The Handbook of Environmental Chemistry 110

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Igor S. Zonn · Andrey G. Kostianoy
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The Montenegrin Adriatic Coast

Marine Chemistry Pollution

Springer

The Handbook of Environmental Chemistry

Volume 110

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The Montenegrin Adriatic Coast

Marine Chemistry Pollution

Volume Editors: Danijela Joksimović · Mirko Đurović · Igor S. Zonn · Andrey G. Kostianoy · Aleksander V. Semenov

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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 four decades, as reflected in the more than 150 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 https://link.springer.com/bookseries/698. 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
Series Editors

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Introduction

Danijela Joksimović, Mirko Đurović, Aleksander V. Semenov, Igor S. Zonn, and Andrey G. Kostianoy

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Abstract This book presents a systematization and description of current knowledge on the physical characteristics and oceanography, marine chemistry and pollution, environmental quality, and legal regime for the protection of the marine environment of the Montenegrin coastline in the South Adriatic Sea. The volume is focused on a specific area and research that has wide appeal in the scientific community based on numerous data collected during research and/or on archival data published in scientific papers. One of the important parts of this book is a

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harmonized implementation of monitoring and methodological proposal, and an assessment of contaminants, including metals, in the marine ecosystem, considering objectives of Water Frame Directive and Marine Strategy Framework Directive. This book is intended for specialists working in the various research fields, from natural sciences (oceanography, chemistry, biology, ecology, maritime) to social sciences, who will provide information on the status of the environment in the Montenegrin coast in the South Adriatic Sea.

Keywords Adriatic Sea, Environmental chemistry, Montenegrin coastline, Pollution

1 Introduction

Today, numerous scientific researches are being conducted worldwide with the aim of testing, improving, and protecting the environment, especially water, as a limited and sensitive natural resource. Urbanization and industrialization of coastal areas, such as the Montenegrin coast, have led to greater pollution of the environment, and thus of the sea. Rivers loaded with industrial and communal wastewater bring large amounts of sediment containing various pollutants. The Adriatic Sea and the Montenegrin coast are exposed to negative human influence and activities that take place on the coast. Human activities lead to the pollution of nature, which is reflected in the entire ecosystem.

The Adriatic Sea is an elongated depression or syncline. Its current form and size originate from early Quaternary transgression. Its northern part was created by mild curving of the Earth's crust, forming a shallow depression or basin that was simultaneously flooded by the sea. This took place at the end of Tertiary, in Pliocene. A part of the depression, the Padua Plain of today, had again dried up during Pleistocene. The southern deep part of the Adriatic was created by caving in of the Earth's crust in the younger Tertiary. This process also created the Otranto Door that connects the Adriatic with the Ionian Sea [1].

According to its origin, ecological properties, and the living world, the Adriatic Sea is a part of the Mediterranean Sea. The Adriatic Sea is a semi-enclosed sea and the largest bay in the Mediterranean. It can also be described as a continental sea due to its deep inland and shallow depths. The North Adriatic is also the northernmost part of the Mediterranean (to 45°47′N), which affects some of its significant physical and biological properties. At the same time, those specific physical properties to some extent affect the Eastern Mediterranean (the Ionian Sea). The Adriatic is connected with the rest of the Mediterranean basin through the Otranto Door (Strait of Otranto) (about 40 n.m. or 72 km in width, and around 741 m in depth), in the south to Derin (Italy). The length of the Otranto Door in direction north-south is 783 km, which is important in the circulation and exchange of water masses between the Adriatic and the Ionian Sea [1–4].

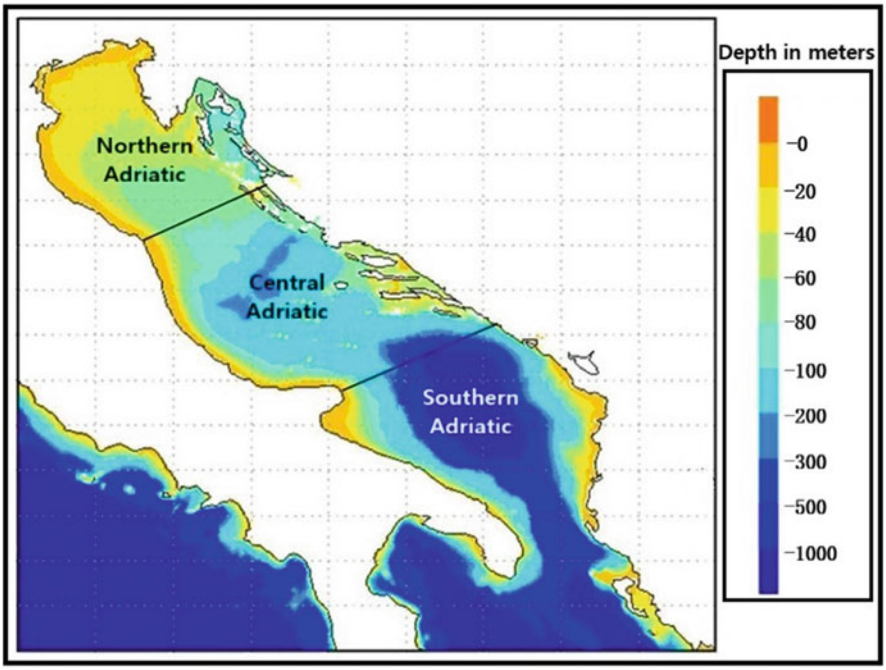

Fig. 1 Division of the Adriatic Sea (modified from [5])

The Adriatic Sea is divided into the northern, central, and southern parts. According to this division, the northern part of the Adriatic reaches the imaginary transversal line connecting Karlobag in Croatia and Ancona in Italy, the central part covers the area between that line and the line Ploče in Croatia and Cape Gargano in Italy, while the southern part covers the area from the line Ploče – Cape Gargano to the Otranto Door (Fig. 1) [5].

The area of the whole Adriatic Sea is 138,595 km^2, which is about 5.5% of the total area of the Mediterranean, and its volume is approximately 34,977 km^3 [1].

Montenegrin coastline length is about 300 km, of which 105.7 km belongs to Boka Kotorska Bay and 11 km are islands. The area of territorial waters up to 12 n.m. is 2,098.9 km^2, the epicontinental belt area is 3,885 km^2, and the shelf area is ≈4,000 km^2. It differs from other parts of the Adriatic by the highest water mass (26,000 km^3 from a total of 32,000 km^3 in the entire Adriatic), the highest depth (1,228 m), the highest current speed (42–88 cm s^{-1}), which is several times higher than in other parts of the Adriatic, the stronger water mass exchange with the Mediterranean, as well as the greatest transparency – up to 60 m [6, 7].

The Adriatic Sea is mostly shallow. The continental slope or shelf and slope, i.e. the area of seabed to about 200 m in depth, account for as much as about 74% of the Adriatic Sea. From northwest to southeast, the depth of the Adriatic Sea increases gradually. The average depth of the North Adriatic is about 50 m, while the average depth of the middle part of the Adriatic is about 200 m [1]. Only 7.7% of the Adriatic

Sea is characterized by depths over 1,000 m. The highest depth of the Adriatic is in the area of the South Adriatic Sea [6]. The average depth of the entire Adriatic is 251 m [7]. The largest part of the bottom, i.e. the benthal of the Adriatic Sea, belongs to the shelf, and a much smaller part to the continental slope, i.e. the batial, the seabed below 200 m depth.

This chapter introduces the Adriatic Sea and the Montenegrin coast of the Adriatic to readers of this book "The Montenegrin Adriatic Coast" which is published in two volumes: "Marine Biology Environment" and "Marine Chemistry Pollution."

2 Sediments Characteristics

In the Adriatic Sea, considering its bottom configuration and bathymetric characteristics, in the area of pelagic, the zone of epipelagic, mesopelagic, and possibly bathypelagic can be distinguished, and in the area of benthal the zone of intertidal and continental slope – shelf [4].

The seabed of the Adriatic shelf is covered with recent sediments of different structures and mineralogical – petrographic composition. Considering the physical structure and different facies of the seabed, we distinguish reefy (rocky), gravelly, scaly, sandy, and muddy bottom. Most of the Adriatic shelf is covered with muddy and sandy sediments. Sandy sediments are formed in the coastal area and shallow parts of the Adriatic shelf, while muddy sediments cover most of the Adriatic basin. These sediments are formed in areas where there is no significant movement of seawater. Sandy sediments cover most of the North Adriatic, a smaller part of the Central and some limited areas of the South Adriatic. Therefore, the North Adriatic is characterized by sandy and the South Adriatic by muddy sediments, while the Central Adriatic is a transitional area [4]. The distribution of sediments in the northern and southern parts of the Adriatic shows that the decrease in sediment particle size is conditioned by the depth and intensity of sea currents [8].

The coast of Montenegro is built of rocks of different resistance (flysch, limestone, and dolomites). Hence, there is a very strong selective abrasion [9]. The coast is mostly rocky, with cliffs and ditches, interspersed with numerous natural sandy and gravelly beaches whose total length is about 55 m. Based on physical criteria, the coast can be divided into three main parts: Boka Kotorska Bay, Riviera Budva (middle part), and Bar – Ulcinj part [10].

According to Lepetić [11], clay is mainly present on the seabed in Kotor and Risan Bay. In the Bay of Tivat, besides clay, clayey silt and clayey silty sand can be found, while in Herceg Novi Bay the seabed is covered with clay, silty clay, sand, and clayey sand. The central parts of the bay are covered with fine terrigenous silt with detrital elements [12]. Underwater reefs are located in the coastal belt of the inner part of Boka Kotorska Bay (the bottom is sandy and muddy), as well as at the entrance to the bay and in the strait Verige (terrigenous mud) [13].

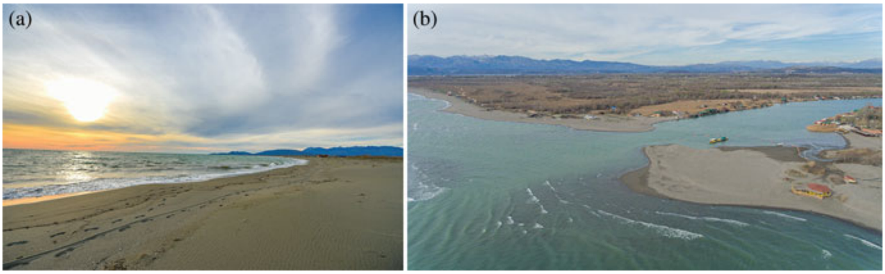

Fig. 2 Velika plaža (**a**), River Bojana (**b**) (photo by A. Pešić [14])

The middle part of the Montenegrin coast is characterized by sandy beaches, which are from several hundred meters to several kilometers long. On the coast of the Bar-Ulcinj region, limestone wreaths turn into capes (Volujica and Mendra) and depressions into sandy-pebble beaches or wetlands (Port Milena and the area of the Ulcinj saltworks). The largest beach, Velika plaža, 12 km long (Fig. 2a), 50–500 m wide, which ends at the mouth of the River Bojana (Fig. 2b), is situated in this region.

The nature of the seabed in front of the open coast is poorly known, and available information is based only on a few studies of benthic biocenoses of the South Adriatic [10].

The structure of the sedimentary bottom, in combination with some other ecological factors, affects the composition and distribution of living communities – biocenosis. In the Adriatic Sea, the most widespread are biocenoses of coastal terrigenous silt, detrital bottoms of the open island area, and muddy bottoms of the open sea.

Benthos and benthopelagic organisms show a particularly strong connection with bottom sediments, while pelagic organisms are not connected with the sediments or have a weak connection [15].

3 Physical and Chemical Characteristics of Seawater

3.1 Salinity

Seawater is generally characterized by physico-chemical properties, such as salinity, temperature, density, presence of gases, nutrients, etc. However, in certain areas or parts of water basins, there are slightly changed conditions compared to the average, which is exactly the case on the Montenegrin coast with the waters of Boka Kotorska Bay [15, 16].

The most important property of seawater is salinity, i.e. high content of specific salts and a constant ratio between macroconstituents. The Adriatic Sea has a high content of salt in water, about 38.3‰; it is lower than the salinity for the Eastern

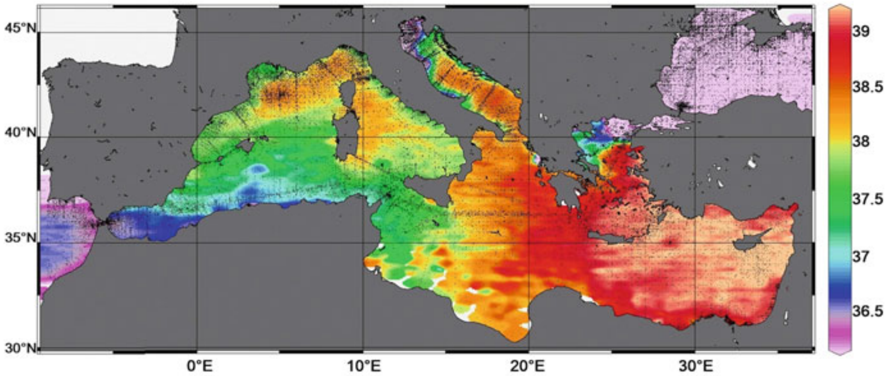

Fig. 3 Seawater surface salinity (‰) in the Mediterranean, Adriatic and Black Seas (https://geografijazasve.me/2017/05/16/salinitet-sredozemnom-jadranskog-crnog-crvenog-i-sjevernog-mora/)

Mediterranean (about 39‰) but higher than the salinity for the Western Mediterranean (about 37‰) (Fig. 3). With the inflow of saltier Eastern Mediterranean water into the Adriatic, and on the other hand, by the influence of freshwater from the land, the salinity of Adriatic water decreases from south to north and from the open sea to the coast [15–18].

In addition to the normal annual fluctuation, there are multiannual salinity fluctuations in the Adriatic as a result of the water masses exchange between the Adriatic and the Eastern Mediterranean. The Adriatic Sea has two annual minima (May, December) and two annual maxima (February, September) [4]. In some years, the saltier Eastern Mediterranean waters enter the Adriatic more strongly, the "Adriatic ingression," which significantly increases the salinity, to 39‰ [4]. Such water is the saltiest and warmest of all types of water that can be distinguished in the Adriatic Sea. The Eastern Mediterranean intermediate water significantly affects the overall water dynamics in the Adriatic Sea.

3.2 *Temperature*

The temperature of seawater is a very important parameter that affects its physical, chemical, and biological properties. The Adriatic Sea is located on the border between the subtropical and temperate climate zone. The continental influence is stronger in the northern part, while the Mediterranean influence is stronger in the central and southern parts, which is why the Adriatic Sea is a warm sea [19].

The Adriatic Sea is characterized by a significant annual sea surface temperature change. The water temperature in its deepest layers is almost always above 11–12°C. The sea is coldest during the winter period when the surface temperature drops to about 7°C. During the summer period in the open part of the Adriatic, the surface temperature is around 22–25°C, and in the South Adriatic and Istria up to 27°C. The temperature of seawater at the bottom can drop to 11.5°C (Jabuka pit) or 12.7°C (South Adriatic Pit). In winter, the average temperature of the entire water column in the North Adriatic is 8–10°C lower than the water column temperatures in the South Adriatic [20]. Surface temperatures in the coastal area recorded the highest values during July and August and the lowest in February.

In the warmer part of the year, especially in summer, the temperature rise or thermocline is formed at a depth of approximately 10–30 m. There, at a depth of just a few meters, the decrease in water temperature is the fastest. At the beginning of winter, due to the cooling of the surface layer, the isotherm is established, first at a higher temperature (around 18–19°C), but due to the cooling, its temperature becomes lower. The cooling of the sea is stronger in the North Adriatic and near the coast [1, 4, 15, 18].

3.3 Nutrients

Phosphates and carbonates are the most important salts in the seawater due to their role in primary production. 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 washed away from the coast and land, while small amounts of seawater phosphates are produced by electrical discharge in the atmosphere. The largest amount of phosphates and nitrates in the seawater derive from processes of organic matter degradation.

The Adriatic Sea is poor in phosphates and nitrates and is classified as a low productive (oligotrophic) sea. Due to different morphological and hydrographic properties, certain parts of the Adriatic Sea are characterized by different productivity. The relatively low productivity of organic matter, as well as the low content of nutrients in the South and mostly in the Central Adriatic, periodically increases due to the entry (ingress) of saline and warmer water from the Eastern Mediterranean. These waters bring higher amounts of phosphate that enable more intensive development of phyto and zooplankton organisms, used as a food by other heterotrophic organisms [21, 22].

3.4 Water Dynamics

Geomorphological features of the Adriatic Sea, its shape and depth significantly affect the dynamics of water masses. According to the origin, sea currents in the Adriatic Sea belong to the gradient currents [19]. Due to the movement of water masses, the Adriatic Sea is divided into three separate horizontal layers: surface, intermediate, and bottom, which have a more or less independent composition of currents although they affect each other to some extent [1, 4, 15].

In the surface layer (to 40 m depth), the flow is cyclonic, i.e. the water flows in the pool counterclockwise. During winter, the upward current prevails, while in summer the outgoing current is dominant. The surface current in the Adriatic Sea ranges from 0.3 to 0.8 knots and is faster along the western side compared to the eastern. In the intermediate layer in the South Adriatic (depth from 40 to 400–500 m) the inflow current prevails throughout the year, while in the bottom layer the outflow prevails, which is especially pronounced in winter when it occurs as an equilibrium flow of water ingress into the surface and intermediate layer [17].

4 Marine Pollution

Global trends are leading to an increasing number of facilities on the coast. The construction of many small ports for all kinds of ships and boats in natural bays, as well as an adaptation of the coast to the tourism development and different purposes, leads to an ecological risk in the Adriatic Sea, in particular.

The South Adriatic is the least polluted area of the Adriatic Sea and at the same time one of the least polluted areas in the Mediterranean. The Montenegrin coastal waters are still under threat by anthropogenic eutrophication due to the great quantity of waste (mostly liquid), resulting from human activities on land. These liquid wastes are dumped directly into the sea without any previous treatment. The wastewater is discharged from old sewage systems into the sea at the distance of a few tens of meters from the shore (rarely at greater depth).

Each of the wastewater outlets, even the one that is completely functional and containing a diffuser, is a potential pollutant. Such locations should be evaded when farming sea cultures, and they should be as far as possible from natural spawning grounds and locations with fish fry (these are most often present at mouths of rivers and streams or around underground freshwater springs, as fresh and seawater mix there).

Marine pollution is a major threat to marine ecosystems. It has been defined as "the introduction by man, directly or indirectly, of substances or energy to the marine environment resulting in deleterious effects such as hazards to human health; hindrance of marine activities, including fishing; deterioration of seawater quality; and reduction in amenities" [23]. Most of the people live within 150 km of the coast and marine pollution occurs as a consequence of increases in population density and industrialization, Fig. 4. The problems of marine pollution are generally limited to coastal waters rather than the open ocean, with the main impacted areas being estuaries, fjords, rias, and their adjoining shelf seas [24]. The sources of marine pollution can be divided into land-based sources, air-based sources, and maritime transportation (which include accidental and purposive oil spills, dumping of ship garbage, etc.). Of course, because marine pollution is defined as a human activity, and humans are land creatures, it might be semantically correct to assert a land-based origin for all marine pollution.

Fig. 4 Marina – Porto Montenegro (Photo by D. Joksimović)

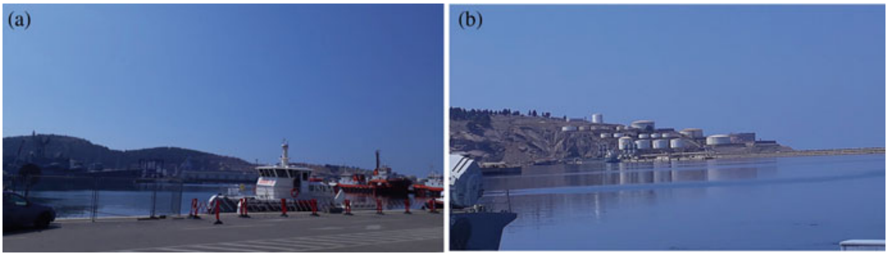

Fig. 5 Port of Bar (Photo by S. Gvozdenović)

The wastewaters of different branches of industry are often not treated sufficiently, so they make unaesthetic conditions in the sea or on its surface (spills of oils, grease, petrol and derivatives, detergents, chemicals). Therefore, they induce great damage to tourism, as they increase the pollution level in coastal areas set apart for tourism.

Disposal of flammable materials into the sea or their transfer between ships leads to high risks (Fig. 5). Each ship is a potential polluter of the sea. Ships in transit, when changing a type of cargo, wash the tanks and dispose the waste materials into the sea. The most common material disposed from ships is oil, and even small quantities of oil can damage great areas of the sea surface. On the surface, oil forms a thin layer that quickly spreads under influence of sea currents, winds, tides, and waves, remaining on the surface for a long time. Oil pollution is also negative for hygienic conditions and can negatively impact tourism.

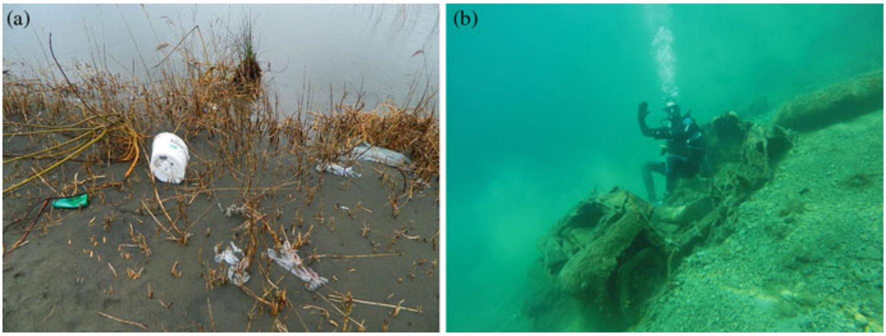

Fig. 6 Marine litter (Photo by M. Mandić [25])

Plastic pollution is being intensively studied and widely reported. Currently, microplastic contamination has moved into the focus of environmental research, with numerous studies addressing the occurrence of microplastics in the water column, in sediments, and filter-feeding organisms, Fig. 6. A major challenge is to identify the effects of microplastics on wild fauna, as well as to understand the trophic transfer of the particles among trophic levels. Several studies have reported the presence of microplastics in marine vertebrates, implying a direct uptake, or trophic transfer to the highest levels of the food web [26].

As a conclusion, it is imposed that determinations of physico-chemical parameters should be accompanied by appropriate biological tests. Life originated in water and without clean and healthy water there is no life. Natural waters contain numerous dissolved substances, many of which are part of not only biological water systems but also other animal and plant species and participate in many processes that take place in living organisms.

As long as chemical composition changes occur within certain limits, water can be considered as unpolluted, so environmental impacts are not observed. Anthropogenic water pollution with inorganic substances originates from extraction and processing of mineral raw materials, metallurgy, energy and chemical industry, agricultural production, traffic, landfills.

An important factor in water pollution is the atmosphere polluted with gaseous, liquid, and solid substances. Significant amounts of metals come from municipal effluents through metabolic waste, corrosion of pipes as well as from the resulting products of industrial activity in the settlements.

