tourist flows are traditionally directed to the countries of Southern Europe and the Mediterranean, due to the warm climate and rich cultural and historical heritage.

[1]The situation in Europe's coastal zone. URL: http://europe.en.int/comm/environment/iczm/situation-htm

The share of tourists coming to Montenegro in the mass tourism market is quite high.

Marine tourism includes long-term and short-term travel or sea trips by comfortable ships and small vessels for sailing. This includes travels on the coast within coastal recreational complexes. The most prominent part of the marine tourism are cruises. Sea cruise is a sea tour, for tourists who are usually arriving into ports on special passenger vessels. Currently, cruise tourism is experiencing revival, with growing cruise fleet and crews.

One factor in the sustainable development of the coastal zone is the harmonization of interests of natural resources and land use, by developing a comprehensive strategy and plan for its recreational use on the basis of the principles of sustainable development, consolidating the legal conditions and restrictions of use of coastal areas. Thanks to the rich resources of the coastal zone of the Boka Kotorska Bay, it is an area with a high population density, with a narrow strip of land with a continuous row of settlements along. The emerging controversy associated with intensive use of coastal resources will inevitably exacerbate problems of socio-economic development of the territories. It is important to harmonize environmental objectives with intense anthropogenic activities, which in this area depends on the continuous expansion of accommodation for holidaymakers in the private sector and urban construction. Biological diversity of the Boka Kotorska Bay and its coastal zone is particularly important for the region. There are numerous algae in the Bay, with the highest diatom number. Most algae phytoplankton species, which is a major producer of organic substance, are algae present in microphytobenthos and periphyton. Their importance is quite high, as since they represent the main source of food for many zooplankton species.

The maximum recorded phytoplankton values indicate changes that may lead to eutrophic conditions in the Bay; however, it can be concluded that the Bay is still moderately trophic. According to two trophic indices TRIX and Fp ratio, natural eutrophication is still dominant over anthropogenic eutrophication in the Boka Kotorska Bay.

Research of phytobenthos in the Boka Kotorska Bay did not start until the second half of the twentieth century and 219 species have been described so far in this area. The highest number of identified taxa in the Bay belongs to the Atlantic phytogeographic element (35.1%), followed by the Mediterranean (18.9%), cosmopolitan (12.2%) and others. Endemic species of the Adriatic Sea are represented with only one species, *Fucus virsoides*, with the Bay as its southernmost distribution limit. Four species of seagrass are found, and meadows of *Posidonia oceanica* and *Cymodocea nodosa* are numerous, especially in the outer part of the Bay. *Zostera noltei* builds meadows together with the *C. nodosa* at several locations, while *Zostera marina* was found at one location only.

One of factors particularly influencing the development of tourism is its seasonal character, which poses the most significant issue, mainly determined by climatic factors. Tourist holiday season lasts from May to October, i.e. about 6 months, with maximum load in July and August, when the highest income is generated in the tourism sector.

Economic development without compromising the environment-driven special approach – Integrated Coastal Zone Management (ICZM) - is a difficult task. The European Commission considers ICZM as a permanent, shared management process, the purpose of which is the introduction of sustainable development for the conservation of coastal zones together while maintaining their biodiversity.

Taking into account the fragility of coastal ecosystems and diversity of activities and users and their interaction, ICZM has to be applied in order to provide sustainable management of the coastal zone of Boka Kotorska Bay which includes protection, preservation and improvement of the environmental status. The application of the vulnerability assessment in determining optimal land uses for the terrestrial part of the coastal zone and marine spatial planning that includes the application of the ecosystem approach in analysing the status of marine environment and determining the objectives of good environmental status provide comprehensive set of tools to support effective coastal zone management of the Boka Kotorska Bay. Therefore, further urgent actions are necessary as to enforce implementation of ICZM and marine spatial planning instruments and tools in the Boka Kotorska Bay.

The Springer's Handbook of Environmental Chemistry is a series of books, monographs and reviews prepared by leading scientists and experts in the field of the environmental issues. A series of environmental issues has repeatedly urged research of the southern seas like the Aral, Caspian, Black, Mediterranean seas and now the Boka Kotorska Bay, which is one of the most famous and most beautiful bays of the Adriatic Sea.

This book will be interesting and useful not only to students, postgraduate students and researchers but also to all professionals associated with the study of ICZM and a wide circle of readers.

The epigraph to the book is already quoted famous English poet, Lord G.G. Byron, who visited the shores of the Adriatic Sea. But we wanted to close this publication with his own words: "At the moment of the creation of our planet, the most beautiful merging of land and sea occurred at the Montenegrin seaside... When the pearls of nature were sworn, an abundance of them were strewn all over this area".

Erratum to: Metal Pollution and Ecotoxicology of the Boka Kotorska Bay

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A. Joksimović et al. (eds.), *The Boka Kotorska Bay Environment,*
Hdb Env Chem, DOI 10.1007/698_2016_40,

The publisher regrets that an incorrect reference list is included in the published chapter. The corrected reference list is now updated in the chapter.

The updated online versions of the original chapter can be found under DOI 10.1007/698_2016_40

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A. Joksimović et al. (eds.), *The Boka Kotorska Bay Environment*,
Hdb Env Chem (2017) 54: 599–600, DOI 10.1007/698_2016_90,

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A. Joksimović et al. (eds.), *The Boka Kotorska Bay Environment*,
Hdb Env Chem (2017) 54: 601–606, DOI 10.1007/978-3-319-51614-1