Water can receive large amounts of pollutants. Regardless of its enormous power of self-purification, certain pollutants, including most heavy metal ions, lead to a significant change in water quality [27]. The greatest danger for water quality deterioration by heavy metal ions is represented by wastewater. The effects of water pollution with heavy metal ions are diverse, and they are first manifested through plants as the most sensitive organisms in the plant-animal-human chain, where they are included in the food chain.

Due to the strong development of the Adriatic-Ionian region (ADRION Region), primarily because of the urban expansion both in coastal and inland areas, intensified maritime traffic, and hydrocarbon extraction activities near the coast, there is a high risk of pollution in this area. To assess and prevent the pollution caused by various hazardous substances, reliable monitoring and evaluation programmes have to be developed. Thus, EU Directives (WFD – Water Framework Directive, MSFD – Marine Strategy Framework Directive) and Barcelona Convention protocols were adopted within the Mediterranean Action Plan of the United Nations Environment Program (UNEP-MAP). The main goal of these directives, besides the assessment of pollution levels, is to implement certain measures in order to prevent and/or mitigate possible hazardous impacts on the marine environment. Common and agreed protocols for pollution monitoring have to be the basis of this integration process. Marine ecosystem-based management, aiming to mitigate human impacts on the world's oceans, has become a very important issue during the last years. However, it turned out that its implementation can be very challenging [28–31]. In order to understand the specific properties, stressors, interactions, and weaknesses of marine ecosystems, both local and regional, and how to effectively manage complex coastal systems, the complementary focused analyses are required [32–34].

This book will for the first time combine all the knowledge about marine chemistry pollution of the Adriatic Montenegrin coast, which is the result of many years of scientific research of the Institute of Marine Biology (Kotor, Montenegro) with associates and partner institutions. This book will cover all aspects of marine chemistry, from the hydrographic and oceanographic characteristics of seawater, the toxicity of heavy metals in the marine environment, the quality of marinas and maritime areas, to the legal regime for the protection of the marine environment from pollution. Also, the volume is focused on a specific area and research that have a wide appeal in the scientific community. It also provides an excellent opportunity to review a specific topic, examine previously untitled aspects, and develop and share new approaches, especially between younger scientists.

About 50 scientists joined from different research institutes and faculties from Montenegro, Serbia, Croatia, Italy, and Russia contributed to the writing of 23 chapters in this book. The book summarizes the basics of pollution, working to use language understandable to those with a limited science background, while remaining useful to those with more. The impacts of pollution on environmental health receive greater attention in this edition. The first set of chapters introduces the general hydrographic and oceanographic characteristics of the South Adriatic Sea, including rivers, forests and agriculture, and regional climate change of the Adriatic Montenegrin coast. The next set of chapters provide basic information on pollution, the concerns that they pose, their sources, and the issues that it poses, as well as information about pollution reduction. The important set of chapters presents data about heavy metals and marine litter, pollution from fish farming activities, and environmental quality of the Adriatic marinas.

We would like to remind here that "The Montenegrin Adriatic Coast" is published in two volumes: "Marine Chemistry Pollution" (present volume) and

"Marine Biology Environment," and these are follow-on volumes after our previous book "The Boka Kotorska Bay Environment" published in Springer in 2017 [35].

The editors of the book are authors of the reference monograph "The Adriatic Sea Encyclopedia" [36], which is based on the Russian version of the Encyclopedia published in 2014 [37] and the Second edition in 2017 [38]. This updated English version was published in Springer at the end of 2020.

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Hydrographic and Oceanographic Characteristics of the Southern Part of the Adriatic Sea

Branislav Gloginja and Luka Mitrović

Contents

Abstract This chapter presents a short summary and a general overview of the Adriatic Sea, particularly the southern part. The Adriatic Sea encompasses the area between Balkan Peninsula and Apennine Peninsula, at geographic latitude 39°45´ N and 45°45´ N, and geographic longitude 12°15′ E and 19°45′ E. The south border in the whole region represents the Strait of Otranto and goes through the line joining Cape St. Maria di Leuca (Italy) – north coast of Corfu island (Greek) – mouth of Butrintit River (Albania). The longitudinal axis measured from the mouth of the River Butrint (Albania) to the Porto di Lido (Italy) is 475 nautical miles and width-axis, perpendicular to the longitudinal, from the Port Omiš (Croatia) to the port Vasto (Italy) is 117 nautical miles. Three principal water masses are presented in the Adriatic Sea the Adriatic Surface Water (AdSW), the Levantine Intermediate Water

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(LIW), and the Adriatic Deep Water (AdDW). The circulation is mostly counter-clockwise or cyclonic, with a flow towards the northwest along the eastern side and a return flow towards the southeast along the western side. The cyclonic gyres vary in intensity according to the season and the sub-gyre of the southern Adriatic tends to persist throughout the year. In the Adriatic Sea prevailing mixed type of tides with a relatively high percentage of salinity.

Keywords Adriatic Sea, Bathymetry, Circulation, Gyres, Hydrography, Montenegro, Oceanography, Tides

1 Introduction

The Adriatic (Fig. 1) is the most continental basin in the Mediterranean Sea (excluding the Black Sea), is enclosed between two mountain chains (Appennini and Balkans), and elongated latitudinally. It has a major axis (oriented from SE to

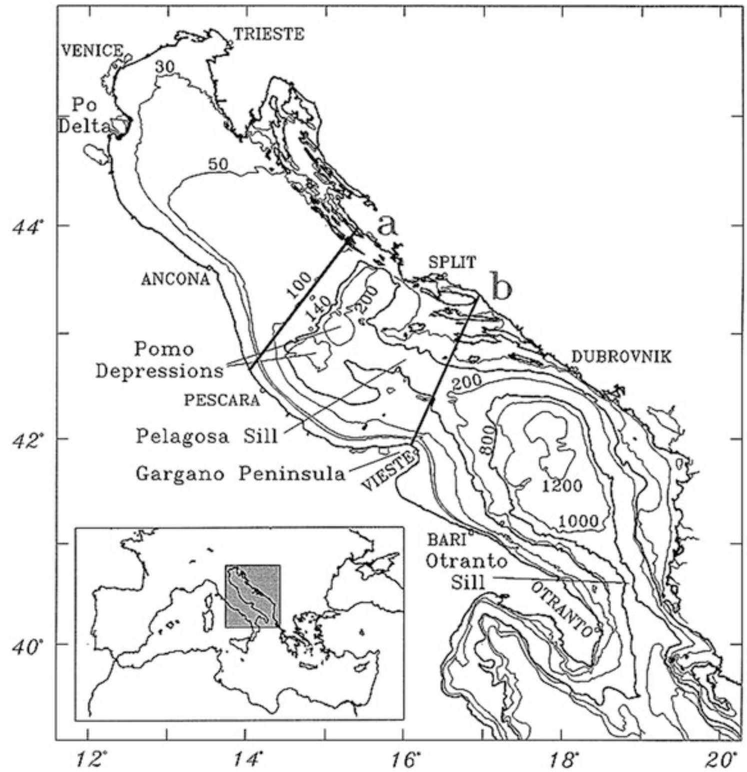

Fig. 1 The Adriatic Sea coastline and topography. Lines a and b define the northern, middle, and southern subbasins

NW) with a length of 800 km and a mean width of 180 km, and is connected to the Ionian Sea by a strait (Otranto) only 74 km wide [1]. The basin shows clear morphological differences, along its longitudinal axis and the transversal one as well, and it is divided into three subbasins [2].

The northern subbasin spans from the northernmost part to the 100 m bathymetric line (part a Fig. 1). The shallowest part of the Adriatic Sea is in the Gulf of Trieste where depths do not exceed 25 m, and up to the line joining Pula-Ancona the greatest depths are up to 50 m. From this joining line, the sea bottom descends in a long and narrow pit, which extends from the island Žirje towards Ortona, named Jabuka Pit with greatest depth of about 240 m. From the Jabuka Pit, the seabed rises to the wide and flat submarine sill (Palagruza Sill), with greatest depth of about 130 m.

The Middle Adriatic is a transition zone between the northern part and the southern subbasin (part b Fig. 1). It is an enclosed area from the 100 m bathymetric line (contour) to the Pelagosa (Palagruza) Sill.

The southern subbasin extends from the coast, between Islands Lastovo and Vis, up to north part of the Peninsula Gargano and on it are Islands Palagruža, Pianosa, and Tremiti. South of the Pelagosa Palagruža Sill, the seabed descends steep into the Southern Adriatic Pit (SAP) with greatest depths in the Adriatic Sea. However, there exists different data about the greatest depth. The Southern Adriatic is 80% of the total volume, with an area of 57,000 km^2, an average depth of 450 m, and a maximum depth of 1,233 m (Fig. 2) and contains a comparatively large bathyal basin with shelf surfaces of varying width; the continental shelf is limited in the Strait of Otranto, 750 m deep and 72 km wide, where important water exchanges with the Ionian Sea take place [3]. In the Strait of Otranto, the seabed again rises on undersea sill on the joining line Otranto – Vlore, the greatest depth is about 740 m. The depths in the channels between islands are about 60–80 m, and depths over 100 m are measured only in Kvarneric and Velebit channels.

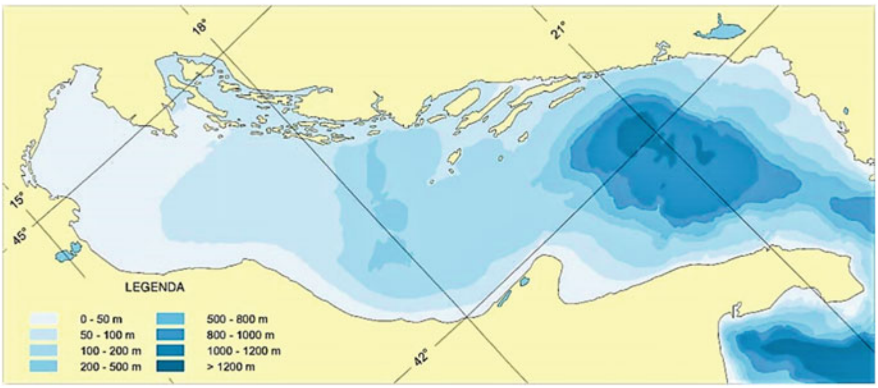

Fig. 2 Bathymetry chart Adriatic Sea (Source: According to [4])

2 Hydrographic Characteristics

2.1 Coast

Two big mountain ranges extend side-by-side along with the direction of the Adriatic Basin, one of them on the Balkan Peninsula and the other on the Apennine Peninsula. These two ranges in the northwest of the Alps continue, creating a bow like an amphitheater around the Adriatic Depression. On the east coast mountain Dinaric chain extends in the direction of NW–SE, parallel to the coastline and the island of the archipelago, and in some places just near the coast. In the central part of the Dinaric Alps, the mountain chain changes direction in the W–E, moving from the shore, so that the direction of the island archipelago, in this section, is the same as the direction of mountains on the mainland.

2.2 Islands

Except for several islands and islets south of Vis Island, between 42 and 43 parallel, all Adriatic islands extend close by its eastern coast. Cape Ploča divides them into two large groups: the north one extending in an almost parallel direction with the coastline and the south one in which bigger islands are extending in the west–east direction. Orographic forms on all islands are very characteristic points for quick and good orientation.

2.3 Seabed

Topographic and morphological forms of the undersea relief are the results of tectonic movements, abrasion, or erosion when this part of the bottom was land or coastal area. The roughness of the seabed is constantly softened by the deposition of recent sediments. It is a slow and continuous deposition. Numerous rivers bring to the Adriatic huge amounts of sediment. Sediments of certain rivers are constantly moving the coast at the expense of the Sea. The Lombardy rivers mostly embark the shallow seabed of the Southern Adriatic and move the coast further into the sea, so the Adria Port by which the Adriatic gain the name is now located 38 km from the coast, and the Roman ports Aquileia and Ravenna are deep in the inside. Due to unequal distances from the coast of the same depths and different increases of the depths, it can be distinguished into two main areas of sedimentation: the coastal area and the area of shallow sea. Coastal area is narrow, somewhere a few meters wide and elsewhere a hundred meters. In this area is stronger erosion than sedimentation factors, such as waves, tides, and currents. Area of the shallow sea covers the coastal area section, up to 1,000 m isobaths, and that means the whole Adriatic, except a small part south of Bay of Kotor. In both areas, sedimentation is influenced by surrounding land. Freshwater which from the land comes into the sea is rich in sediment which is deposited at great distances from the coast. Lombardy rivers, especially River Po, deposit a great sediment amount far from the mouth, along the Western Adriatic coast. As well, rivers on the eastern coast influence the sedimentation in the Adriatic, but it is slightly in relation to the deposition of rivers from the Lombardy area.

2.4 Tides

In the Adriatic Sea tides are of mixed type, with a pronounced inequality in height. In syzygy (new and full moon) tides are semidiurnal (12 h period) and in quadrature (first and last quarter) they are diurnal (24 h period). In transitional moon phases occurs mixed tides. Development of tides, i.e., the progress of tidal waves is shown by cotidal lines – lines of the equal arc delay (arc delay is the time interval which passes between Moon culmination and performance of high water; Figs. 3 and 4). In syzygy when tides are semidiurnal, in the Southern Adriatic phases are equal on its east and west coasts, and in the middle and Northern Adriatic they increase counterclockwise around the point between Ancona and Pag. This rotation of tidal wave is called amphidromy, having its center as the amphidromic point. Rotation of tidal wave lasts for 12 h and is equal to the period of a complete semidiurnal tide oscillation. The consequence of amphidromy is that the tides in middle and Northern Adriatic at all places through which passes cotidal lines different by 6 h so that while high tides occur on one coast, low tides occur on the other. Tidal amplitudes rise suddenly from the amphidromic point to the north, while to the south rises slower. In quadrature when tides are diurnal amphidromy is slower. High and low waters occur at the same time all along the basin, i.e., tides are in the phase. Tidal amplitudes are smaller than in syzygy, rising from the south to the north. In general, tidal amplitudes rises from the south to the north. From the Otranto Strait to Bakar this rise is small,

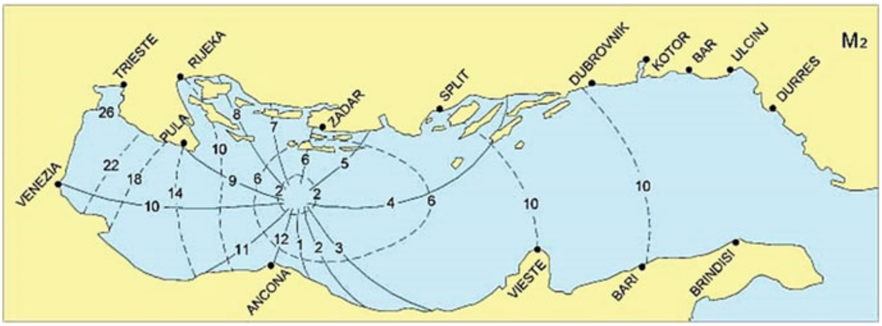

Fig. 3 Cotidal lines (–) in hours and lines of equal amplitudes (– – –) in centimeters for major semidiurnal component M2 (Source: According to [4])

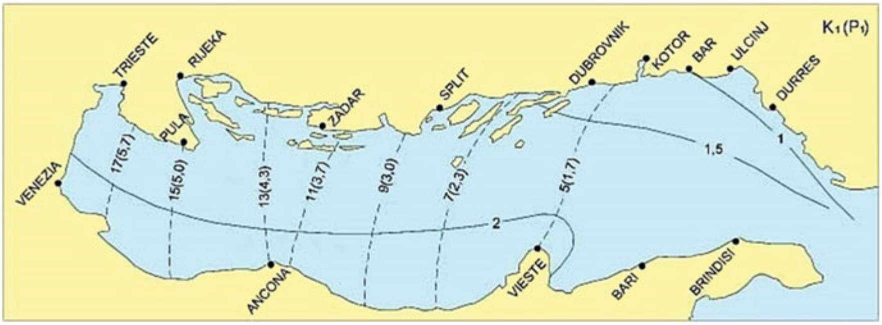

Fig. 4 Cotidal lines (—) in hours and lines of equal amplitudes (— — —) in centimeters for diurnal components K1 i P1 (Source: According to [4])

whereas from Bakar to the north it is great due to a rapid decrease in depth and the Adriatic Basin cross section [4].

Almost a regular tidal course is distributed by oscillations of the sea level influenced by atmospheric factors: air pressure and wind. With an increase of air pressure the sea level decrease and vice versa, with a decrease of air pressure the sea level rises. A change in air pressure of 1 hPa causes a change in the sea level of 1 cm. Strong winds, depending on wind direction, bring water to the coast or carry it off the coast, also causing oscillations of the sea level. Increase in air pressure and strong, persistent north winds (Bora and Tramontana) may cause a decrease in the sea level of up to 50 cm in the South and Middle Adriatic, or up to 60 cm in the Northern Adriatic. Decrease of air pressure and strong, persistent south winds (Sirocco, Libeccio) may cause a rise in the sea level of up to 80 cm in the Middle and Southern Adriatic, or up to 150 cm in the Northern Adriatic, which may cause floods in some ports [4].

3 Oceanographic Characteristics

The Adriatic Sea, with its surface of about 138,600 km^2 and its overall depth of 240 m, comprises a volume of roughly 35,000 km^3, occupied for 5% by the northern region, for 15% by the middle one, while the southern region occupies 80% of the total volume, with an area of 57,000 km^2 and an average depth of 450 m [5, 6]. The Adriatic supplies up to one-third of the freshwater flow received by the entire Mediterranean. It is estimated that the Adriatic's entire volume is exchanged into the Mediterranean Sea through the Strait of Otranto every 3–4 years, a very short period and likely due to the combined contribution of rivers and submarine groundwater discharge [7]. Duration of 150–168 days is estimated as the residence time in the Adriatic Sea for a drifting particle [8].

3.1 Currents

The general circulation is cyclonic with a northwest flow along the eastern coast and a return southeast flow along the western coast. There are three principal water masses in the Adriatic Sea: the Adriatic Surface Water (AdSW), the Levantine Intermediate Water (LIW), and the Adriatic Deep Water (AdDW), Fig. 5 [9].

The basin is characterized by the sinking of colder and heavier waters during the winter, by a relevant surface warming during the summer season and heavy rainfalls and river runoff (in particular by the Po River) during spring and autumn [2, 10]. The circulation is mostly counterclockwise or cyclonic, with up to three closed cells (in the southern, middle, and northern basin, respectively; Fig. 5). Both intensity and location of the coastal currents (Western Adriatic and Eastern Adriatic Current) and of the gyres above the Middle and Southern Adriatic Pits have significant seasonal variations [10]. The typical winds Bora and Scirocco blow along the eastern coast of the Adriatic Sea, prevailing during the colder part of the year and their role is fundamental to trigger and regulate water masses circulation. In summer is prevailing nice and dry weather with characteristic NW wind (maestral). Annual wind shows a NNW-SSE directionality in the Southern Adriatic Basin while an omnidirectional behavior may be observed at higher latitudes. Near the coastal line, winds show more irregular occurrences due to interactions with the local geomorphology. During the warmer seasons, sea and land breezes are rather frequent

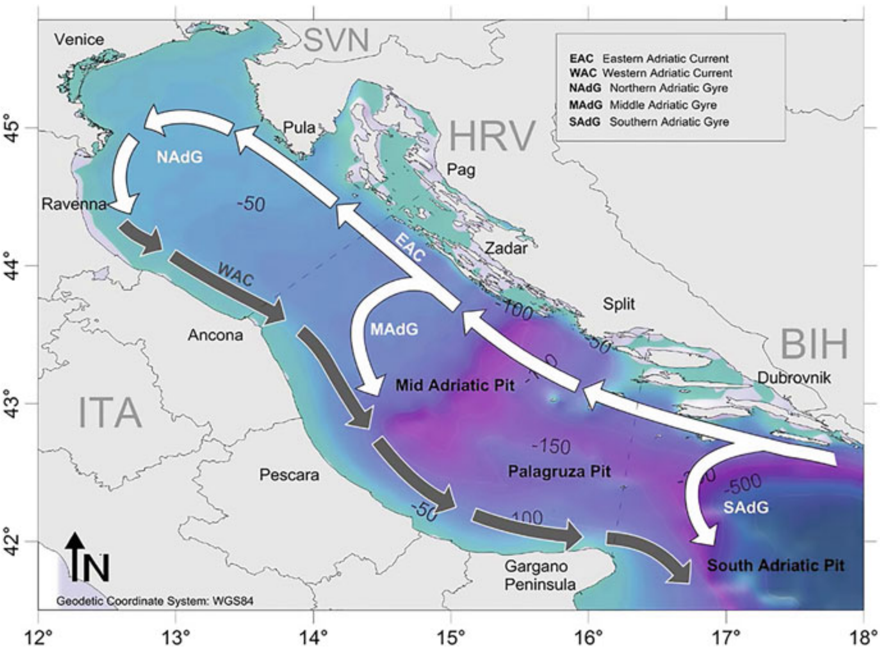

Fig. 5 Three paths followed by the main seasonal Adriatic currents

[11]. The overall Adriatic thermohaline circulation arises from the opposite effects of the thermal and haline forcing. The reciprocal variability of heat and water fluxes may be responsible for the variability of local circulation features. The Western Adriatic Current is due to the lower density of coastal waters than offshore waters (controlled to a large extend by the runoff of the Po and other Italian rivers). These waters are exchanged through the Strait of Otranto and replaced by other warmer water masses producing the Eastern Adriatic Current. The deep waters of the Adriatic can be separated into two categories: the first, clearly formed in the Northern Adriatic Region, cool and relatively less saline, found in the North and Middle Adriatic, and the second of much higher temperature and salinity, in the Southern Adriatic [2]. Deep waters production in the Adriatic Sea is an important process affecting water-mass characteristics [10] of a large portion of the Eastern Mediterranean and plays a crucial role in the complex and climate-sensitive thermohaline system of the Eastern Mediterranean [12]. The necessary conditions for the production of the deep waters are generally met in the Adriatic Sea, even if the Adriatic Sea is extremely sensitive to interannual variations with some winters rich in their production and others hardly forming any [10].

The climate characteristics are manifested in pronounced extremes of sea temperature, salinity, and other characteristics. Differences in the surface sea temperatures between summer and winter periods are high, as well as differences in salinity during the seasons. Winds which blow in the Adriatic are not of permanent character; therefore, they cannot establish certain circulation system, and even they influence the currents, especially in the coastal area.

3.2 Sea Surface Temperature

The Adriatic Sea is a warm sea with pronounced annual fluctuation of sea surface temperature. During the winter when under the influence of meteorological factors cooling is the most intensive, sea temperatures fall to a minimum. At this time of the year, there are also greatest spatial differences in the sea surface temperature, and thus in the extreme northwest the sea temperature is about 7°C, while in the Strait of Otranto about 14°C. Temperature rises rapidly in spring reaching values about 17°C to 18°C all over the Adriatic. In summer, the sea surface temperatures reach values of 22–25°C, the open sea being warmer than the decrease, this cooling being more intensive in the coastal water due to the influence of continent, so that the open sea is warmer than the coastal waters. Sea surface temperature reaches values of 14–18°C. In the coastal area, sea surface temperature reaches its maximum in July and August and its minimum in February. In the open sea area, the extremes are about 1 month late [4]. The lowest temperature has been recorded in the vicinity of large river mouths and in the areas with submarine springs, as the seawater is very much diluted by freshwater: in exceptional meteorological conditions the sea surface in these areas freezes over. In certain years, the influence of the Mediterranean on the Adriatic is greater than usual, making surface temperatures in the Adriatic higher than average.

3.3 Sea Surface Salinity

Salinity of the Adriatic Sea is in average about 38.3 psu, which is lower than salinity in the East Mediterranean and higher than the one in the West Mediterranean. The Northern Adriatic has a lower salinity than the Middle and Southern Adriatic due to the influence of Alpine rivers (especially the River Po). In the salinity variation, the Adriatic has two annual minimums: in May and December, and two maximums: in September and February. In the years when Mediterranean influences more intensively on the Adriatic, saltier water from the Mediterranean enters the Adriatic and increases its salinity, so then the salinity is over the average values and sometimes reaches the values above 39 psu.

Both surface salinity and temperature fields show large-scale patchiness during the spring–summer seasons. The salt balance of the surface layer is clearly affected by freshwater river runoff and the maximum values of salinity are found in winter (37.40 psu), while minimum values occur in summer (36.79 psu). The surface temperature has a clear seasonal cycle with maximum values of temperature during summer and maximum mixed layer depths during winter [2].

In 2015 and 2016, in the Southern subbasin was performed 2 ESAW cruises (Evolution and spreading of the Southern Adriatic Waters). The transect was between Bari (Ba; Italy) and Dubrovnik (Du; Croatia, Fig. 6).

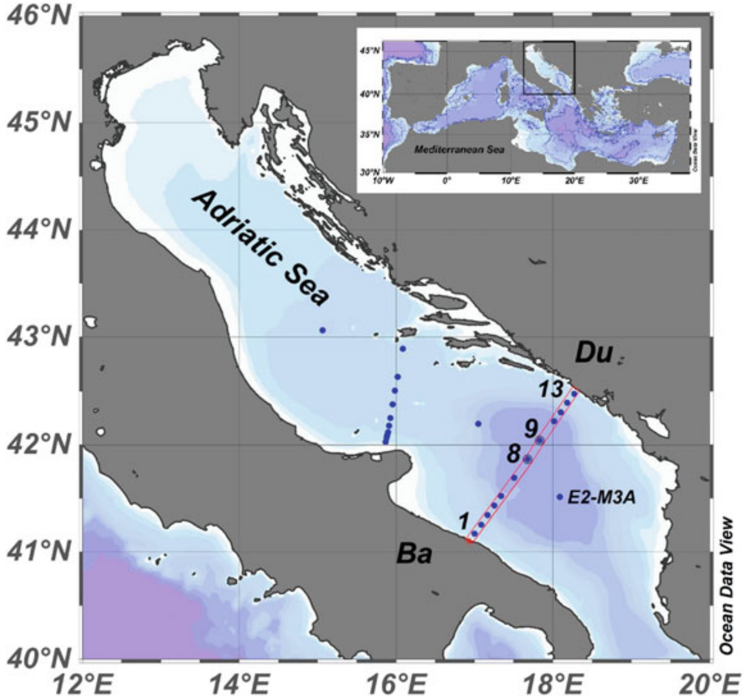

Fig. 6 The Adriatic Sea – Red line indicates the Southern Adriatic Pit transect

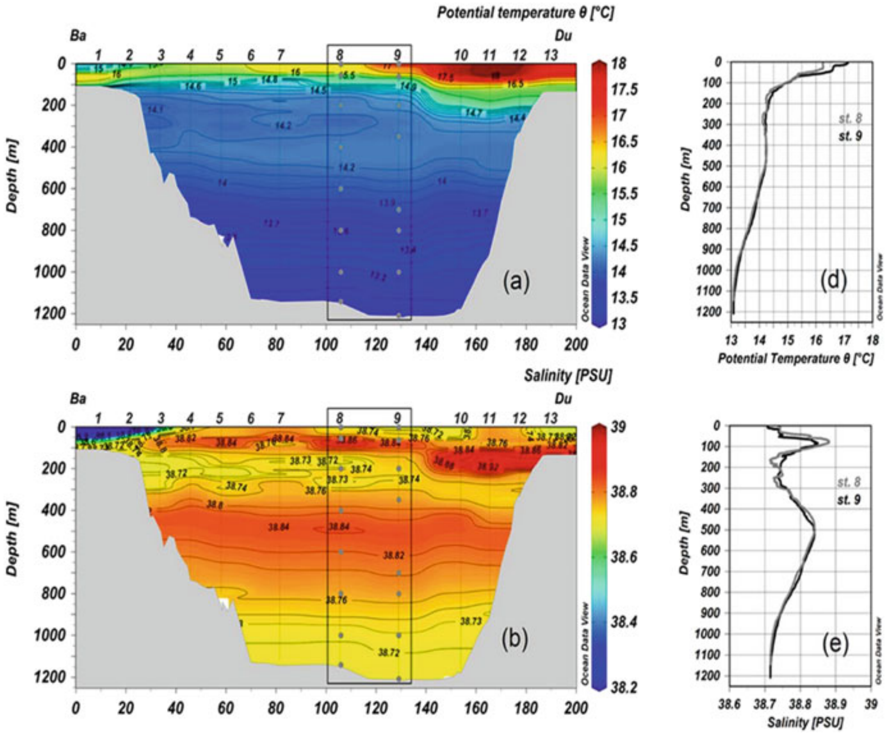

Fig. 7 Vertical distribution of (**a**) potential temperature, (**b**) salinity, and vertical profiles data collected in December 2015

The parts of data (temperature and salinity) collected during winter cruise on the station 8 and 9 (data collected in the Southern Adriatic Pit) are presented in Fig. 7.

In December 2015, the upper layer (the water column between the surface and 100 m depth) along the Ba-Du section was quite heterogeneous, which might be due to the contrasting water masses transported into the SAP by the Eastern Adriatic Current along its eastern side [2] and by the Western Adriatic Current along its western side (Fig. 7). In particular, relatively warm and saline waters moving along the eastern margin of the SAP protruded offshore, reaching the central zone of the pit (Fig. 7a, b) due to local cyclonic circulation. There complex features, such as mesoscale eddies, determine large thermohaline differences among close stations, especially between stations 8 and 9 [13]. The upper intermediate layer, between 100 and 400 m, although more homogeneous, was characterized by the presence of water with properties (θ > 14.30°C and S up to 38.95 psu) typical of the Ionian surface water and the LIWs/CIWs (Levantine/Cretan Intermediate Waters). In the central zone of the SAP, θ gradually decreased with increasing depth, while S had a structure with alternating fresher and saltier layers. Moreover, between 200 and 300 m depth, a branch of fresher water with local S minimum ~38.70 psu extended from the western flank towards the center of the pit (Fig. 7b).

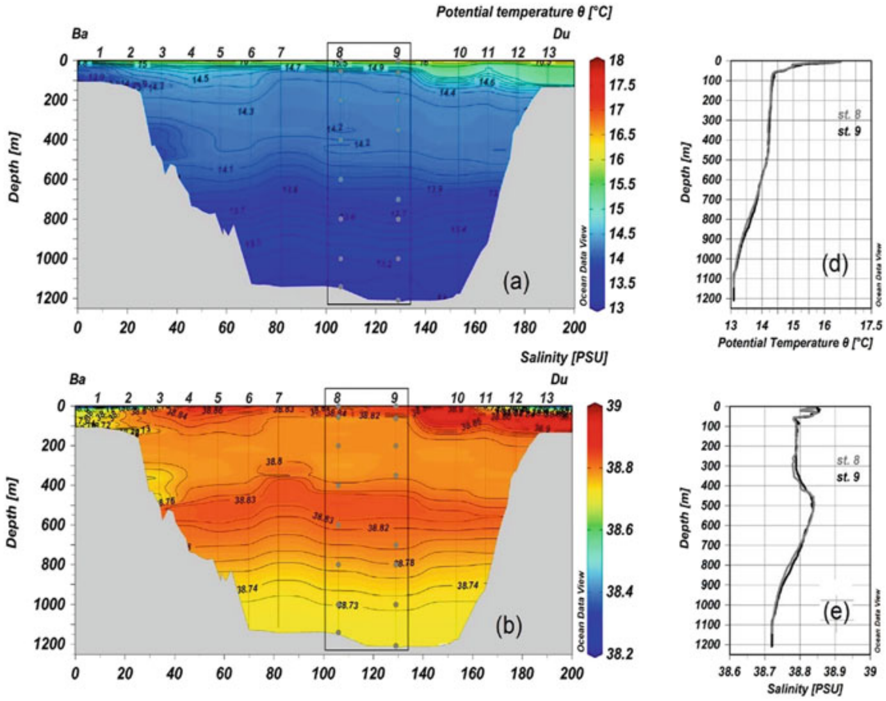

Fig. 8 Vertical distribution of (**a**) potential temperature, (**b**) salinity, and vertical profiles data collected in April 2016

In the lower intermediate layer, between 400 and 800 m, instead, S increased up to 38.84 psu, while θ slightly decreased down to 13.60°C. The deep layer (>800 m) of the SAP was occupied by relatively cold, less saline, and dense waters likely formed during previous winters in the northern Adriatic. At the time of the cruise (December 2015), θ and S in the deep layer had values of 13.10°C and 38.71 psu, respectively [13].

The data collected from the second cruise in April 2016 (Fig. 8) shows the largest differences with respect to the previous cruise in December 2015 particularly in the upper layer temperature, due to the season signal. The temperature differences between the western and eastern flanks, as well as between the surface and bottom layers over the western shelf, diminished with respect to December 2015 (Fig. 8). At the two nearby stations, 8 and 9, the thermohaline properties were almost uniform. The highest S values (~38.94) measured in April 2016, associated with the LIW influence, and were slightly lower than those observed in December 2015 (~38.95). From the physical parameters, we inferred that the doming structure, typical of the cyclonic circulation in the SAP, was much more enhanced in April than in December. This means that the subbasin-scale cyclonic gyre was probably stronger in April than in December, favoring lateral exchanges along the perimeter of the SAP. The lateral exchange between both coastal flanks and the middle of the transect seemed less active with respect to December 2015 [13].

4 Conclusion

The Adriatic Sea was explored in detail during the previous period. Hydrographic and oceanographic data are available and well explained. However, climate change has a great impact on the hydrographic and oceanographic characteristics of the Adriatic Sea; therefore, it is necessary to continue research in the future to obtain new information.

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Rivers of the Coast of Montenegro

Goran Barovic, Dusko Vujacic, and Velibor Spalevic

Contents

Abstract The Montenegrin coast, thanks to its hydrological characteristics of surface and groundwater, is a very interesting area. It shows an obvious example of the mutual influence of climatic characteristics on the geological base, which manifested itself in almost all its variations. In this relatively narrow space, the characteristics of water behavior in karst and their unpredictability have been shown. The immediate hinterland of the Montenegrin coast is known for a very high amount of precipitation that is emitted during the year without any surface flow. A certain number of flows has been ascertained in this region, but a very small number can be stated to have complete flow references. The largest number of streams has a torrential character and is in a very high degree of endangerment from various factors – pollution, occupation of the riverbed, disposal of various types of waste, natural flourishing, etc.

The research was performed in two phases, through topographic analysis on maps with a scale of 1:25 and through a field tour of the area to specify details that could not be determined on the basis of data from the map. Research has established that the catchment area of the Montenegrin coast has two separate units: the immediate

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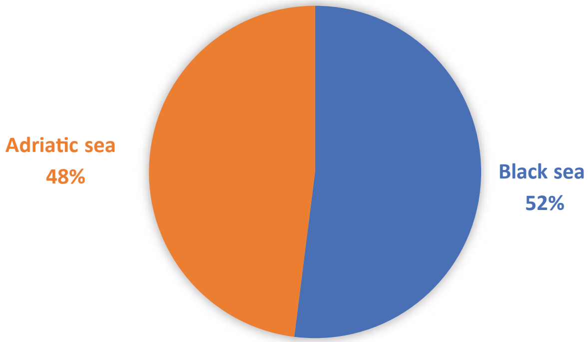
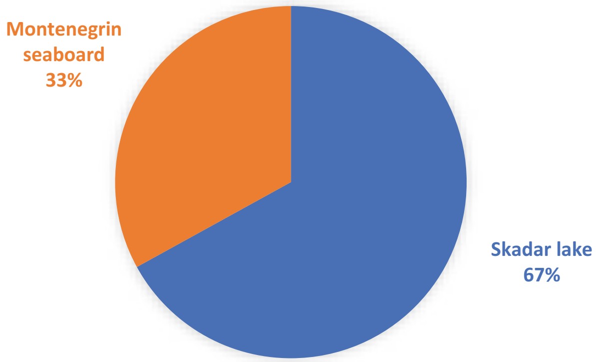
basin of the Adriatic Sea and the catchment area of the River Bojana. The paper is oriented towards presenting the state of surface waters and their morphometric characteristics, which have not been paid attention to in previous research. Previous inspections of watercourses in Montenegro have mostly been related to the lengths of large rivers without detailed analysis of small watercourses, which are mostly in the zone of the Montenegrin coast. A special feature of the data presented in the paper is the coordinates of the sources given for all observed watercourses and the calculation of the share of falls (from the source to the mouth) of the flow in its length. The paper presents tabular representations and data analysis by lengths, ranked by rows, as well as analysis of altitudes of sources. This is a very important element due to the characteristics of the relief that characterizes the investigated region, because the insight into the relief characteristics revealed a sudden change in altitude in a relatively small area.

Keywords Endangerment of watercourses, Karst, Montenegro, Morphometry, Rivers, Surface flows

1 Introduction

The territory of Montenegro is divided into two catchment areas, the Black Sea basin and the Adriatic Sea basin. The Black Sea basin is slightly larger and covers 7,188 km^2 or 52% of the territory and the Adriatic Sea basin covers 6,624 km^2 or 48% of the territory (Fig. 12). Of the 6,624 km^2 of the Adriatic basin, the largest part, or 4,460 km^2 (67%) belongs to the Skadar Lake Basin, which includes the Morača and Zeta Basins, as well as the immediate Skadar Lake Basin, while the remaining 2,164 km^2 or 33% of the territory belongs to the immediate Montenegrin coast, the Bojana Basin and the Trebišnjica basin (Fig. 12).





One of the relief unities in the area of Montenegro that has a clearly defined space is the zone of the Montenegrin coast. Its relief is clearly detached from the neighboring area of the deep karst, which has a great impact on it. The Montenegrin coastal area is separated by the peaks of the Orjen – Lovcen-Sutorman – Rumija mountain range from the inner part of Montenegro. According to the relief characteristics, this space can be assessed as narrow, with steep sides and several extensions.

The climatic characteristics of the area determine the large amount of precipitation that is excreted during the year. It is important to point out the characteristic that the mentioned barrier stops warm and humid air masses, so the highest precipitation is emitted in this area in relation to the rest of the territory of Montenegro. The amount of precipitation is indicated by the fact that the largest amount of precipitation in Europe (1,938–8,063 mm) was recorded at one point on the Orjen (Crkvice). However, despite such a large amount of precipitation, a relatively small number of surface flows have been recorded in this area, which is a consequence of the geological composition of the terrain, which will be elaborated in other chapters of this work. The study of the terrain clearly shows that the largest amount of water is lost in the karst base, and through very complex systems it appears on the surface or below the surface of the sea. The Montenegrin coastal zone has a variable distribution of precipitation during the year. The largest quantities are excreted at the end of autumn, during winter and spring. The annual amount of precipitation that is excreted on the Montenegrin coast can be seen through the following examples: Herceg Novi 1,867 mm, Budva 1,425 mm, Bar 1,377 mm. There is a slight decrease in the amount of precipitation as we move from west to east, and the reason is the height and geomorphological characteristics of the outback. The average annual value of air temperature in this area is 16°C.

In the area of the Montenegrin coast, it was stated that all waters are drained towards the Adriatic Sea. In further regionalization, we can single out the direct basin of the Montenegrin coast and the River Bojana. In the direct basin of the Adriatic Sea, 32 outflows were found, while 15 watercourses belong to the Bojana River Basin [1].

In the realization of the work and determining the characteristics of watercourses, in addition to consulting the literature, two methods were used:

1. Topographic analysis of space and determination of morphometric indicators for watercourses on maps 1: 25.
2. Field research and verification of measurement parameters from the map. This part is especially important when naming watercourses for which the name is not written on the map.

2 Rivers of the Montenegrin Coast

1. *Sutorina* is the biggest watercourse in the area of Herceg Novi. It is located in the west part of municipality. It is located at 95 m above sea level and receives two tributaries on the left side. The tributaries obscure Sutorina, especially after heavy rains. This problem was partially alleviated by channeling the lower part of the stream (about 4 km), which alleviated the obscure of the sea in the area around the mouth in Igalo [2].
2. *Presjeka* is a left tributary of the Sutorina. It originates from several smaller streams in Mojdež at 125 m, collecting water of Glogovac, Lovac, and Voda and others [2].
3. *Trtor* is a tributary of the Sutorina and represents an intermittent flow. Its source is the zone of the Ratiševina settlement, and the watercourse is very endangered by construction, communal, and other waste and is in the phase of overgrowing the riverbed.
4. *Izvor* occurs at an altitude of 302 m in the area of the village Trebešinj. The total length of the stream is 1,675 m, and with the included drop from the source to the mouth, it is about 1700 m.
5. *Ljuti Potok* originates south of the settlement of Kameno, below the road leading to Orien, at an altitude of 295 m (Fig. 1). The length of the stream is 1825 m, including a fall it is 1840 m. It flows west of the Lukovik elevation (395 m) and the hamlets of Matkovići and Tusupi, descending to Topla where it flows into the sea.
6. *Sasojevicki potok* represents the right stream which forms several smaller streams, and meeting with Sopot it forms Opačica. It originates in the hamlet of Sasovići at 170 m above sea level northwest of Kučansko polje. The length of the stream from Sasovići to Kućansko polje is 1.38 km.
7. *Sopot* occurs in the sides of the same name at 40 m above sea level in the region of Kuta. It is a short occasional stream 1.32 km long that flows peacefully through the northeastern and central part of Kutrsko polje. Similar to Sasojevicki potok, it is quite endangered by overgrowing, construction works, and waste disposal.
8. *Opacica* originates at 30 m above sea level from a spring cave that collects numerous streams from the outback of Sopot (Fig. 2). It flows through Kučansko polje and is a calm watercourse due to a small difference in the altitude of springs and estuaries. The length of the stream is 2,350 m and the fall does not affect its total length. According to research by M. Radulović [3] underground channels of

Fig. 1 Ljuti spring (Photo by G. Barovic)

this watercourse before appearing on the surface, descend to as much as 8 m below the sea surface, but the barrier of the Paleogene flysch does not allow mixing with sea water, so it is the only spring in Boka whose water does not become salty in summer. It receives several smaller occasional tributaries from the hamlets of Marici on the left and Nikičenovići, Brežina, and Magazin on the right.

9. *Manitovac* occurs on the slopes of Mamedovina at about 180 m above sea level, achieving a drop of 172 m over a length of about 2050 m. Even with this flow, the difference between the source and the mouth is not a significant factor in determining the total length.

It is necessary to emphasize that in the zone of the Morinj Bay, there are very strong Morinj springs which, according to research, drain the western and southwestern sides of the Orien. They are directly dependent on the amount of precipitation in the nearby outback, so during heavy rains springs and occasional streams that are up to 800 m from the sea start working. (Veliki spring, Suvi spring, and Svrčak). Numerous exploratory drillings were done in the outback of Morinj well in order to solve the water supply of the surrounding area, but it was determined that during the dry period, the water in all the springs became salty, which is why further works on their capture were abandoned [4].

10. *Sopot* is an occasional spring located along the road Lipci – Risan, at 40 m above sea level and the length of the stream is 75 m. Speleological and diving research

Fig. 2 Opačica (Photo by G. Barovic)

has determined that the Sopot canal descends to 35 m below sea level. The main canal, about 380 m long, alternately descends and climbs, so depending on the amount of water coming from the immediate hinterland, it is cut by siphons. Eventually, the main channel forks into two parts, a shorter left (20 m) and a longer right (100 m) but at the ends they turn into cracks. The water of Sopot occurs at two submarine springs – springs at 28 m and 36 m, which are clearly visible on the sea surface at larger inflows. With a larger amount of precipitation in the hinterland, the karst channel Sopot cannot accept all the water that comes from the hinterland, so it occurs at the dry cave entrance, for most of the year, forming a fantastic waterfall that flows into the sea from a height of 40 m. The waters of Sopot are saline, so they were not taken into account for the possible exploitation of drinking water [5].

11. *Spila Risanska* is located northwest of the settlement Risan at about 20 m above sea level, while its length is 245 m. Very similar to Sopot, Spila is a karst spring that is directly dependent on the immediate hinterland, the connection with the abysses of the Grahovska River, and also the zone of Dragalj, Zvečevo, and Crkvica, has been established by coloring. The results of the dyeing, which were performed in 1959, confirmed the connection of Spila with the Grahovska River, where it was determined that the dye traveled for about 3 days, during which it covered about 16.8 km with a drop of 745 m in height. Speleological research has established that the total length of the Spila Risanska canal is 435 m, of which 350 m are submerged canals, while the greatest depth of the examined canals is 72 m. As with Sopot, the waters of Spila are occasionally saline, but during the rainy period, i.e., strong inflows, they are used to supply water to Risan [5].
12. *Ljuta (Orahovačka ljuta)* belongs to the group of Orahovac springs and is located next to the road Perast – Kotor. In addition to Ljuta, there are two

other strong springs, Ercegovina and Cicanoca kuća, which have been tapped for the water supply of Kotor. Ljuta springs at 30 m above sea level and forms a stream about 325 m long. Ljuta represents, by the amount of water, the largest brackish spring in the Bay of Kotor. Speleological research investigated a part of the Ljuta canal, where it was determined that it descends to 120 m below sea level, and that a hydrological connection with Trešnjevo and Njeguški polje in the hinterland was determined. The coloring confirmed that the Orahovac springs have a connection with the catchment areas of the Kotor springs, which means that the hinterland of Kotor represents a unique aquifer from where water is fed besides the mentioned (Orahovac springs) and the Kotor springs, Gurdić, Škurda, and Tabačina [5].

13. *Škurda – Tabačina* belong to the group of Kotor springs. They are located along the western gate of the city and together with Gurdić they have a very complex hydrological structure and connection with the abysses on Krsac (part of Njeguško polje). The springs are of ascending siphon character, which are supplied with water through two branches. One, the right branch, comes from the direction of the Volujak elevation (1,091 m above sea level) and the other, the left branch from the direction of Krsac. These two branches meet at about 320 m above sea level, from where a series of narrow surdup, cut into the Kotor sides, where, during heavy rains, it occurs at 28 m above sea level in the form of a waterfall. These springs are saline during weaker inflows, because their underground channels descend up to 12 m below sea level. These sources are tapped for the supply needs of Kotor [5].
14. *Gurdić* is one of the groups of Kotor springs and is located next to the eastern gate of the city. It belongs to the brackish springs, estaveles, and springs, depending on the inflow from the hinterland. Its source is about 12 m below sea level. About 740 m of underground channels were measured by speleological diving, of which 626 were filled with water. The explored canals have a siphon character and descend to about 51 m below sea level. The hydrological connection between Gurić and the abyss on Lovćen and Ivanova korita, as well as the spring of Tabačin, was determined by coloring [5].
15. There are several streams that occur in the southern foothills of Lovćen, of which *Koložun* stands out. It springs at 945 m above sea level and during the 11.7 km long stream it receives water from some smaller, intermittent streams. It originates on the southern slopes of Koložunske grede (1,427 m above sea level) and flows in the southeast-northwest direction, so near Šišić it changes the direction of flow to the northeast-southwest to Radanovići, where it returns to the initial route to Krtola Bay, where it flows into Tivat Bay field.
16. *Suha rijeka* is an occasional stream that occurs in the settlement of Glavatičići, at 185 m above sea level. It has a south-east-northwest direction, flowing between the Kablić elevation to the north and Skožna to the south, after almost 4.5 km it flows into the sea in the area of Bigovo Bay. This is an occasional flow that is active during the rainy season.
17. *Jaška rijeka* is a watercourse formed by the confluence of Lukavica and Drenovštica on the western slopes of Donja gora (348 m above sea level). This flow occurs at only 5 m above sea level and flows through Mrčevo polje

to Jaz Bay where it flows into the sea. Its course is short and is only about 2.5 km.

18. *Lukavci* is the upper part of the Jaška River. It is formed at 22 m above sea level on the northern slopes of Donja gora, collecting the waters of several temporary streams. It also has a relatively short course, like most watercourses in this zone, of 2.85 km.
19. *Drenovštica* is a tributary left of the Jaška river. It springs at 436 m above sea level in the village of Gornji Pobori. It flows from the spring to the southeast, bypassing the Trebaljevica elevation, and downstream it turns southwest towards the Grbaljska lastva, crosses Mrčevo field and, meeting the Lukavci watercourse, forms the Jaška river. Drenovštica is longer than the rivers from this zone, and at 4.9 km in length, it has a drop of 431 m.
20. *Građevica* River is formed at 307 m above sea level and downstream collects water from several smaller streams (Kaludrak, Piratac, Tolinjak) on the northern slopes of Dubovica, passing through Podostrog and Podmaine. It flooded the Budva field with its sediment. Of the approximately 3.4 km of the total flow, only the short lower part is canalized before the inflow on Budva beach. Like most streams on the Montenegrin coast, Građevica is endangered by unplanned construction, but also by dumping waste in the riverbed itself and the space that gravitates to it.
21. *Vještica* is, like the previous ones, an occasional stream, which occurs during heavy rains. It springs at 724 m above sea level on the southern slopes of the Cerovica. Its flow direction is north-south. During its course, from 4.18 km, it gathers smaller springs (Boretske vode and Košljun) to Bečićka beach where it flows into the sea.
22. *Bečićka River* originates in Brajići in the hamlet of Prentovići at 858 m above sea level. Descending down the steep side east of Kosmač, next to Čučići about the locality of Rafailovići, where it flows into the sea. The total length of the flow is 4.43 km, most of which is occasional flow, active only during heavy rains, and only part of Čučići is an active watercourse for a longer period of time.
23. *Šumet* springs at 270 m above sea level in the village of Denasi. It has an east-west direction in the length of less than a kilometer (0.98 km) to the beach of Sveti Stefan where it flows into the sea. In recent years, the watercourse has been significantly endangered by unplanned construction and irresponsible waste disposal.
24. *Đurmanski potok* springs at 242 m above sea level on the southern slopes of Lokvica. It flows past the settlements of Đurmani and Mišići to the Bay of Čanje, where it flows into the sea. The length of the stream is 3.2 km and with the same problems as the previous watercourses: turbidity, construction works, and waste disposal.
25. *Smokvica* (Fig. 3) is a watercourse which occurs at 43 m above sea level in the settlement of BRCA. It has a slight drop, but also a short course of 0.92 km. Drains water from the immediate hinterland (Mala Vrsuta 666 m above sea level and Jelica 426 m above sea level).

Fig. 3 Smokvica (Photo by G. Barovic)

26. *Željeznica* (Fig. 4) springs on the southern slopes of Sutorman at 580 m above sea level, collecting water from several springs (Pišutnica, Đolaza, Manduka, Duboki do, Banja, and Kučina) [4] flows past Gorna gora, Ribnjak, Zupca to the entrance to Barsko field where it flows into the sea reaching a length of 6.87 km. The lower part of the watercourse is canalized to reduce sediment and to not endanger the lower part of the stream as well as the beach next to which it flows.
27. *Kolijevka/Dumezića* stream originates at 880 m above sea level on the southern slopes of Vrsuta (1,183 m above sea level) south of Marka's head (1,064 m above sea level) flows east to Gornja gora where it changes its name to Dumezića stream from where it flows south where south of Ribnjak at 163 m above sea level. It flows into Kolijevka as its left tributary.
28. *Velja River* springs at an altitude of 260 m above sea level in the southern slopes of Rumija, east of the Tuđemili settlement. It flows towards Zupci, where it flows into Željeznica south of V. Brijeg at 62 m above sea level. The length of the watercourse from the source to the connection with Željeznica is 2.61 km.
29. *Rikavac* springs on the southern slopes of Kulumrija at 440 m above sea level, it flows southwest to the settlement of Čeluga, from where the further part of the stream is canalized, due to the large amount of sediment and the torrential character of the watercourse, which it brought with it from the upper part of the stream. In the earlier period, before the construction of the Port of Bar (1908–1912) the waters of Rikavac used to flood Barsko field and create problems for this part of the field. Due to this, a tunnel was dug through the hill Volusia, 1,050 m long, and thus the waters of Rikavac were conducted directly into the sea, which eliminated the mentioned problem.
30. *Vruća River* springs at 735 m above sea level in Mikulići on the southern slopes of Rumija. It flows west through the notch between the northern slopes of Lisina

Fig. 4 Željeznica (Photo by G. Barovic)

and the southern slopes of Mrjlik to Čeluga where it flows into Rikavac at 45 m above sea level. The hot river has a length of 5.59 km and, similarly to Rikavac, during heavy rainfall it carries with it a large sediment, which can partially endanger it.

31. *Grahovska River* is located in the field of the same name, where it originates in its northwestern part and disappears in abysses in the southeastern part of the field. A dam was built on it in the 1960s of the last century, which formed a reservoir. Today it has a length of just over 5 km (from the dam to the abyss). The reservoir was built for the purpose of irrigating the fields and increasing agricultural production.
32. *Brdela* springs at 170 m above sea level in Preskalja. It cut its course between Možura in the west and Brdela (western part of Briska gora). Leaving the gentle canyon valley, its course crosses into Ulcinjsko polje until it flows into the Solana pools.

3 The Catchment Area of the River Bojana in the Zone of the Montenegrin Coast

1. *Bojana* (Fig. 5) is one of the largest tributaries of the Adriatic Sea (Fig. 5). It flows from Skadar Lake and is directly related to the movement of water in it. The length of the Bojana watercourse is 39.63 km of which a part belongs to Albania (about 17.5 km). South of the village of St. Nicholas Bojana is divided into two tributaries. The state border between Montenegro and Albania stretches in the middle of the left arm, while the right arm and the island of Ada belong to Montenegro. The depth of the river is between 2 and 4 m, depending on the

Fig. 5 Bojana (Photo by G. Barovic)

water level of Skadar Lake. It is navigable along its entire length for ships up to 2 m in draft. Bojana does not have many tributaries, but two significantly influenced its flow. Watercourses in the area of Albania, Kiri, and Drim caused significant changes. According to Roman records, Morača and Bojana used to be a single stream, but it was recorded that the level of the lake increased at the end of the eighteenth and the beginning of the nineteenth century. Kiri blocked the flow of Bojana with a large amount of sediment, which resulted in raising the level of Skadar Lake. The map from 1838 [6] clearly shows a large area of Skadar Lake and that the Drim flows in a north-south direction and flows into the Adriatic Sea southeast of Bojana. In the middle of the nineteenth century, the bifurcation of the Drim occurred and it slowly merged with the river Kiri, bringing a large sediment that caused the lowering of the level of the Bojana riverbed and Skadar Lake. This trend continued later, and is very relevant today. The Island of Ada, formed in the second half of the nineteenth century, began to be formed by the sinking of an Italian warship (1882), which appeared as a basis for the large sediment that Bojana carries. The long axis of the island is 2.8 km and the shorter 1.8 km and the highest height is 4.8 m. Part of the island has been turned into a tourist complex while the other part is overgrown with dense Mediterranean vegetation [4]. Bojana has four right tributaries, namely Kravarski potok, Vija e lisnes, Miđanska River, and the Island of Šasko Lake.

2. *Untitled* occurs on the northwestern slopes of Kravarsko polje, on the north side of the Maja e Gerenjetit at 140 m above sea level. In most of the year there is an occasional flow, dependent on precipitation in the hinterland. The length of the stream, until the meeting with Cukal, is 2.58 km.

3. *Cukal* is formed by merging several smaller, occasional streams that occur on the northern sides of Kravarsko polje. With a small drop, it is only 8 m and has a short course of about 850 m to the junction with
4. *Kravarski spring* originates at about 10 m above sea level in Kravarsko field by merging the Cukal watercourse and a smaller occasional stream that occurs on the northern slopes of Maja e Gerenjetit, flows through the northern part of Sukobinsko field to the confluence with Bojana. The total length of the stream is about 4.2 km, while the very end of the watercourse coincides with the state border of Montenegro and Albania.
5. *Rastička River* collects water from several occasional streams in Donji Rastiš, north of the Granica elevation, at 35 m above sea level and has a relatively long course, compared to other second-order streams (5.45 km).
6. *Anamalski spring* originates in the northern part of the field of the same name. The length of the course to the confluence with the Rastica river, where it forms the Via e Lisnes, is 2.13 km long.
7. *Vija e lisnes* is a short watercourse that arises from several smaller watercourses that flow through the Animal field, the largest of which is the Rastička river (5.45 km). It achieves a very short fall, less than a meter and its length is about 1.65 km.
8. *The River Midjana* is the longest tributary of the Bojana with a length of 13.46 km. Its source is at 445 m above sea level on the southern slopes of Rumija, north of the Mide site. On the right side, it receives two rapid tributaries, Kalimanski spring, 2.08 km long, and on the left the Lulićka river 1.6 km. All watercourses have fluctuating water levels and depend on precipitation in the source part of the territory.
9. *Kalimanski spring* originates from a spring in the village of Kaliman and flows, a little more than 2 km to the south until it meets the river Lulica where they form the Midjanska river.
10. *Masuka* originates northeast of Krutska Mountain, in the area of the village of Kaliman and after a flow of 1,244 km flows into Kalimanski stream.
11. *The Lulić River* is formed by several streams on the southern banks of the Rudin, and its course extends in a north-south direction, west of the Vladimir elevation (487 m), west of Svrigać, after a flow of 1.6 km it flows into the Midjanska river.
12. *Lake Šasko* is surrounded on the north by Šaski brdo, Ambulski brdo, the elevation of Šulani and Fraskaljelo, on the west by Briski field and on the south by Briska gora. The border to the east is the Fraskanjelsko field, through which a runoff of the lake about 1.4 km long was formed. The entire area of Fraskanjelsko field is swampy and is very dependent of the level of Bojana, which formed it with its sediment. Šasko Lake is fed by water from the Mrkovska/Međuriječka River.
13. *The Mrkovska/Međurječka River* originates in Mali Kaliman, collecting water from several smaller streams, then flows south to Mrkovsko polje, from where it turns east to Kruta, after which it changes its name to Međurječka. After crossing the Kruta, it turns south to Brijeg, from where it again changes direction to the west on the northern slopes of Briska gora, flows through Briska field,

flowing into Šasko Lake. Part of Brisko field, west of the settlement of Donja Klezna, is a swampy area through which the flow cannot be precisely defined. The total length of the stream is 18.78 km with a drop of 984.3 m.

14. *Kozminac* is a tributary of the Mrkovska River, with a short course of 1.14 km and a drop of a little more than 200 m. It originates on the southeastern slopes of Lisinje, north of the settlement of Vulići.
15. *Goranski spring* is formed by merging Pelinković spring and Kovačević fountain on the northern sides of Vučići hill. It has a direction of extension, west–east, stretching between the hill Kodra (157 m) in the north and Brijeg in the south. Its length is about 2 km with a drop of 30 m.

4 Flow Ranking

The ranking of flows on the Montenegrin coast was done as follows (Fig. 6). Zero-order flows are the main flows in the river basin, in this case the Bojana River, while in the immediate basin of the Montenegrin coast there are no such flows, because watercourses flow directly into the sea. First order flows are tributaries of the main/zero order streams. Second-order flows are those flows whose merging creates first-order flows or flows into it directly. Third-order flows are those whose merger creates second-order flows or flow directly into them.

When determining the lengths of watercourses in this paper, it was taken into account that the map shows the orthographic projection of watercourses. In order to obtain the actual length of the measured flows during the measurement, data on the altitude of the source (or the origin of the flow, in cases when the flows are formed by merging two smaller flows) and the altitude of the confluence (or crossing the border of Montenegro or composition with another flow) were taken. The total decrease, i.e. the difference between the altitude of the source and the altitude of the estuary was calculated as follows (Fig. 7):

$$H_r = H_i - H_u$$

where: H_r – relative height, H_i – altitude of the source, H_u – altitude of the source.

The flow length was determined in such a way that the mapped flow length was calculated according to the total drop.

$$\mathrm{dr} = \sec\ \beta\, \mathrm{d}$$

In this way, the values of flow lengths were obtained, which included the average drop from the source to the source [7].

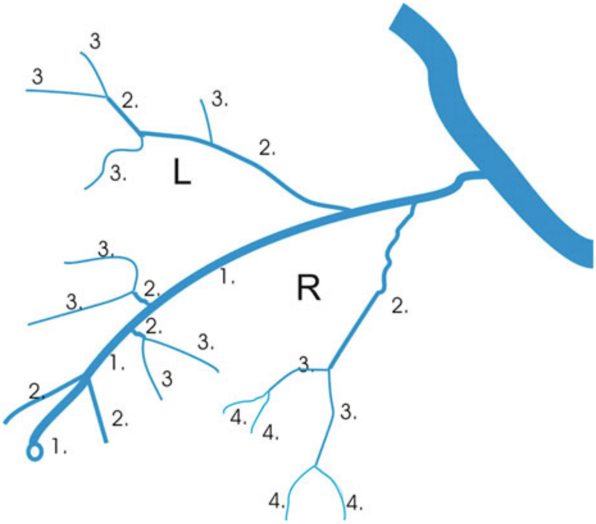


Fig. 6 Ranking of flows in a river system

5 Morphometric Characteristics of Waterflows in the Observed Space

Within the Adriatic Sea basin from the territory of the immediate basin of the Montenegrin coast, the following units stand out:

- Immediate basin of the Montenegrin coast,.
- River Bojana with its basin

5.1 Adriatic Sea Basin from the Montenegrin Coast

In the immediate basin of the Montenegrin coast, 32 watercourses have been observed. In the research, care was taken to process the streams that are shown in full line on TK 25000, but also some watercourses that are recognizable or stand out for their importance. Long-term measurements have shown that the zone of the immediate hinterland receives significant amounts of precipitation, but that the lithological basis has conditioned the formation of a relatively small number of streams on the surface.

In the mentioned geospace, 32 streams were registered, which were divided into two rows (Figs. 8, 9 and Table 1).

- In the first row, 22 streams were registered, of which the longest is Koložun with 11.73 km in length, and the smallest is Sopot with 80 m in length. Due to its importance, Gurdić was also included in the ranking of watercourses, but he was not included in the ranking. The average length of first-order streams is 3.23 km.
- In the second row, the longest is River Vrućа, 5.59 km and the smallest, Manitovac with 2.05 km. The mean value of the length of the streams in the second row is 3.13 km.

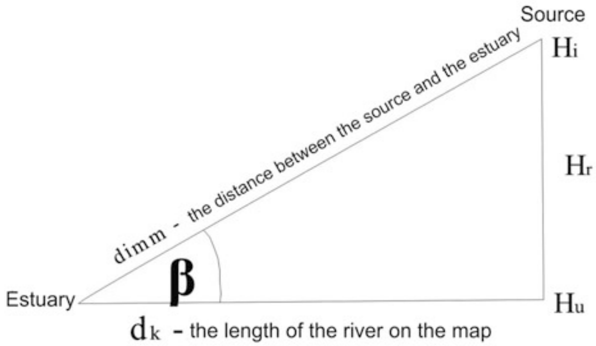


Fig. 7 A scheme for calculation of the main river parameters. *dk* mapped length, *dimm* length calculated in proportion to the map with the realized drop, and the verification was done by applying the Pythagorean theorem $d_r = \sqrt{d^2 + H^2}$

Similar to Bojana, there are great differences between the springs that flow directly into the Adriatic Sea, as a consequence of the geomorphological characteristics of the terrain.

- In the first-order streams, Kaložin has the highest spring, which springs at 945 m above sea level and the lowest is Jaška river with 5 m above sea level. The mean value of the source, in the case of streams in the first row, is 262.4 m. The altitude of the sources of all streams from this order is the same, 0 m above sea level (Table 2).
- Of the flows from the second row, the highest source is Kolijevka, a tributary of the Railway with 880 m above sea level and the lowest Lukavci, a tributary of the Jaška River which springs at 22 m above sea level. The mean altitude of the second-order flow source is 358 m above sea level at the source, the highest estuary has the Cradle at 163 m above sea level and the lowest Lukavci and Drenovštica which merge and form the Jaška river at 5 m above sea level (Table 3).

We have two more streams in the Adriatic Basin in the immediate zone of the Montenegrin coast, the Grahovska River and the Brdela stream, which by their position and hydrographic characteristics belong to its basin, but do not flow directly into the sea. The Grahovska River originates at 780 m above sea level and after 5.1 km of length it sinks in Grahovsko field, appearing in Risan Bay. The hill is formed at 170 m above sea level and at 3 m above sea level enters the pools of the Ulcinj saltworks.

5.2 *Bojana River Basin*

Bojana is the largest tributary of the Adriatic Sea in Montenegro and in a large part of its course represents the border watercourse with neighboring Albania. The total length of the Bojana River is 39.62 km, of which the border river is 21.82 km. It has a very small drop along the entire length of the stream, of only 5.5 m and is extremely dependent on the fluctuation of water levels in Skadar Lake.

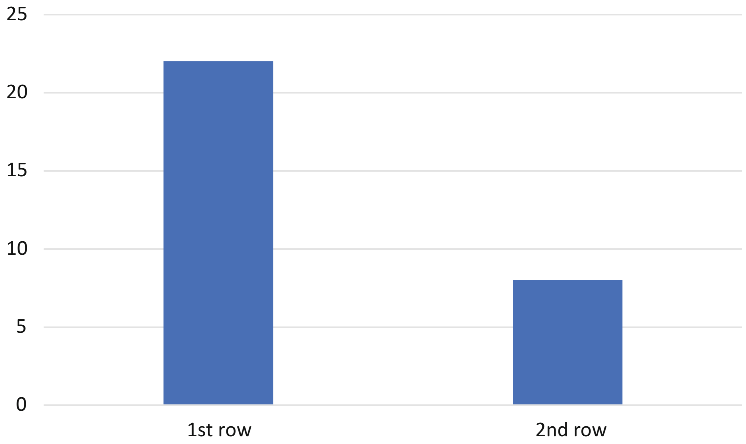


Fig. 8 Comparison of the number of flows in rows near the immediate basin of the Montenegrin coast

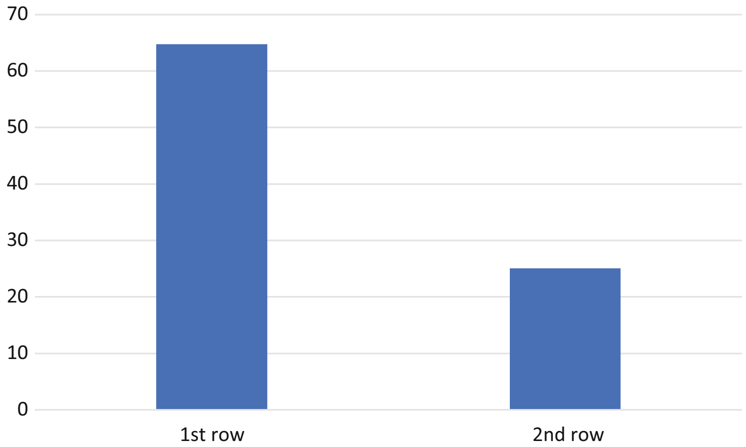


Fig. 9 Comparison of the length of flows in rows near the immediate basin of the Montenegrin coast

In the territory of Montenegro, the Bojana receives tributaries only from the right side of its course, because as already mentioned, part of its course makes it a border river, so the paper will process only the flows that are in the territory of Montenegro.

The right tributaries are divided into three rows.

Table 1 Flow in the Montenegrin coast

1	2	3	4		5		6		7	8	9	10
			Source coordinates		Tributaries		Elevation in m		Distinction			
No	Name of stream	Basin	X	Y	l/r	Row	Source (i)	Estuary (u)	i–u = H	Length in m	Total length in km	Note
1	Sutorina	Adriatic	4,704,750	6,536,700	–	1	95	0	95	7,025	7.02	
2	Presjeka	Sutorina	4,704,600	6,540,700	L	2	125	15	110	1,850	1.85	
3	Trtor	Sutorina	4,703,950	6,541,850	L	2	228	8	22	2,325	2.32	
4	Izvor	Adriatic	4,703,475	6,543,300	–	1	302	0	302	1,675	1.70	
5	Ljuti spring	Adriatic	4,703,025	6,544,325	–	1	295	0	295	1,825	1.84	
6	Sasojevićki spring	Opačica	4,702,325	6,547,200	R	1	170	5	165	1,375	1.38	
7	Sopot	Opačica	4,702,600	6,548,525	L	1	40	5	35	1,325	1.32	
8	Opačica	Adriatic	4,702,600	6,548,550	–	1	5	0	5	1,300	1.3	
9	Manitovac	Untitled	4,701,675	6,549,775	L	2	180	8	172	2,050	2.05	
10	Sopot	Adriatic	4,707,950	6,556,375	–	1	40	0	40	75	0.08	
11	Spila Risanska	Adriatic	4,708,500	6,557,600	–	1	20	0	20	425	0.43	
12	Ljuta	Adriatic	4,705,000	6,563,525	–	1	30	0	30	325	0.33	
13	Škurda – Tabačina	Adriatic	4,698,425	6,564,900	–	1	320	0	320	1,325	1.36	
14	Gurdić	Adriatic	4,697,850	6,563,925	–	1	−12	–	0	0	0	
15	Koložun	Adriatic	4,689,875	6,567,650	–	1	945	0	287	11,700	11.73	
16	Suha river	Adriatic	4,687,425	6,561,800	–	1	185	0	185	4,425	4.42	
17	Jaška river	Adriatic	4,684,400	6,565,625	–	1	5	0	5	2,525	2.52	
18	Lukavci	Jaška river	4,687,000	6,564,600	R	2	22	5	17	2,850	2.85	
19	Drenovštica	Jaška river	4,687,550	6,567,725	L	2	436	5	431	4,925	4.94	

(continued)

Table 1 (continued)

1	2	3	4		5		6		7	8	9	10
			Source coordinates		Tributaries		Elevation in m		Distinction			
No	Name of stream	Basin	X	Y	l/r	Row	Source (i)	Estuary (u)	i–u = H	Length in m	Total length in km	Note
20	Grdjevica	Adriatic	4,685,225	6,568,575	–	1	307	0	307	3,425	3.43	
21	Vještica	Adriatic	4,685,950	6,571,775	–	1	724	0	724	4,125	4.18	
22	Bečića river	Adriatic	4,682,872	6,673,425	–	1	858	0	858	4,350	4.43	
23	Šumet	Adriatic	4,679,400	6,575,300	–	1	270	0	270	950	0.98	
24	Đurmanski spring	Adriatic	4,670,250	6,585,350	–	1	278	0	278	3,062	3.07	
25	Smokvica	Adriatic	4,666,375	6,588,700	–	1	43	0	43	925	0.92	
26	Željeznica	Adriatic	4,668,075	6,592,525	–	1	580	0	580	6,850	6.87	
27	Kolijevka/ Dumezića potok	Željeznica	4,667,550	6,590,775	L	2	880	163	717	2,793	2.88	
28	Velja river	Željeznica	4,665,950	6,594,925	R	2	260	62	198	2,600	2.61	
29	Rikavac	Adriatic	4,662,050	6,596,450	–	1	440	0	440	6,225	6.24	
30	Vruća river	Rikavac	4,660,750	6,598,800	R	2	735	45	690	5,550	5.59	
31	Grahovska river	Adriatic	4,725,200	6,552,125	–	1	780	692	88	5,100	5.10	From the dam to the chasm
32	Brdela	Solana	4,649,275	6,604,275	–	–	170	3	164	7,450	7.45	

Table 2 Length analysis by rows – Montenegrin coast

	No. of streams	Total length (km)	Max. length (km)	Min. length (km)	Mean length (km)
1st row	22	64.79	11.73	0,8	3.23
2nd row	8	25.09	5.59	2.05	3.13

Table 3 Analysis of altitudes of sources by rows – Montenegrin coast

	No. of streams	Elevation of sources (max) (m)	Elevation of sources (min.) (m)	Distinction (m)	Elevation of sources (mean) (m)
First row	22	945	5	945	262.4
Second row	8	880	22	858	358

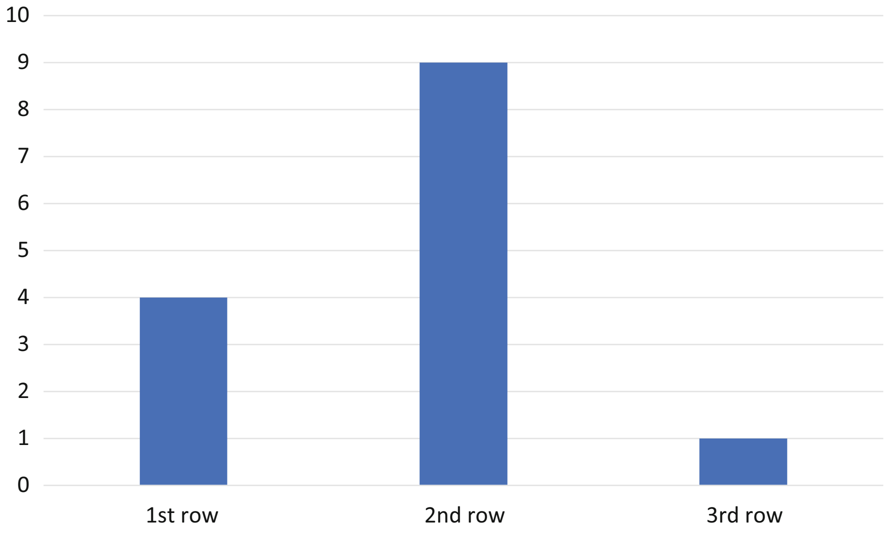


Fig. 10 Comparison of the number of flows in rows near the right tributaries of the Bojana

- In the first row, there are four watercourses, longest of which is the Miđanska River with 13.46 km and the smallest a runoff of Šasko Lake with only 1.4 km. The average length of streams in this row is 5.19 km.
- In the second row there are nine streams, the longest of which is the Mrkovska / Međurječka River, which flows into Šasko Lake with a length of 18.78 km and the smallest length is Cukal, of only 850 m, which participates in the formation of Kravarsko potok. The average length of the flows in the second row is 4.07 km.
- In the third row, only one stream was registered, Masuka with a length of 1.24 km. (Figs. 10, 11 and Table 4).

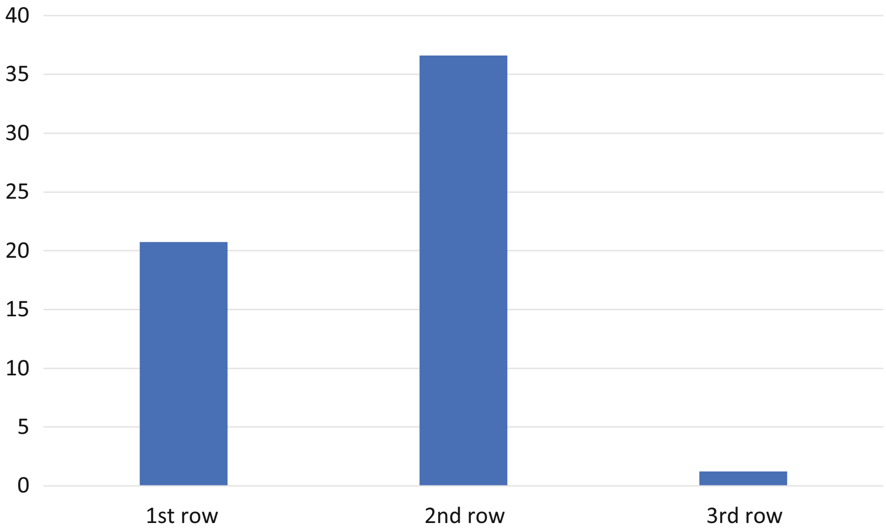


Fig. 11 Comparison of flow lengths in rows near the right tributaries of the Bojana

Table 4 Analysis of estuary elevations by rows – Montenegrin coast

	No. of streams	Elevation of estuary (max.) (m)	Elevation of estuary (min.) (m)	Distinction (m)	Elevation of estuary (mean) (m)
First row	22	0	0	0	0
Second row	8	163	5	158	25

- With the tributaries of the first order, there is a big difference in the altitudes of the springs, unlike the sources, which are approximately the same, which is a consequence of the geomorphological characteristics of the terrain on which they are formed. The highest source is the Miđanska River 445 m above sea level while Vija e lisnes and Šasko Lake are formed at only 4 m above sea level. The altitudes of the estuaries cannot even have a big difference, because they do not exist in the Bojana. The average altitude of the source at the first-order streams is 115.75 m and the estuary 3.5 m.
- In the second row, the difference in the altitude of the source is even greater. The highest source is the Mrkovska / Međurječka River 990 m and the lowest tributary Vija e lisnes at only 12 m. The average height of the spring at the streams in the second row is 222 m. The highest estuary is Kozminac, a tributary of the Mrkovska / Međurječka River at 255 m, and the lowest is the tributary Vije e lisnes, at 4 m from where it is formed. The average value of the altitude of the source is 227.77 m and the estuary 52.52 m.
- In the third row there is only one stream, Masuka, which springs at 270 m and at 88 m it enters the Kalimanj stream (Tables 5, 6, 7, 8 and Fig. 12).

Table 5 Flow in the Bojana River Basin

1	2	3	4		5		6		7	8	9	10
			Source coordinates		Tributaries		Elevation in m		Distinction			
No	Name of stream	Basin	X	Y	l/r	Row	Source (i)	Estuary (u)	i–u = H	Length in m	Total length in km	Note
1	Bojana	Adriatic	4,657,625	6,623,875	–	1	5.5	0	5.5	39,625	39.63	
2	Untlited	Kravarski spring	4,656,350	6,611,925	L	2	140	10	130	2,575	2.58	
3	Cukal	Kravarski spring	4,655,775	6,613,100	R	2	18	10	8	850	0.85	
4	Kravarski spring	Bojana	4,654,875	6,613,100	R	1	10	4	6	4,225	4.23	
5	Rastiška river	Vija e lisnes	4,655,025	6,611,400	R	2	35	4	31	5,450	5.45	
6	Anamalski spring	Vija e lisnes	4,651,425	6,611,925	L	2	12	4	8	2,125	2.13	
7	Vija e lisnes	Bojana	4,650,750	6,613,875	R	1	4	3.5	0.5	1,650	1.65	
8	Miđanska river	Bojana	4,656,125	6,604,900	R	1	445	3.5	441.5	13,450	13.46	
9	Kalimanski spring	Miđanska river	4,655,000	6,604,650	R	2	209	71	138	2075	2.08	
10	Masuka	Kalimanski spring	4,654,100	6,603,925	R	3	270	88	182	1,225	1.24	
11	Lulić ska river	Miđanska river	4,654,450	6,606,575	L	2	94	58	36	1,600	1.60	
12	Šasko lake	Bojana	4,648,125	6,612,775	R	1	4	3	1	1,400	1.40	
13	Mrkovska/ Međurječka river	Šasko lake	4,657,850	6,602,025	–	1	990	5.7	984.3	18,788	18.78	
14	Kozminac	Mrkovska/ Međurječka rijeka	4,656,550	6,600,625	R	2	467	255	212	1,144	1.14	
15	Goranski spring	Mrkovska/ Međurječka river	4,650,550	6,603,650	R	2	85	55	30	2000	2	

Table 6 Maximum, minimum, and mean values of the length of the right tributaries of the Bojana

	No. of streams	Total length (km)	Max. length (km)	Min. length (km)	Mean length (km)
First row	4	20.74	13.46	1.40	5.18
Second row	9	36.61	18.78	1.14	4.07
Third row	1	1.4	1.24	1.24	1.24

Table 7 Right tributaries – springs – Bojana

	No. of streams	Elevation of sources (max) (m)	Elevation of sources (min.) (m)	Distinction (m)	Elevation of sources (mean) (m)
First row	4	445	4	441	115.75
Second row	9	990	12	978	227.77
Third row	1	270	270	0	270

Table 8 Right tributaries – estuaries – Bojana

	No. of streams	Elevation of estuary (max.) (m)	Elevation of estuary (min.) (m)	Distinction (m)	Elevation of estuary (mean) (m)
First row	4	4	3	1	3.5
Second row	9	255	4	251	52.52
Third row	1	88	88	0	88

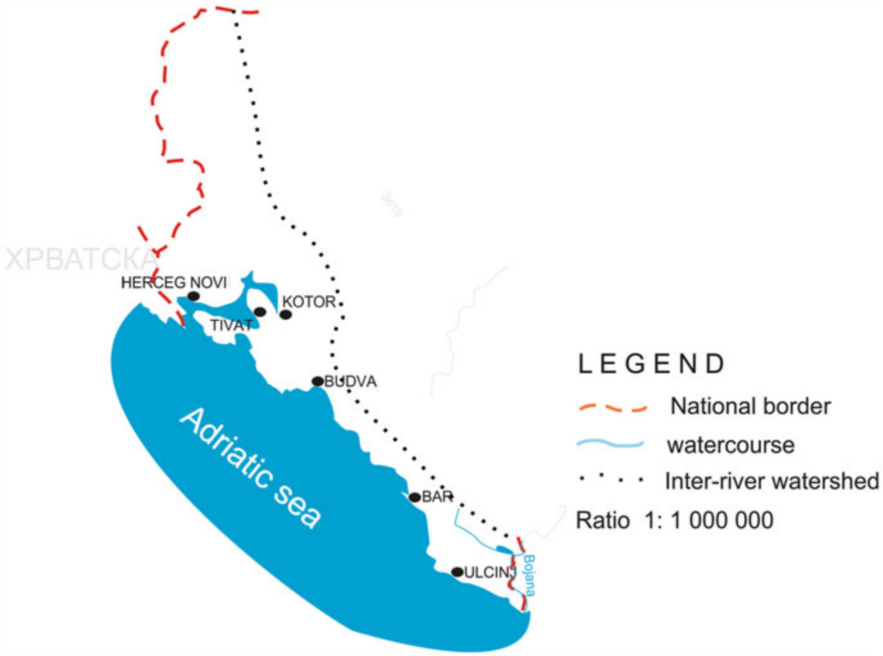


Fig. 12 Position of the catchment area of the Montenegrin coast and Bojana River in relation to the territory of Montenegro

6 Conclusion

Several common characteristics can be defined for the investigated watercourses of the Montenegrin coast. Due to the configuration of the terrain, they have a relatively short flow, have a torrential character with large amplitudes of water levels because they depend on the inflow of water from the immediate hinterland; most watercourses are occasional in character because during the dry season they dry up due to lack of water. The lower parts of the streams are calmer and their riverbeds are covered with sediment that they bring with them from the upper new streams, they are in a high degree of endangerment due to unplanned urbanization and most are significantly endangered by numerous pollutants that culminated in the last 20 years.

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Forests of the Coast of Montenegro

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Contents

Abstract This chapter presents the forest ecosystems of the Montenegrin coast. The characteristic of the Montenegrin coast is according to the data of the First National Forest Inventory the forest cover of as much as 49.9% of total area. These are mainly low forests, as well as degradation stages of these forests in the form of shrubs and macchia, which have a distinct protective function. The significance of these

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ecosystems is manifold. It can be seen through protection, soil, water, habitat and biodiversity protection, as well as through aesthetic function and landscape characteristics. This chapter also reviews the greatest risks to these ecosystems, fires and soil erosion processes.

Keywords Forest fires, Montenegrin coastal forests, Soil erosion

1 Introduction

The forests of the Montenegrin coast primarily have an ecological function. The main function of these forests is to protect the soil in habitats that are prone to erosion, as well as to protect the water, to protect the fauna and flora. Coastal forests do not have a great economic potential expressed through the production of wood assortments, but they represent a great potential of non-wood forests products (medicinal plants, honey plants, forest fruits) and have an invaluable function in the protection of karst areas. Also, these forests, in addition to the pronounced protection function, have other functions, such as aesthetic – landscape, recreational, tourist and educational.

Exploitation of wood and other forest products in this area is currently at a fairly low level. Existing tree species and ecological conditions on the karst do not ensure the production of more valuable wood assortments. The needs for firewood and small wood assortments in this area are decreasing due to the migration of the population to cities and the use of other energy sources for heating.

As the forest stands of this area are mainly located on areas that are prone to erosion (pluvial and aeolian), their dominant function is precisely in the protection of these areas from erosion. In addition to fulfilling this function, these forest stands are important for maintaining the water regime in the coastal karst, and also for providing a safe habitat – refuge for many other species that are related to and depend on the forest ecosystem. On the other hand, the belt of macchia, which has not been cut intensively by the local population lately, has been significantly recovered and strengthened, but has increased the risk of its destruction by fire.

Fires in the entire Southern Adriatic belt are a big problem because they most often occur during dry periods during the year. Evergreen vegetation and its degradation forms, coniferous planted forests – most often consisted of Aleppo pine (*Pinus halepensis* Mill.) are very sensitive to fires, both underground fires – litter fires, and ground and high fires, which spread easily and quickly at the slightest wind, and thus difficult to control. This problem is bigger if it is known that fires can drastically devastate the vegetation cover and the soil layer, which is very difficult to restore, most often in the grassy form or low bushes of thorny bushes formations.

In coming period it is necessary to improve the model for securing funds for financing of care measures and the protection of these forests. Payments for environmental services could be a way to manage such ecosystems [1, 2] and represent something that should be implemented as soon as possible.

2 State of the Forest

2.1 Forest Distribution

For the purposes of compiling the National Forest Inventory (NFI), the coastal belt is defined as an area that stretches from the sea coast to the peaks of the mountain range Orjen – Lovćen – Sutorman – Rumija. According to the data of the First National Forest Inventory, the coastal belt has a degree of forest coverage of 49.9%, and together with the forest land they make up 69.5% of the coastal zone area (Table 1). Coastal belt forests make up 7% of the total forest area of Montenegro, but only 3.4% of the wood volume of Montenegrin forests is located in this area [3]. The structure of forests is unfavourable in terms of cultivation form, so that coppice forests, thickets, shrubs, and maquis make up 73.2% of forests by area. The average wood volume is 73.1 m^3/ha, and the volume increment is only 1.8 m^3/ha.

When looking at the situation in the municipalities of the Montenegrin coast, the forest cover is 49%, which is slightly less than the average forest cover in Montenegro, which is 59.5%. Forest land makes up 15.5% of the area of these municipalities, while this category at the level of Montenegro occupies an area of 9.9%. Forests and forest land in coastal municipalities occupy 64.6% of the area (Table 2). Almost all forests are natural structures and are distinguished by the richness of biodiversity that characterizes hundreds of species of flora, which ensures their multifunctionality and stability.

In recent decades, certain areas of former barren lands, pastures and agricultural areas in the Littoral have been overgrown with forests due to the influence of natural processes. These are mostly macchia, shrubs, low and coppice forests that have a very important protective role in the karst area, as well as many other important public functions for the coastal area (Fig. 1) [4].

The migration of the rural population to cities and the ban on keeping goats in the previous period has led to a natural progressive succession of vegetation in recent decades, which resulted in vegetation cover has increased and barren areas occupy less space [5]. Improvement of the condition of forests on karst – progressive succession of vegetation is clearly visible and takes place naturally. The process should be accelerated by care measures, where there are favourable environmental conditions for the development of climatogenic communities.

The Mediterranean and sub-Mediterranean area represents a significant potential for the development and use of public forest functions expressed in the ecological and social functions of forests, and the future development of forests in this area should be directed in that direction.

Table 1 Forest and forest land area for the coastal belt [3]

Region area		Forest area			Forestland area			Forest and forestland area		
Area (determined via GIS) (ha)	% of land area in MNE	Area (ha)	% of total forest area in MNE	%of region area	Area (ha)	% of total forestland area in MNE	%of region area	Area (ha)	% of total f. and fl. area in MNE	%of region area
11,6261.0	8.4	57,967.0	7.0	49.9	22,885.6	16.6	19.7	80,852.6	8.4	69.5

Table 2 Areas of forests and forest land by municipalities [3]

	Area	Forest area		Forestland area		Forest and forestland area	
Municipality	ha	ha	%	ha	%	ha	%
Bar	62.686.07	29,374.10	46.9	5,220.28	8.3	34,594.38	55.2
Budva	11,515.68	5,183.09	45.0	1,389.22	12.1	6,572.31	57.1
Kotor	34,922.18	19,681.21	56.4	10,033.26	28.7	29,714.47	85.1
Tivat	5,258.16	1,383.70	26.3	2,150.71	40.9	3,534.41	67.2
Ulcinj	26,790.32	11,648.73	43.5	1,730.80	6.5	13,379.53	49.9
Herceg Novi	23,073.34	13,285.75	57.6	4,965.15	21.5	18,250.90	79.1
Total	164,245.75	80,556.58	49.0	25,489.42	15.5	106,046.00	64.6

2.2 Tree Species Represented in Coastal Forests

The most common tree species in coastal forests are: *Fraxinus ornus, Quercus pubescens, Ostrya carpinifolia,* and *Fagus moesiaca* (Fig. 2). The number of tree species in coastal forests is about 50 (Table 3) [3]. A small number of invasive species have been recorded, the most important of which are *Ailanthus altissima* (Mill.) and *Robinia pseudoacacia* L. [6].

2.3 Forest Communities

The first altitude belt (from the sea shore to 300 m above sea level) is characterized by an evergreen belt of macchia with the remains of the original holm oak forests (*Quercus ilex*), which is joined by the strawberry tree (*Arbutus unedo*) and other species in the lower floors [7, 8]. This belt is typical for Luštica, parts of Grblja, the surroundings of Budva, Bar and especially Ulcinj, where fragments of kermes oak (*Quercus coccifera*) and Skadar oak (*Quercus robur scutariensis*) can be found, as well as alluvial forests of white and brittle willow (*Salicetum albae – fraqilis, Salicetum albae mediterraneum*) and hemp and tamarix shrubs (*Viticetum agni – casti, Vitici, Tamaricetum dalmaticae*), which frame and separate them from the sand dunes and the swampy alluvial plain of the Ulcinj field. The natural forests of Skadar oak, white hornbeam, ash and white poplar that stretch from Velika plaža to Albania, with the island of Ada in the centre, form the largest complex of floodplain forests on the east side of the Adriatic coast. We should also mention the chestnut forests (*Castanea sativa* Mill.) which do not occupy a large area but have not only biodiversity significance but also for its direct contribution to the landscape and environment of part of the Bay of Kotor [9].

After this belt, going to higher altitudes, there are deciduous belts:

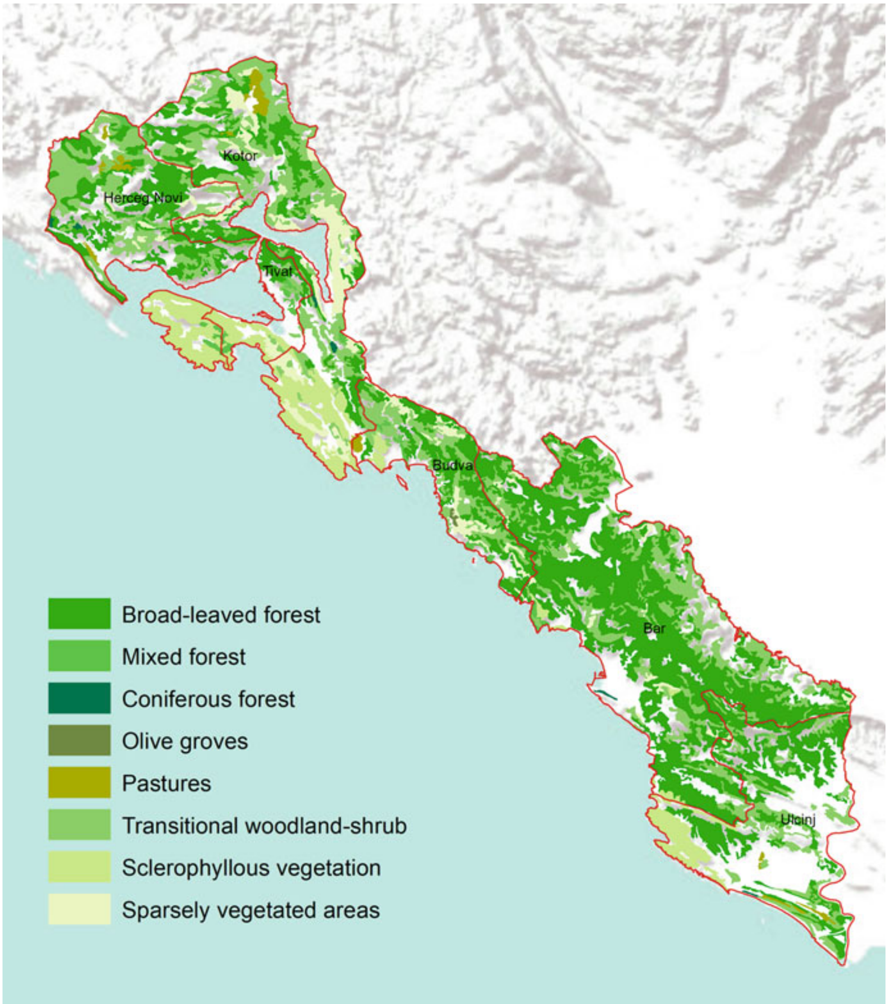

Fig. 1 Forest distribution

- Belt of 300 m above sea level. up to 900 m above sea level which are characterized by woodpecker forests (*Carpinus orientalis*) joined by black ash (*Fraxinus ornus*), downy oak (*Quercus pubescens*), Macedonian oak (*Quercus trojana*) and other species in the lower floors, as well as mixed low hardwood forests with black hornbeam (*Ostrya carpinifolia*) dominance. Shrubs and low forests of black hornbeam and black ash with sedges, *Seslerio-Ostryon* (Vol. 40) Lac. et al. 82. cover most of this belt [7].
- Belt above 900 m asl it is inhabited mainly by beech, on Orjen and Lovćen, while on Rumija only the northern exposures. Forest of Turkish oak, *Quercion cerridis* Lak. 76, they are also building a higher sub-belt in Montenegro, which ranges

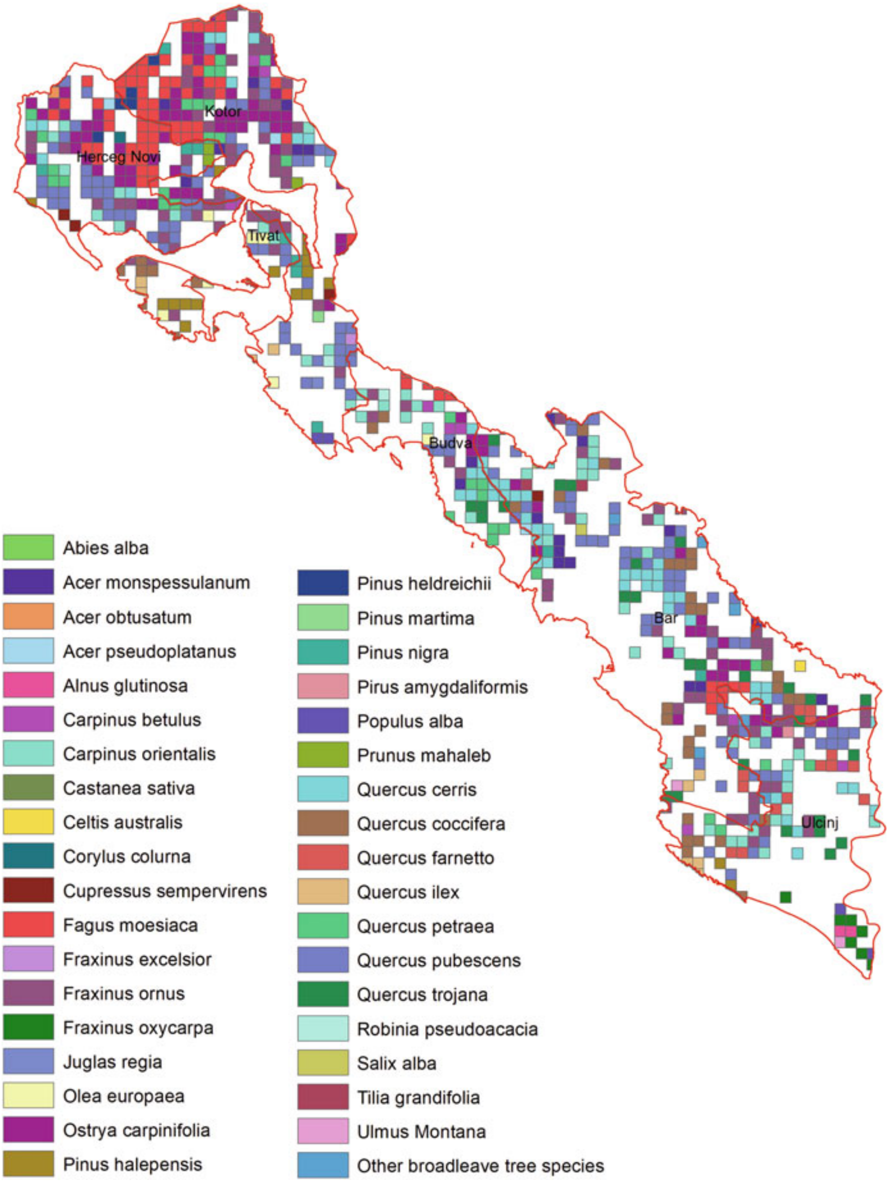

Fig. 2 Tree species distribution

from (500) 700 to (1300) 1500 m above sea level on the coastal mountains, and from 500 to 1,000 m on the southern exposures of the middle and continental southeastern Dinarides (Blecic and Lakusic, 1976). After the beech belt, on the very mountain tops – especially on Orjen, there is an endemic pine munika – *Pinus heldreichii* Christ [10, 11].

Table 3 Tree species distribution and growing stock by tree species [3]

Tree species	P forest (ha)	P %	N/ha	V (m^3)	V/ha	V %	Zv/ha	Zv %
Abies alba	43.79	0.1	23	5,847	133.5	0.1	0.0	0.0
Acer campestre	75.36	0.1	1,792	4,321	57.3	0.1	1.6	0.1
Acer heldreichii	38.48	0.1	385	1,456	37.8	0.0	1.3	0.1
Acer monspessulanum	1,216.39	2.3	1,021	43,989	36.2	1.1	1.1	1.4
Acer obtusatum	287.43	0.5	1,645	25,772	89.7	0.7	2.3	0.7
Acer pseudoplatanus	241.57	0.5	525	16,998	70.4	0.4	1.4	0.4
Ailanthus glandulosa	4.91	0.0	4,020	377	76.7	0.0	2.6	0.0
Alnus glutinosa	239.71	0.4	575	32,072	133.8	0.8	4.4	1.1
Carpinus betulus	472.00	0.9	1,402	34,302	72.7	0.9	1.9	0.9
Carpinus orientalis	3,807.97	7.1	2,649	155,294	40.8	4.0	1.3	5.0
Castanea sativa	84.15	0.2	293	14,839	176.3	0.4	2.5	0.2
Celtis australis	8.78	0.0	1,187	505	57.5	0.0	1.6	0.0
Corylus colurna	79.53	0.1	144	3,172	39.9	0.1	0.8	0.1
Cupressus sempervirens	269.36	0.5	491	40,679	151.0	1.0	5.2	1.4
Fagus moesiaca	6,008.50	11.2	766	1,229,852	204.7	31.5	3.8	23.4
Fraxinus excelsior	124.85	0.2	1977	3,319	26.6	0.1	0.9	0.1
Fraxinus ornus	7,971.39	14.9	2022	272,669	34.2	7.0	1.1	8.5
Fraxinus oxycarpa	676.15	1.3	932	139,066	205.7	3.6	4.8	3.3
Malus sylvestris	37.01	0.1	1,082	2,241	60.6	0.1	2.1	0.1
Morus alba	0.59	0.0	16,704	38	64.4	0.0	0.0	0.0
Olea europaea	480.92	0.9	305	16,394	34.1	0.4	0.8	0.4
Ostrya carpinifolia	6,194.10	11.6	1,605	340,710	55.0	8.7	1.8	11.1
Pinus halepensis	1,468.64	2.7	320	196,560	133.8	5.0	3.6	5.3
Pinus heldreichii	461.54	0.9	202	45,189	97.9	1.2	1.5	0.7
Pinus maritima	93.82	0.2	410	18,945	201.9	0.5	6.0	0.6
Pinus nigra	802.96	1.5	529	235,229	293.0	6.0	7.7	6.3
Pirus amygdaliformis	59.23	0.1	170	396	6.7	0.0	0.4	0.0
Pirus communis	47.03	0.1	714	4,223	89.8	0.1	2.4	0.1
Populus alba	134.88	0.3	61	11,518	85.4	0.3	0.8	0.1
Populus tremula	5.53	0.0	357	1,377	248.9	0.0	6.4	0.0
Prunus mahaleb	263.92	0.5	483	8,549	32.4	0.2	0.8	0.2
Quercus cerris	2,435.76	4.6	628	183,808	75.5	4.7	1.9	4.7
Quercus coccifera	1,861.76	3.5	941	65,110	35.0	1.7	0.8	1.5
Quercus farnetto	1,172.42	2.2	942	107,903	92.0	2.8	3.0	3.6
Quercus ilex	552.94	1.0	1,215	15,068	27.3	0.4	1.0	0.5
Quercus petraea	2,712.42	5.1	794	147,802	54.5	3.8	1.3	3.7
Quercus pubescens	7,758.39	14.5	545	372,631	48.0	9.5	1.4	10.8
Quercus robur	48.83	0.1	235	5,786	118.5	0.1	2.2	0.1
Quercus trojana	1,415.88	2.6	805	58,953	41.6	1.5	1.3	1.9
Robinia pseudoacacia	264.93	0.5	411	14,212	53.6	0.4	2.0	0.5
Salix alba	9.58	0.0	515	694	72.5	0.0	8.2	0.1
Sorbus aria	18.86	0.0	3,140	980	51.9	0.0	1.5	0.0

(continued)

Table 3 (continued)

Tree species	P forest (ha)	P %	N/ha	V (m^3)	V/ha	V %	Zv/ ha	Zv %
Sorbus aucuparia	15.08	0.0	2,618	2,471	163.9	0.1	5.1	0.1
Sorbus austriaca	83.07	0.2	3,329	6,879	82.8	0.2	3.0	0.3
Sorbus torminalis	8.36	0.0	4,156	976	116.8	0.0	4.5	0.0
Tilia grandifolia	13.72	0.0	792	1,570	114.5	0.0	2.1	0.0
Tilia parvifolia	83.49	0.2	329	4,461	53.4	0.1	1.3	0.1
Ulmus Montana	181.75	0.3	818	9,206	50.6	0.2	1.3	0.2
Other broadleaved tree species	228.07	0.4	494	5,396	23.7	0.1	0.6	0.1

Apart from natural communities, in the middle of the twentieth century there were numerous afforestation actions mainly with Aleppo pine and cypress seedlings. These forests were occasionally damaged by fire. Coastal pine forests (*Pinion halepensis-maritimae* Lak. 72) and Illyrian black pine forests (*Pinion nigrae-illyricae* Lak. 72) currently cover about 1,900 ha, have a share of 0.3% of Montenegrin forests, an average volume of 147 m^3/ha.

In all the aforementioned belts, due to the extensive destruction of forests in the long history of human civilization in this area, there are a lot of degraded areas inhabited by secondary vegetation. The climatogenic communities of holm oak, medunca and white hornbeam forests are today largely degraded and replaced by macchia, gargoyle and rockery. The importance of macchia is reflected in the protection of these terrains from the continuation of earlier erosion [12]. The protection of macchia is important for the biodiversity and to prevent soil erosion. Macchia also gives characteristic Mediterranean landscape shape.

2.4 *Typical Mediterranean Forest Related Natura 2000 Habitat Types*

Coastal Area of Montenegro[1] harbours a significant number of Natura Habitat [13] including forest related habitat types (forests/woodlands and scrubs[2]) with typical Mediterranean character. This group of Natura 2000 habitat types is accommodated along the Coast in a narrow vegetation belt from the shoreline up to 400 m a.s.l.

Typical Mediterranean forest related Natura 2000 habitat types belong to forest association *Orno-Quercetum ilicis* (forests of Holm Oak and Ash) and include:

[1]Administratively include 6 (six) costal municipalities: Herceg Novi, Tivat, Kotor, Budva, Bar and Ulcinj.

[2]Scrubs include a variety of shapes and sizes a named as *matorral*, *maquis*, *garrigue* and *phrygana* depending on their location, soil, degree of degradation, human usage and species composition.

5210 Arborescent mattoral with *Juniperus* sp – includes Mediterranean and sub-Mediterranean evergreen sclerophilous scrub/shrub formations with Juniper (*Juniperus phoenicea, Juniperus oxycedrus*) dominance, often open type, but sporadically completely dense. This habitat comes as a progradation stage (due to overgrowth) of former pastures/open grasslands.

5230 *Arborescent matorral with *Laurus nobilis* – Laurel formations (*Laurus nobilis*) are present in relatively humid areas. Real forests (> 5 m height) are very rare and occupy very small areas. Sparse Laurel formations with <5 m height belong to 5310 *Laurus nobilis* thickets. Out of Laurel in that habitat type dominate Holm Oak (*Quercus liex*), but also Downy Oak (*Quercus pubescens*).

5330 Thermo-Mediterranean and pre-desert scrub – are xerophytic shrub formations which include very specific relict, 2 to 3 m high open plant community with Tree Spurge (*Euphorbia dendroides*). This habitat type is present on very steep and inaccessible habitats, sometimes on almost vertical cliffs.

91M0 Pannonian-Balkan Turkey oak – Sessile Oak forests – are typically present in continental but also arrive to Mediterranean zone between 250 and 600 m a.s.l. In this forest dominate thermo-xerophytic species including Turkey Oak (*Quercus cerris*), Italian Oak (Quercus frainetto) and Sessile Oak (*Quercus petraea*).

91AA *Eastern White Oak woods – include azonal forests of White Oak (*Quercus pubescens*) that occupy southern warm steep slopes, with presence of typical thermophilic sub-Mediterranean species.

9250 *Quercus trojana* woods – are supra-Mediterranean or meso-Mediterranean forests, often low forest or scrub formations, dominated by (semi)deciduous Macedonian Oak (*Quercus trojana*) followed by Junipers and Maples adapted to xerophytic conditions, accommodated between 50 and 850 m a.s.l. Alternate in mosaics with forests of Hornbeam and other thermophilic Oaks.

9260 *Castanea sativa* woods – are supra-Mediterranean and sub-Mediterranean forests of Chestnut (*Castanea sativa*), including old stabilized plantations, present in enclaves at very few locations. In Boka Kotor Bay these forests are associated with Laurel and their stands are located at low altitudes 10–200 m a. s.l.

9290 *Cupressus* forests (*Acero-Cupression*) – includes only old stabilized plantations dominated by Cypress (*Cupressus sempervirens*) with shrubs and ground flora layers normally developed.

92A0 *Salix alba* and *Populus alba* galleries – are forests of Willows (*Salix alba, Salix fragilis*) and Poplars (*Populus* sp.), usually present at river banks. This habitat type also include hygrophilous deciduous trees (*Ulmus sp., Salix sp., Alnus sp., Acer sp., Tamarix sp., Juglans regia, Quercus robur, Q. pedunculiflora, Fraxinus angustifolia, F. pallisiae*), as well as vines.

92D0 Southern riparian galleries and thickets (*Nerio-Tamaricetea* and *Securinegion tinctoriae*) – are forest galleries and shrubs of Tamarix (*Tamarix* sp.), Oleander (*Nerium oleander*) and Hemp (*Vitex agnus-castus*) usually on river banks, but also along the lakes and lagoons. However, Oleanders are missing in this habitat type.

9340 *Quercus ilex* and *Quercus rotundifolia* forests – are forests, i.e. forest formations dominated by Holm Oak (*Quercus ilex*), usually present on carbonates in meso-Mediterranean or supra-Mediterranean zones. Today, they are degraded into *maquis* with Juniper or other species, sometimes excluding Holm Oak. Here are also present formations of Kermes Oak (*Quercus coccifera*) that suit to this habitat type because of the composition of species.

9540 Mediterranean Pine forests with endemic Mesogean Pines – are forests of thermophilic Pines (*Pinus pinea, Pinus pinaster, Pinus halepensis, Pinus brutia*) that replaced former (para)climax forests of Holm Oak (*Quercetea ilicis*). This habitat type includes old stabilized plantations or spontaneously, secondary formed stands of Pines, presented in the areas of their natural distribution, with floristic structure similar to natural stands.

3 Risks

Among the numerous factors influencing the destabilization of forest ecosystems, anthropogenic factors have dominant and often decisive role. Human activities, direct or indirect, cause significant damage, which directly affects the state of the entire environment.

The complex of negative impacts includes: Forest fires, erosion processes, conversion of forests and forest land into construction, waste disposal, works on infrastructure facilities, etc.

3.1 Forest Fires

Forest fires are one of the biggest problems of forest protection and forestry in general. The main reasons for that are that they can cover large areas in a short time, cause large loss of wood mass, that destruction affects the entire ecosystem (plants, animals, land), cause air pollution, destroy objects and loss of human lives.

Forest fires are a global environmental and economic problem. In addition to the listed direct damage and firefighting costs, indirect damage from forest fires should be mentioned, which are as follows:

- Favourable conditions are created for the reproduction of harmful insect species.
- Phytopathogenic fungi also appear in fires.
- Forest weeds appear.
- With the disappearance of the forest, the microclimatic conditions change.
- Degradation and further soil erosion processes continue.
- Costs of removing burnt wood.
- Remediation and reforestation costs.

Due to the dry and hot summers, coastal forests are prone to fires. As a natural response, we have permanent devastation forms of maquis, gargoyles and shrubs. Many plants are pyrophytes, i.e. plants whose reproductive potential is expressed after a fire. For these species, smaller fires are a way to recycle nutrients and eliminate other, competing floral elements. Plant communities in these areas have adapted to frequent fires and pyrophytic plants have become more prevalent, while some less adapted plant species have disappeared.

Fires affect soil chemistry or organic matter, hydrophobicity and soil pH. On the soil surface, the flame front produces a temperature of about 500°C, which destroys flora and fauna in the soil and leads to charring of the soil and the formation of a hydrophobic layer, which promotes landslides and erosion as one of the worst consequences of fire [14]. The intensity and duration of erosion after a fire depend on several factors such as soil texture, terrain slope, layer regeneration ability and precipitation intensity. It is not uncommon for erosion due to residual roots in the soil to occur only after a few years unless vegetation is restored. Over time, this remaining roots rot and soil stability is lost, and excessive erosion occurs subsequently [15].

Due to their geographical position in the Mediterranean and the increasingly pronounced negative impact of climate change, forests in the Montenegrin coastal zone are particularly endangered. Forest fires are the most serious threat to coastal forests [12]. Insufficiently developed network of forest roads, pronounced relief as well as a decreasing number of inhabitants in the rural part additionally complicate timely intervention in the event of forest fires.

Forest fires pose a latent threat to the loss of forests and forest lands. Increasingly frequent occurrences of forest fires, which, especially in the coastal and coastal part of Montenegro, often take on large proportions and, in addition to forests, endanger other natural ecosystems, settlements and human lives cause justified concern. Particularly prone to fires are forest ecosystems on karst in the coastal area where pines such as Aleppo pine (*Pinus halepensis*) and maquis predominate.

Restoration of vegetation and biocenosis as a whole is a faster process if the burned areas are small, surrounded or in direct contact with recent forest vegetation. When the fire destroyed vegetation in large areas and significantly damaged the land, the succession of vegetation is slower and restoration is more difficult. In these places, the former forest is replaced by non-forest vegetation of the fire, which is characterized in the earliest stages by the dominance of annual plants (therophytes). Among them, there are species that are not affected by fire from the surrounding vegetation, but also weeds and adventitious species that are affected by the conditions created by the fire [16].

In the ecosystems of maquis, garrigue and shrubs, the succession of vegetation to the pre-fire stage is relatively short. The existence of different stages of succession, their number and duration depends on environmental factors.

For successful remediation, it is necessary to know the basic plant communities and their indicator values, which can serve as an indicator in which direction the vegetation should be directed and supported, in order to achieve ecosystems of more favourable structure, greater stability and value than before the fire. The time for sowing or planting certain woody species in the Mediterranean should be highest in autumn and winter, due to their advantages, which are most climatically caused [17, 18].

It should be noted that preventive forest protection measures and biological control methods should have a primary character. It is necessary to establish a more efficient system of fire protection, monitoring, as well as efficient remediation of fires with increasing forest openness by maintaining existing and building new forest roads.

3.2 Erosion Processes

Soil erosion is a natural process in which water and wind transfer soil material from one place to another. Water and wind in their movement have a certain mechanical energy with which they move the components of the soil and carry them downstream. In doing so, depending on a number of factors, erosion can occur normal (geological) or accelerated (excessive).

Very intensive soil erosion processes are taking place in Montenegro. These processes are not of the same intensity in certain narrower areas and regions. Some areas are, thanks to the prevailing natural (different soils, topography, geology, vegetation, land use and climate) and anthropogenic factors in them, far more endangered by these processes, and thus the occurrence of far greater damage. Montenegro consists of three clearly separated regions: coastal, central and northern, and we can conclude that erosion processes are far more pronounced in the coastal and northern region, and much less in the central.

An extremely important factor in the development of soil erosion is the condition of the vegetation cover, especially in areas extremely susceptible to these processes. This protective vegetation cover consists of numerous species of tall and low trees, shrubs, grasses and other plants, whose roots bind loose soil material and with their developed canopies and leaves protect the soil from the destructive influence of raindrops, which greatly prevents or mitigates erosion processes.

The greatest kinetic energy that water receives in its circulation is that which raindrops have when they reach the ground, because then the water has the highest speed. This energy must be destroyed by contact with the soil surface, which leads to a weakening of the cohesion of the soil and its preparation for further strong erosion.

The plant cover destroys this energy in a very simple way, receiving the impact of raindrops on its above-ground organs and leaves and destroying their kinetic energy by friction. If we analyse this form of destruction of the kinetic energy of water, we will see that the role of plants in this regard is useful if they have more developed and lower crowns and if there are more leaves on the soil. Hence, young deciduous forests, and even grasses until they are mown, are the best protectors of soil from erosion. Rare large trees or forests with decorated crowns represent almost no protection of the soil from erosion in this area.

Underground organs of plants, roots and veins are another factor that opposes erosion. These organs provide the veins at a certain depth and thus perform its reinforcement, creating the cohesion, so that the soil is no longer opposed to erosion by individual particles, but by a mass of connected particles. This factor is also stronger in the protection of soil from erosion if the network of veins is denser, smaller and closer to the surface. On this basis, too, young forests and uncut grass represent the best protection of the soil from erosion.

The two factors described are related, as we have seen, to the destruction or reduction of the kinetic energy of water droplets and to the increase of soil cohesion. After the water reaches the soil, a new movement of water occurs, depending on the slope of the land, which the first two factors have not changed. But the plant cover still acts strongly against erosion, creating greater roughness and greater porosity of the soil. The water slows down the movement and sinks, continuing further underground, very slow movement, harmless to the ground. This happens in two ways: first, that the plants, developing a network of underground organs, create a significant porosity of the soil for the purpose of obtaining air and water from the surface; secondly, the plant leaves form a porous and rough humus cover. This type of soil is able to strongly absorb water, so there is no movement on the surface, and thus no erosion processes. Vegetation has a special beneficial effect on water runoff and water regime, and the coefficient of runoff from land areas covered with vegetation, due to stronger evaporation and plant nutrition, is lower than the coefficient of runoff from bare surfaces. Swelling occurs in a completely different, mild form, uniformly, without particularly pronounced highs and lows. Watercourses abundantly fed with spring and spring water never dry up, destructive water does not occur at all, and swelling is contained mainly in the form of useful water.

The area that covers the Montenegrin coast can be viewed from several aspects of the problems arising from the natural processes of soil erosion, which are taking place in this area continuously and intensively [19]. These processes cause great damage every year in the form of floods, which are reflected in initiating traffic jams, flooding and sedimentation of agricultural land and many residential, tourist and other commercial buildings.

As the most excessive forms of soil erosion are torrents that carried into rivers, into the sea, on flat-fertile lands, on settlements, roads and other objects, triggered soil material, thus causing great damage. Torrents are natural watercourses of extremely rapid flow, with very variable intensity and unstable riverbed, transfer and deposition of sediments. In Montenegro, they occur in many places and cause great damage. Torrents in the Montenegrin coast cover a third of the total area of the Coast, which is between 300 and 330 km^2, of which strong erosion affects an area of about 85 km^2. These are the following torrent basins: (1.) Sutorina (27.0 km^2); (2.) Meljinski potok (3.6 km^2); (3.) Repaj (20.0 km^2); (4.) Pijavica (6.5 km^2); (5.) Jošica (1.5 km^2); (6.) Seljanovo (3.9 km^2); (7.) Rosino (1.5 km^2); (8.) Gradiošnica (4.5 km^2); (9.) Morinjski potok (8.7 km^2); (10.) Mala – Risan (1.9 km^2); (11.) Velika Škurda (2.0 km^2); (12.) Mala Škurda (1.0 km^2); (13.) Zvironjak (6 km^2); (14.) Vrmac (0.5 km^2); (15.) Markov rt. (1.5 km^2); (16.) Lješnica (2.0 km^2); (17.) Krimalj (5.0 km^2); (18.) Koložunj (10.3 km^2); (19.) Lukavac (6.0 km^2); (20.)

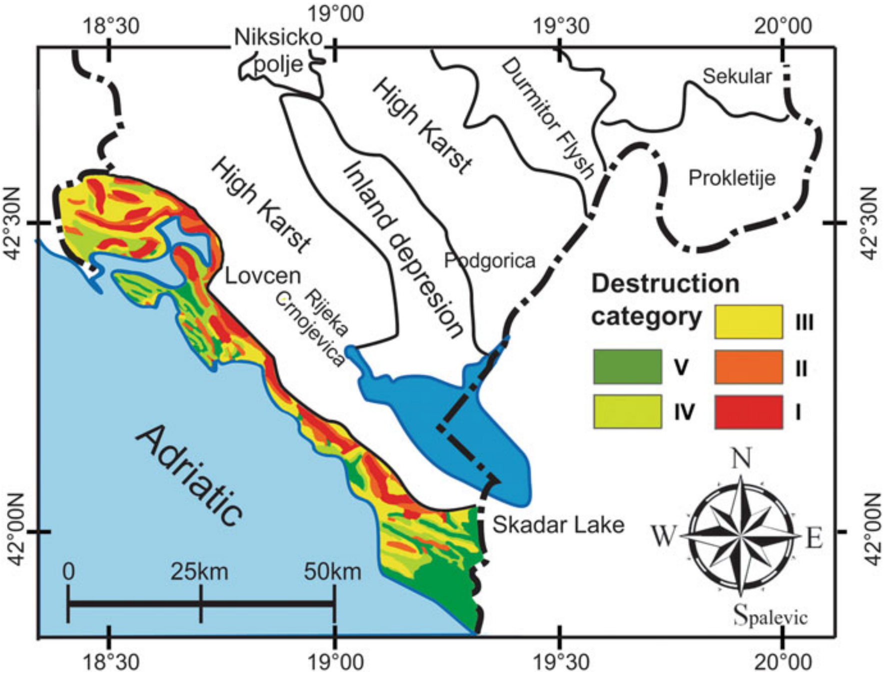

Fig. 3 Map of soil erosion of the Montenegrin coast

Drenovštica (12.0 km^2); (21.) Grđevica (10.2 km^2); (22.) Boretski potok (4.0 km^2); (23.) Bečići potok (10.0 km^2); (24.) Kukački potok (3.0 km^2); (25.) Rafailovića potok (1.0 km^2); (26.) Valještica (6.0 km^2); 27.) Ličak (1.5 km^2); (28.) Praskvica (3.0 km^2); (29.) Popovština (3.0 km^2); (30.) Porubica (5.0 km^2); (31.) Sutomorski potok (8.0 km^2); (32.) Željeznica (25.0 km^2); (33.) Rikavac (27.0 km^2); (34.) Međureč (25.0 km^2); (35.) Mide (25.0 km^2); (36.) Brajša (10.0 km^2); (37.) Rastički potok (3.0 km^2); (38.) Sukobinski potok (3.0 km^2).

Processes affected by erosion are presented on a simplified map of soil erosion of the Montenegrin coast (Fig. 3).

The history of protection of the Montenegrin coast from erosion and torrents begins at the end of the nineteenth century. The Austro-Hungarian authorities, under whose administration most of our Montenegrin coast was at the time, began planned and systematic work on arranging torrent watercourses in order to protect existing facilities and agricultural areas in the lower areas and on the shores, as well as areas intended for urban settlements and ports. Such activity continued to some extent during the Kingdom of Yugoslavia, as well as the Socialist Federative Republic of Yugoslavia (SFRY), until the end of the 1960s where problems of permanent financing occurred and almost completely stopped this initiative of systematic protection of this kind of land degradation. The problem of protection of the Montenegrin coast from erosion and torrents should be treated with more attention, and this problem must be systematically addressed.

4 Conclusion

Given that coastal forests are characterized by low-yielding coppice forests, shrubs and other degradation stages that occupy a significant part of this area, coastal forest management should be directed towards strengthening stability, protective-regulatory and socio-cultural functions of the forest. The development of forestry in the coastal area must be based on multifunctionality, on professional criteria, and on the principles of the forestry profession, in order to emphasize the general useful functions of forests and ecological balance in space, i.e. on the principle of sustainable development. Existing forest ecosystems need to be more adequately protected, natural regeneration encouraged, their stability and biological diversity maintained, and existing forms of forest vegetation should be translated into a higher form by supporting indigenous species. It should be borne in mind that many unfavourable conditions affect the difficult maintenance of forest vegetation and raising its quality such as: shallow and skeletal soils, uneven distribution of precipitation, frequent fires, very steep slopes, poorly developed network of forest roads and others. In order to enable the maximum achievement of forest benefits, economic valorisation of forest functions should be made in accordance with the purpose. Achieving knowledge about the monetary value of forest functions that are not valorised on the market as the production of wood and non-wood products will serve in determining priorities and public investments in forest management.

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The Agriculture of Adriatic Montenegrin Coast

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Contents

Abstract The coastal zone occupies a narrow strip of Montenegro's territory, and it is the most densely populated region in Montenegro. This region comprises six municipalities: Bar, Budva, Herceg Novi, Kotor, Tivat and Ulcinj. The main characteristic of rural areas in the coastal region is the fragmentation of agricultural holdings, negative demographic trends, underdeveloped rural infrastructure and low degree of commercialization of agricultural holdings. In the field of agricultural production, the basic orientation is focused on the development of Mediterranean agriculture and mariculture. In the upcoming period, it would be necessary to put the existing natural resources into the function of agriculture development, primarily organic farming. Complementarity of agriculture and tourism is increasingly important, since the broad range of domestic products enrich the tourism offer, making it unique. Through the affirmation of national cuisine and specific Montenegrin products, tourism can be a powerful generator for Mediterranean agriculture development. To achieve the objectives set, the return of young and well-educated people to rural areas and their focusing on agricultural production is essential.

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1 Introduction

Montenegro is situated in South-Eastern Europe, and its total area is 13.812 km^2 with a population of 620.029 (2011). The area of Montenegro is characterized by a diverse and specific relief, as well as specific geomorphological features of the terrain. One of the geomorphological features of Montenegro's territory is access to the sea. To the west, it borders Croatia and Bosnia and Herzegovina, to the north and north-east Serbia and to the south-east and east Albania, and the south-west, it accesses the Adriatic Sea. Montenegro has a seashore of 288 km in length and 2.450 km^2 of the territorial sea, which is the main resource for the development of maritime economy and tourism and is also of great significance for the food production sector. The coastal area covers a narrow strip of Montenegro's territory; a high chain of mountains stretching in parallel along the coast divide it from the inland part of the country. The main peaks separating the coastal region from the central and northern region in Montenegro are Orjen (1.895 m), Lovćen (1.749 m), Sutorman (1.175 m) and Rumija (1.585 m) [1]. Montenegro's coastal area stretches from Debeli Brijeg to the north-west to the Bojana River near Ulcinj to the south-east. The Skadar Lake with its narrow shoreline is included in the broader determination of the territory that the maritime valorisation complex is linked to. The distance from the Lake Skadar area to the sea is very short, and the Bojana River is a natural link between the Lake Skadar and the Adriatic Sea [2]. The coastal region comprises the following municipalities: Bar, Budva, Herceg Novi, Kotor, Tivat and Ulcinj. According to the area occupied, the biggest is the Municipality of Bar (598 km^2), and the smallest is the Municipality of Tivat (46 km^2). Coastal municipalities cover an area of 1.591 km^2 or approximately 11.55% of Montenegro's territory. According to the last Census in 2011, the population of 149.705 lived there, accounting for 23.5% of the total population of Montenegro [2].

The coastal region is the most competitive in Montenegro, with the competitiveness of 32% above the national average in Montenegro. The key positive factors for the competitiveness of the coastal region are population growth, quality of basic and business infrastructure and the share of the population with university degree in the total population aged 15 and above [3]. Mediterranean climate is typical of this area, with long and warm summers and mild, rainy winters. Thanks to a mild climate, the conditions for the development of agriculture, particularly for olive growing, citrus and other Mediterranean cultures are favourable. The most suitable areas for agricultural production are meliorated coastal fields: Ulcinjsko (100 ha), Zoganjsko (110 ha), Mrčevo (220 ha), Tivatsko (80 ha) and Sutorinsko fields (120 ha) covering the total area of 640 ha Štojska Greda in the hinterland of the Velika Plaža (Long Beach) have excellent potential for agricultural production (around 1.000 ha). Rural hinterland actually has a significant production potential.

In recent years, particularly in the period of economic boom (2007–2009), the land was sold intensively, and new housing facilities were built. Change of purpose of the land harms agriculture and weakens the socioeconomic status of rural areas.

2 Analysis of the Agricultural Situation in Montenegro and the Coastal Region

Agriculture is one of Montenegro's key economic sectors and one of the most important income sources for the population. The specific character of Montenegro's agriculture results from the available area on one side and multiple diversities in terms of relief, climate, land and waters, on the other. Soil as the most important natural resource is quite diverse, and soils of modest fertility, acid reaction and lighter mechanical composition, often skeletal and shallow, prevail.

The main characteristic of Montenegro's agriculture is the fragmentation of farms, extensive agriculture and the low level of marketability of production. The said characteristics are also factors of limitation to agriculture development. While agriculture in Montenegro has a long tradition, after World War II, intensive industrialization took place resulting in decline in the economic power of the countryside and agriculture. Industrial production multiplied and industry became the sector with the highest share in the gross domestic product [4]. Intensive industrialization is reflected in the decreased share of agricultural population in the general population Table 1, as well as in changes in the structure of agricultural areas Table 2.

In the period 1960–2010, the total agricultural area was reduced by 16%, the total arable area decreased by 2.2%. The coastal region disposes of 51.072 ha of agricultural land. In the structure, the highest share is that of pastures (62.7%), meadows (12.4%), gardens and arable fields (12.3%), orchards (10.6%), vineyards (1.5%) and ponds, fishponds and reeds 0.6% [7]. Natural conditions are favourable for fruit (olive and citrus) and vegetable production. The fields in the coastal hinterland are favourable for small ruminants farming, as they are rich in honey plants and

Table 1 Agricultural population share (%) 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: Andrijašević and Rastoder (2006) History of Montenegro from the ancient times to 2003 [5]

Table 2 Agricultural area (ha) by land use category, agricultural censuses 1960 and 2010

	1960	2010	2010/1960
Agricultural area	615.019	516.798	84.03%
Arable area	192.903	188.703	97.82%

Source: Statistics Office of the Republic Montenegro (1966) Agriculture – Statistical overview 1947–1965, Monstat (2012) Statistical Yearbook 2012 [6, 7]

medicinal plants, wild fruits (pomegranates, figs., etc.). Taking into account the natural potential for agriculture development in the coastal region, this paper analyses the current situation and its possible development directions for the future.

2.1 Overview of Agriculture Development in Montenegro

Agricultural production in Montenegro has a long tradition. The agriculture development depended not only on economic conditions but also on natural conditions. Arable land in Montenegro was scarce – it was fragmented, scattered and barren, especially in the southern areas. Small farms were unsuitable for the use of machinery, and there were no conditions for more intensive agricultural production.

Following the Berlin Congress (1878) and gaining independence, numerous initiatives and measures were taken to improve the situation in agriculture. These measures included the hiring of international experts, the education of local experts and the provision of financial assistance from the state budget, giving awards to best farmers, etc. [8]. Prince Nikola ordered every soldier to plant a grapevine plant and every officer to plant an olive tree. Numerous exhibitions and courses were organized on fruit growing, and assistance was provided to mitigate the effects of harmful organisms and plant diseases [9]. Following the Berlin Congress, when Montenegro got its coastline, the country also got 132.147 olive trees and several olive mills used to produce olive oil. The number of olive trees grew to 150.000 at the beginning of the twentieth century [10].

Later on, after losing its independence, the Montenegrin farmer tried to produce everything he needed for his family's livelihood. He sought to provide himself with the most needed foodstuff-bread, sowing wheat and corn on land that was not able to provide a satisfactory yield. A clear example of the ineffective use of land is the Boka Kotorska. According to data from 1932, there were 2.000 ha of arable land in the Boka Kotorska, with 83% of these areas under wheat and maize. Production was not sufficient to feed the population of the Boka Kotorska, so imports of about 10.000 kg of cereals were needed every year. Those data clearly indicate that the conditions for grain production in the Boka Kotorska were not favourable [11].

Nowadays, agriculture and tourism are strategic sectors of Montenegro's development. The share of agriculture in the overall gross domestic product was 8% in 2013 [12].

Almost entire production takes place on family agricultural holdings, with an average size of 4.6 ha of utilized agricultural land [13]. 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. Land resources are not properly distributed. Land plots of up to 0.5 ha account for 31.6% of the total agricultural land. About 54% of the holdings use only 0.1 to 1 ha of agricultural land, and only 0.9% of the holdings cover areas above 100 ha [13]. In the coastal region, the farm structure is the least favourable, while the northern region has the highest number of holdings using larger areas of agricultural

Table 3 Agricultural land in Montenegro by category (ha) in 1965 and 2012

Year	Total agricultural area	Arable fields and gardens	Orchards	Vineyards	Meadows	Pastures	Ponds, reeds, fishponds
1965	584.673	65.580	8.880	1.409	112.693	393.621	2.490
2012	515.717	45.809	12.028	4.512	126.726	323.998	2.644

Source: Statistics Office of the Republic Montenegro (1966) Agriculture – Statistical overview 1947–1965, Monstat (2012) Statistical Yearbook 2012 [6, 7]

land. Table 3 below gives an overview of the structure of agricultural areas in Montenegro according to the data from 1965–2012.[1]

The data analysed show that in the agricultural area structure, pastures prevail (67.32%) in 1965, as well as in 2012 with the share of 62.82%. The share of meadows was 19.27% (1965) and 24.57% in 2012. The land structure has favourable natural conditions for livestock farming. Livestock farming was one of the main occupations in the rural area of Montenegro, which influenced the development of psychological and physical characteristics of people in these areas [14]. However, this sector is not yet sufficiently developed, and the reasons lie primarily in fragmented holdings and traditionally extensive production methods with insufficient utilization of natural resources.

Demographic trends are very important for the development of Montenegro's agriculture. In the past, Montenegro used to be a country with prevailing small farms, and the rural population had no opportunity to find employment outside agriculture, i.e. in the city. This led to the agrarian overpopulation and stratification of the rural population. Industrial development and the biggest migration from villages to the cities in Montenegro's history took place following World War II. However, its development was also one of the factors, which had a major impact on the dynamics of other industries (especially energy sector), the development and establishment of numerous social institutions, the construction of transport infrastructure and the development of skilled human resources and technical intelligence [4]. Migrations from the north to the coastal region of the country caused also changes in the population age structure, having a negative effect on the development of agricultural production. Table 4 provides an overview of general population trends, by regions, in the period 1948–2011.[2]

During each census, the increase in the share of the population in the central and coastal regions is noted, together with the decline in the share of the population of the northern region in the total population of Montenegro.

Internal migrations, combined with external migrations, have affected significantly the changes in the demographic image of Montenegro and have contributed to uneven regional development. Northern region (dominantly rural) accounts for more

[1]Since 2012, the use of the new EUROSTAT methodology has started.

[2]Source: The author's own calculation based on the data from "Demographic trends in Montenegro from the mid-20th century and perspective until 2050", Monstat, 2008.

Table 4 Total population trends by regions 1948–2011

Year	Regions		
	Costal	Central	Northern
	Share in total population (%)	Share in total population (%)	Share in total population (%)
1948	18.5	34.2	47.3
1953	18.1	34.6	47.3
1961	17.7	36.1	46.2
1971	18.3	38.3	43.4
1981	19.8	41.0	39.2
1991	21.9	42.6	35.5
2003	23.5	45.1	31.4
2011	24.0	47.3	28.7

Source: The author's own calculation based on the data from "Demographic trends in Montenegro from the mid-twentieth century and perspective until 2050", Monstat, 2008 [15]

Table 5 Montenegro's regions, main indicators

Region	Population	Size (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 (2011) Population census 2011 [17]

Table 6 Labour force on family agricultural holdings by gender and age structure

Categories	Labour force total	Holding holder		
		Total	Male	Female
Up to 24	6.717	344	307	37
Age between 24 and 34	11.340	2.387	2.228	159
Age between 35 and 44	15.675	5.993	5.540	453
Age between 45 and 54	21.562	11.675	10.769	906
Age between 55 and 64	19.849	12.197	10.657	1.540
65 and above	23.198	16.228	13.037	3.191
Montenegro – total	98.341	48.824	42.538	6.286

Source: Monstat (2011) Agriculture Census 2010, Structure of agricultural holdings, Special interest topics [18]

than 50% of the territory of the state, but it is populated by less than one-third of the population [16]. In the coastal region, 25% of the total population lives on 11.5% of the territory of the state Table 5.

The labour force is an important indicator of agricultural development. According to the data in Table 6, the age of about 38% of the holders of family agricultural holdings is above 55 years. Out of the total number of holders, women account for 13% only.

In the upcoming period, it would be necessary to continue with the measures aimed at the development of rural areas, such as improvement of infrastructure, development of non-agricultural economy, building local institutions, etc. Improving rural infrastructure helps improve living standards and reduces regional disparities, increasing the attractiveness of rural areas.

2.2 *Overview of Agriculture Development in the Coastal Zone*

The Adriatic region has always been divided into a narrow coastal strip and a more spacious hinterland. The differences in the relief and climate provided the basis for the differentiation of social and economic forms of life. In the area from which one can "see" the sea, narrowing down to around a hundred metres at some points, large and prosperous cities with a gentle agricultural environment developed as far back as in the ancient times. In the immediate hinterland, living was poor, relying on small nomadic and semi-nomadic livestock breeding, with typical transhumance, moving the cattle to highlands in summer and back to lowlands in winter. Life in the hinterland was rather difficult, and it was always a place that migratory masses were coming from. It has always been a reservoir of vital population. In the past, the strongest support to livelihood was provided by farming sheep, goats and bovine animals of the buša breed [19]. In 1930, goats, donkeys, mules and hinnies prevailed in the coastal region [11]. Grapevine was grown most in the District of Boka Kotorska and the District of Bar in the period 1935–1939. In the immediate hinterland of the Coast, the Vranac variety dominated, followed by Kratošija and Lisičina. In this period, the number of olive trees was half a million. The yield was modest, so some parts of the Boka Kotorska had to import olive oil. In 1932, up to 50,000–60,000 kg of oil was produced in the Boka Kotorska. During the period observed, farmers were supported by the state by the provision of less expensive planting material, a range of training events free of charge on the topic of the protection of certain agricultural crops and others. Corn, barley, rye and wheat were the most frequently grown cereals [20]. By organizing fairs, exhibitions, the state made effort to support agriculture development. Three agricultural exhibitions were organized in the District of Bar. The first was organized in 1922 in Bar with more than 300 exhibitors with more than 800 different agricultural products. The second was organized in 1928 in Virpazar and the third in 1932 in Bar [11]. The hinterland has always played the role of the "agricultural pendant" [19]. High birth rate at the time when most of the population depended on agriculture as a basic source of existence resulted in high agricultural overpopulation. Thus the data from 1900 show that population density in the Boka was low but agricultural[3] was quite high Table 7.

[3]Total population on arable land unit.

Table 7 Population and population density in the Boka Kotorska in 1960

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

Source: Crkvenčić and Schaller (2005) "Boka Kotorska: socio-political changes and ethnic composition development by 1918" [21]

Settlements located further from the coast were scattered and were formed at higher altitudes. There was a marked difference in the pedological soil composition, which affected its cultivation and exploitation. Since coastal areas had more favourable living conditions, migration of population from higher grounds to coastal settlements was notable. The migratory trends caused abandoning of traditional agriculture and engaging of the population in maritime transport and trade [21]. Maritime activities resulted in the spatial mobility of the coastal population and its movement to places with more favourable conditions for shipbuilding, trade, etc. Seafarers, shipbuilders and merchants moved not only from one place to another within our ethnic area but also abroad [19]. Descent of the population from higher slopes towards the coast resulted in forming of the new settlement Tivat, where Austrians built an arsenal. A 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 [16]. Migrations from the rural areas in the hinterland led to the launching of other activities. The first mention of a factory in Montenegro dates back to 1834 and refers to the manufacture of tiles and bricks in Krtole, near Kotor.

In the first decades following World War II, major industrial facilities were built, creating a numerous class of industrial workers. Montenegro's industrial production was increased 40 times from 1947 to 1979 [22]. During that time, the Adriatic region was the most deagrarized region of Yugoslavia. Active agricultural population of the Adriatic region decreased by one quarter [19]. With the restoration of land ownership to its original owners, agricultural production was almost abandoned. Orchards and vineyards were cleared away; irrigation and drainage systems were not functioning any more. Thus, for example, in the area of Grbalj, peaches and other fruits were grown, and today only viticulture is still present, to a lesser extent. In the area of the Municipality of Ulcinj, agricultural land in the Valdanos Bay has significant agricultural potential but is neglected.

The coastal region today disposed of 50.815 ha (9.8% of the total) agricultural land, of good fertility, which consists of deep alluvial-diluvial and brown anthropogenic soils. Natural preconditions allow for the development of fruit and vegetable production, as well as small ruminants farming.

Limited natural resources, natural characteristics of the area and orientation towards tourism development impose future development of the coastal region based on the principles of the green economy, with agriculture providing a significant contribution.

2.2.1 Geographical and Climatic Conditions for Agriculture Development

In addition to its latitude and altitude, Montenegro's climate is determined also by the presence of large water areas (the Adriatic Sea and Lake Skadar), the sea's deep cutting into the mainland (the Boka Kotorska Bay), moderately high mountainous hinterland (Orjen, Lovćen, Rumija), Ulcinjsko Field to the farthest south-east and the mountain massif of Durmitor, Bjelasica and Prokletije. Large water areas, height and direction of coastal mountains and relief influence its climate both locally and regionally, creating great differences in a small area between the coastal climate and the climate of the high mountainous region with numerous transitional forms of the local climate between them.

Montenegro's coastal region has a Mediterranean climate characterized by long hot and dry summers and relatively mild and rainy winters. A much harsher climate is present in the karst fields at a distance of 40 to 80 km from the Adriatic Sea, as well as in the fields that are quite close to the Adriatic (about 20 km) but are separated from the sea by high mountains.

The average number of days with precipitation in the coastal region is about 115–130. The rainiest month on the coast is November, and July is the driest. 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) [21]. The mountainous hinterland of the Adriatic – the area with the highest precipitation in Europe is a mountain area above the Kotor Bay (Krivošije). In this area, on the steep slopes of the Orjen in the location Crkvice (940 m above sea level), the average precipitation is around 5.000 mm per year (which is European maximum rainfall), and in record years almost 7.000 mm, with marked precipitation of an orographic character.

In the coastal region, there are 2.750 sunshine hours, on average, and in the mountainous areas farther from the sea from 1.550 to 1.900 h. The sunniest area is the south-eastern part of the coast around Bar and Ulcinj. Typical winds are bora and scirocco. Bora is the most common and strongest in winter. Scirocco or jugo covers a large area of the sea and forms large waves from the offshore towards the coast, and its strength and frequency are increasing from the north-western to the south-eastern part of the coastal area. Bora has the strongest gusts in winter in Herceg Novi with a maximum of 65.6 m/s.

Unutilized agricultural land, both privately and state-owned, has significant potential for an increase in agricultural production. According to statistical data from 2014, the total area of the utilized land in Montenegro is 223.131 ha. Ownership rights are unresolved in a part of agricultural land.

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. Grapevine, olives and tobacco grow well on terra rossa, vegetables in gardens and clover in arable fields. The flysch[4] zone along the northern coast is covered by luxuriant evergreen vegetation (oak, laurel, etc.).

As regards agriculture development, the greatest opportunities are provided by flat fields of alluvial and alluvial-colluvial soils from Herceg Novi to Ulcinj (total area of around 8.300 ha): Sutorina (120 ha), Kutsko Field (80 ha), Tivatsko Field (700 ha), Crmnica (400 ha), Mrčevo Field (400 ha), Barsko Field (600 ha), Markovsko Field (240 ha), Ulcinjsko and Zoganjsko fields (1.300 ha), Štoj (1.000 ha), Šasko Field (400 ha) and Anamalsko Field (2.400 ha).

These fields are areas with a potential for the development of more intensive agriculture, since there is a possibility for the development of several agricultural sectors, from intensive vegetable production both in greenhouses and in the open field to setting up of various perennial plantations (citrus, grapevine, olive and other fruit species) to the production of fodder for various livestock species (Fig. 1). These are also areas where irrigation is possible, which further increases its agricultural potential. At the same time, the greatest pressure from other sectors and the risk of a permanent change of use, thus making it unavailable for agriculture, is affecting larger flat areas [1].

2.2.2 Population Structure in Montenegro by Regions

The coastal region is characterized by a high population density, a dense network of settlements and concentration of population in urban areas. Geographical position and natural conditions have contributed to the urbanization of the coastal region along the shoreline. The population density in the coastal region is 93.5 inhabitants per km^2, significantly above the population density in Montenegro (45 inhabitants per km^2). The intensive population growth is the result of the sudden economic prosperity of the coastal area. 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 [2]. In settlements in the hinterland, and in particular in the hilly and mountainous areas, depopulation process is evident.

Migrations from the northern region to the central and coastal regions, as well as migration from rural towards urban areas contributed to uneven regional development. This led to one-quarter of the population in Montenegro settling in an area of

[4]Flysh-sequence of sedimentary rocks where marl, sandstone, clayey shale and limestone interchange.

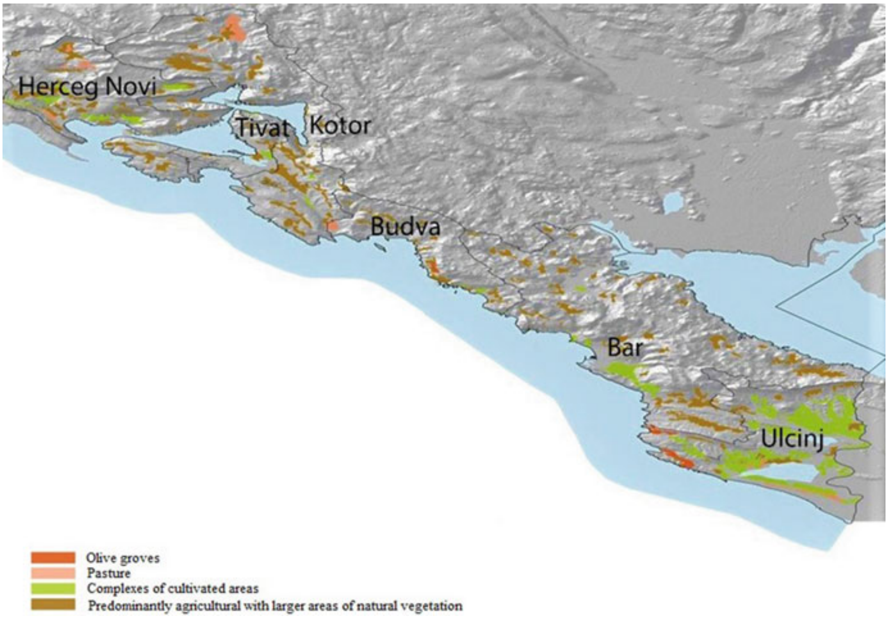

Fig. 1 Overview of agricultural areas by Corine Land Cover classification. Source: Ministry of Sustainable Development and Tourism (2013) Analysis of the attractiveness and benefits for agriculture, CAMP project [23]

Table 8 Regional population structure in Montenegro (1961–2011) – share (%)

	1961	1971	1981	1991	2003	2011
Northern region	46.19	43.44	39.19	37.17	33.01	28.68
Central region	36.13	38.28	41.00	42.56	43.30	47.33
Coastal region	17.68	18.28	19.81	20.27	23.69	23.98
Total	100.00	100.00	100.00	100.00	100.00	100.00

Source: Spatial Plan of the Republic of Montenegro by 2020 [24]

just over 10% of the territory, located in the coastal region. Table 8 below provides an overview of the regional structure of Montenegro's population in the period 1961–2011.

The faster economic development of coastal municipalities in the late 1960s and 1970s resulted in establishing big companies employing a large number of workers. The drivers of economic development were the Port of Bar, saltworks in Ulcinj and shipyards in Bijela and Tivat. Tourism facilities have become the backbone of the development of the entire region, and tourism development has been given primacy over agriculture and industry. Rural areas remained depopulated, resulting in an unfavourable age structure. The average age is over 50 years.

2.2.3 Rural Areas

Rural areas are recognized as a low-density area dominated by agricultural and forestry activities. It is an organic community where people have time for each other. Rural areas are determined by four components: countryside, agriculture, technology and the environment [25]. According to OECD, rural area is an area with population density below 150 inhabitants per m2. At the regional level, geographic units are grouped 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 [16].

Following the World War II, 72.4% of the population in the coastal region of Montenegro was rural, and the highest share of urban population was in the Municipality of Ulcinj, 60%, and the lowest in the Municipality of Bar, 12.1%. A significantly higher share of rural population 63.6% lived in villages in the hinterland, while 36.4% lived in rural settlements on the coast. The average population density in 1948 was 43.9 inhabitants per km^2 which was significantly higher than the average of the Republic of 27.3 inhabitants per km^2. The highest population density was in the Municipality of Tivat, 109.3 inhabitants per km^2, and the lowest in Budva, 31.4 inhabitants per km^2 [26]. The population was mainly engaged in agricultural production and to a lesser extent in tourism, maritime affairs, trade, industry, etc.

According to the Census 2011, the largest share of the urban population in the total population is in the central region (79.6%), followed by the coastal (58.3%), and the smallest share is in the northern region – 40.3%. Table 9 below gives an overview of the population by municipalities, urban and rural settlements in the coast of Montenegro, according to the Census 2011.

The data suggest that in the Municipality of Bar only, the share of the population in rural settlements (57.88%) is higher than in urban settlements (41.97%). In other coastal municipalities, the share of the population in rural settlements is lower than the share in urban settlements. In 2003, the lowest share of the rural population was recorded in the coastal region of 40.2%, while according to the Census 2011, it rose slightly to 41.8%. The population in the rural settlements on the coast is increasing, while in the villages in the hinterland, the number is in the decline, and only 29.8%

Table 9 Overview of the population by municipalities, urban and rural settlements on the coast of Montenegro according to the Census 2011

Municipality	Bar	Herceg Novi	Ulcinj	Kotor	Tivat	Budva	Coastal region
Total population	42.048	30.864	19.221	22.601	14.031	19.218	148.683
Urban settlements	17.649	19.536	10.707	12.583	10.118	15.995	86.558
Rural settlements	24.339	11.328	9.214	10.018	3.913	3.223	62.095

Source: Monstat (2011) First results of the Census of population, housing and dwellings in Montenegro [27] of the rural population of the region live there. Kotor registered the largest decline in the population in the period 2003–2011 [26].

At the beginning of the twenty-first century, population density on the coast of Montenegro has been growing due to faster economic development. According to the 2011 Census, population density is 94.1 inhabitants per km^2 and is the highest in Montenegro. The most densely populated municipality is Tivat with 308.8 inhabitants per km^2, while Kotor is the most sparsely populated municipality of the region with 67.4 inhabitants per km^2. In terms of area, Tivat is the smallest municipality of the region (46 km^2).

2.2.4 Agricultural Holding

Agricultural holdings are the key entities in agriculture development, and they play an important role in the development of rural areas. According to the census 2011, the total number of agricultural holdings was 48.870. Of this number, 48.824 are family agricultural holdings, while only 46 are registered as business entities.

According to the 2010 Census data, 98.341 persons were working on 48.824 family farms, while 46 businesses entities employed 608 people. Calculated in annual work units, almost 30% of the total number of employees in Montenegro are engaged in agriculture, indicating a higher share of employment in agriculture (3–4 times) compared to its contribution to total GDP [12]. The main characteristic of the holding is a low specialization level. About 80% of all agricultural holdings are mixed-type holdings, and only 8.0% of the total number of holdings are so-called specialized holdings for pig and poultry breeding, followed by 4.5% of holdings with mixed crops and mixed livestock farming. The number of holdings according to the last Census in 2010 decreased by about 25% compared to the 1960 Census when Montenegro had 64.918 holdings [16]. In Table 10 the data shown concern the number of holdings according to the Censuses in 1960 and 2010.

In the coastal region, the number of agricultural holdings decreased significantly in these 50 years. According to the agricultural census 1960, the total number of agricultural holdings in Montenegro was 11.084, while according to the Census 2010, there were 4.801 holdings. The lowest number of holdings is situated in the Municipality of Tivat (169) and the largest number in the Municipality of Ulcinj, which recorded the mildest decline since 1960.

According to the class type by the 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. Small farms have always been dominant in Montenegro. Table 11 provides an overview of family agricultural holdings by the class size of utilized land in the municipalities of the coastal region, according to agricultural censuses in 1960 and 2020.

These data show that in the intercensal period (1960–2010) significant changes occurred in the rural areas of the coastal region. The total number of agricultural holdings has been significantly reduced, and the structure of the size class of the land

Table 10 Number of agricultural holdings in the coastal region (Censuses 1960 and 2010)

	Bar		Budva		Herceg Novi		Kotor		Tivat		Ulcinj	
Census	1960	2010	1960	2010	1960	2010	1960	2010	1960	2010	1960	2010
Number of agricultural holdings	4.373	1.814	604	203	1.792	522	1.621	362	550	169	2.144	1.731

Source: Statistics Office of the Republic Montenegro (1966) Agriculture – Statistical overview 1947–1965, Monstat (2011) Agricultural Census 2010 (Key Variables – Land and Livestock Resources) [6, 13]

Table 11 Family agricultural holdings by the class size of utilized agricultural land by municipalities of the coastal region (Censuses in 1960 and 2010)

	Bar			**Budva**			**Herceg Novi**		
Family agricultural holdings by the class size of utilized land	**1960**	**2010**	**Index 2010/ 1960**	**1960**	**2010**	**Index 2010/ 1960**	**1960**	**2010**	**Index 2010/ 1960**
Total number of agricultural holdings	4.373	1.814	41.48	604	203	33.61	1.792	522	29.12
Landless	–	37	–	–	38	–	–	31	–
<1.00 ha	1.604	1.425	–	318	145	–	658	402	–
1.00 < 10.00 ha	2.692	344	–	283	20	–	1.069	77	–
10 ha and more	77	8	–	3	–	–	65	–	–
	Kotor			**Tivat**			**Ulcinj**		
Family agricultural holdings by the class size of utilized land	**1960**	**2010**	**Index 2010/ 1960**	**1960**	**2010**	**Index 2010/ 1960**	**1960**	**2010**	**Index 2010/ 1960**
Total number of agricultural holdings	1.621	362	29.12	550	169	30.72	2.144	1.731	80.73
Landless	–	6	–	–	6	–	–	7	–
<1.00 ha	518	306	–	290	145	–	537	1.121	–
1.00 < 10.00 ha	997	30	–	253	9	–	1.491	593	–
10 ha and above	106	–	–	7	–	–	116	10	–

Source: Statistics Office of the Republic Montenegro (1966) Agriculture – Statistical overview 1947–1965, Monstat (2011) Agricultural Census 2010 (Key Variables – Land and Livestock Resources) [6, 13] used has been changed. In the size-class structure, land up to 1 ha prevails as follows: Bar 78.55%, Budva 71.42%, Herceg Novi 77.01%, Kotor 84.53%, Tivat 85.79% and Ulcinj 64.76%. The changes are the result of the ageing population in the hinterland of the coastal cities, which are threatened by complete depopulation.

3 Conditions for Agriculture Development in the Coastal Region

3.1 Natural Conditions for Agriculture Development in the Coastal Region

Montenegro is rich in natural resources. The most significant are biodiversity, waters, sea and the coast, land and mineral resources. The availability of these resources is a product of different geographic factors and their interactions, including the position, topography, climate and geological history.

3.1.1 Bar

The geographical position of the Municipality of Bar is very favourable. The territory of the Municipality is located in the south-eastern part of Montenegro's coast between the Lake Skadar and the Adriatic Sea, between 41°57′48″ and 42°18′36″ north latitude and 18°56′10″ 23°19′20″ east longitude. With the associated water surface of the lake of 128 km^2, it occupies an area of 726 km^2 and the surface of the land is 598 km^2. It borders municipalities of Budva, Cetinje and Ulcinj. The position of Bar is the starting point for the shortest link between Eastern Europe and the Adriatic Sea and the Mediterranean, and the line Belgrade-Southern Adriatic is the backbone of this link that all transport routes are flowing into, towards the Adriatic, and that other areas are connected to [28].

The Port of Bar is very important and enables connection of Bar both with cities on the Adriatic coast and with the whole world as well. The Municipality of Bar consists of three parts: (1) coastal zone, (2) the Lake Skadar shore and (3) the mountain zone of the Rumija.

Coastal zone – for the development of tourism and maritime economy, tourism, boating, agriculture and fisheries
The Lake Skadar shore – development of eco-tourism, agriculture, fisheries and water management
The mountain zone of the Rumija – the zone of livestock and tourism development

Relief Bar is surrounded by numerous mountains. The characteristics of the relief and all its elements have both a direct and indirect influence on the use of space and natural and man-made resources in general. Geomorphological characteristics of the

Municipality of Bar are such that to a certain extent they are a factor of limitation to the development, taking into account the modest resources of terrains suitable for the development of intensive agricultural production. The territory of the municipality can be divided into three morphological units: (1) the strip along the seashore – Bar Riviera; (2) the strip along the banks of the Lake Skadar – the Lake Skadar area; and (3) the central strip of the municipality hilly-mountainous area with the Rumija, Sutorman, Lisinj and other massifs. Along the coastal area, there are several larger and smaller bays and capes, showing the indentation of the seashore. The steep slopes of the mountains rise above the coastal zone, while the settlements are formed mostly on less steep terrain. Elevation of the hinterland of the coastal zone is mostly 700 to 900 m a.s.l., and the highest peak of the Rumija is at 1.594 m a.s.l. Such configuration of the terrain results in a mix of continental and marine influences and weather conditions vary considerably in certain areas above Bar, depending on the altitude.

Climate Apart from being one of the sunniest places in the Southern Europe, with an average of more than 2.500 sunshine hours during the year, the climate of the Municipality of Bar is characterized by long and warm summers and mild winters. Mean annual temperature is 15.6°C. In July, the average air temperature is 23.4°C and in January 8.3°C. Summers in Bar are long and dry, and due to warm influence of the Adriatic Sea, winters are mild and rainy. Typical Adriatic winds are blowing in Bar and the surrounding area: bura – the cold wind; jugo or scirocco – the wet wind; pulenat, mistral, burin and danik (day wind); and noćnik (the night wind). The most frequent and most intensive wind is bora. During more than 300 days a year, the mean monthly temperatures are above 10°C, and during the period of 6 months, temperatures are above 15°C.

Precipitation Favourable thermal regime over the year and low precipitation, except in the second half of autumn, a slight cloudiness, etc., provide favourable conditions for setting up settlement, tourism development and other urban activities. Mean annual number of days with precipitation above or equal to 10.0 l/m^2 ranges between 43 to about 80. Bar and Sutomore have 43 of such days. Most of the rainfall (more or equal to 20.0 l/m^2 of precipitation) occurs during 20 to 25 days in the coastal part of the municipality, up to about 200 m of absolute altitude. On average, there are 38 rainy days during winter in Bar during the year.

Soil The territory of the Municipality of Bar does not dispose of significant areas of fertile land, so special attention has to be paid to the preservation and proper use of the pedological cover in this area. Most of the surfaces Bar are covered by terra rossa. These soils can be used for agricultural production on slopes of up to 20%. Resedimented and anthropogenic terra rossa on hard carbonates can be used for agriculture. Fragmented and scattered areas and waterlessness are the key factors of limitation to more intensive agricultural production on them. On the Adriatic side, olives, fig trees, tobacco, almonds, carob, grapevine, etc. grow well, while on the side of the Lake Skadar, climatic conditions are not favourable for olive growing. Other crops on terra rossa are ruined by drought (grains, maize). Irrigation during the dry period would result in the production of high-quality products: citrus fruits, peaches, vegetables, etc. Areas significant for agricultural production are areas covered by terra rossa in the region of Možura and Velika and Mala Gorana (Goransko Field). Chernozem, usually on compact limestone (buavica, rendzina), also covers larger areas of the Municipality of Bar, but at higher altitudes, above 700 m. They are used as fields for potato production and where fertilized, also for the cultivation of other crops. Brown soils on flysch are the zones with the lushest vegetation, the most advanced agriculture and settlements. Olive groves (Bar), citrus fruits plantations, orchards and gardens are set up on them. They cover mainly the central and lower sides of the slope and hilly positions within the Municipality on milder slopes. Soils in coastal fields are the only flat land potential of the Municipality of Bar, where the terrain configuration allows for intensive agricultural production. In addition to agro-technical measures, they require drainage for the evacuation of surface water (Barsko Field – 1.000 ha, Crmnica 500 ha). Anthropogenic soils on the coast are not a natural but a social resource developed from generation to generation. Nowadays, they are seriously threatened by erosion due to neglect.

3.1.2 Budva

The area of Budva belongs to the coastal region of Montenegro, which has all the typical characteristics of a Mediterranean area. Apart from extraordinary natural conditions for the development of tourism, the maritime economy and some agricultural sectors, for the time being, it does not dispose of other significant natural resources. The Budva Riviera occupies the central part of Montenegro's coastal area, covering 122 km^2. The Municipality of Budva is situated in the southern, coastal part of Montenegro, between 42°10′ and 42°20′ north latitude and 18°49′–19°00′ east longitude.

At the shoreline of 27 km, there are 17 smaller and larger sandy beaches, starting from Jaz in the north to Buljarica in the south. To the north-west, it borders the Municipality of Kotor, to the north-east and east the Municipality of Cetinje and to the south-east the Municipality of Bar. The mountain range rises and stretches along its entire territory.

Relief In view of the morphological characteristics of the territory, there are three distinct vertical zones: A coastal strip up to 100 m a.s.l.; coastal flysch zone from 100 to 500 m a.s.l.; and Lovćenska Prečaga, slopes and flat areas of the Lovcen "Mountain", from 500 to 1,400 m a.s.l. The coastal strip is indented, with cliffs, bays, beaches and isthmuses. The Municipality of Budva also has attractive organized beaches, most notable of which are Buljarica, Petrovac, Bečići, Jaz, Slovenska Plaža, Mogren, Miločer, etc. The coastal flysch zone is favourable for construction, agriculture and transport. It is intersected by numerous rivulets and streams. The Budvansko Field is almost entirely covered by structures, while the potential of Buljaričko and Mrčevo fields (Jaz) has not yet been utilized yet. "The Mountain" is separated from the other two zones by steep escarpments, up to several hundred metres high. From a plateau at 600–700 m a.s.l, the following peaks rise: Čainski Vrh (1.326 m), Goli Vrh (1.087 m), Ilijino Brdo (841 m), Šuman (791 m), Dražimir (722 m) and Kopac (720 m). One part of the National Park Lovćen is situated in this zone.

Climate The Municipality of Budva has a Mediterranean climate with mild but rainy winters and long dry summers. Budva has about 2.300 sunshine hours a year, which is at the very top of the tourist metropolises in the Mediterranean. Sea temperature ranges from 11.7°C in February to 24.7°C in August. The average sea temperature between May and October is about 18°C, which means the bathing season lasts almost 6 months. The most common winds are bura (north wind, blowing from the continent and can reach a speed of 12 to 15 m/s), jugo or scirocco (blowing from the sea and bringing rain or cloudy weather) and mistral (blowing during the summer months, cools down warm summer days and suitable for sailing).

Precipitation Air humidity on the territory of the Municipality is relatively low and ranges from 67 to 75% and is the lowest during the summer – in July 67% and August 69%. Precipitation usually takes the form of rain, with an average precipitation of about 1.578 mm. The maximum of rainfall is in November, while the minimum is in July and then in August and June. Secondary maximum of rainfall is in March and the minimum in January. The precipitation is unevenly distributed, so in the summer, there are often none at all. Also, there are frequent fluctuations from year to year. Most rainfall occurs in autumn, then in winter, while summer is the driest season of the year. Snow falls above 600 m a.s.l., but due to the proximity of the sea, it does not last for long.

Soil The following soil types are present on the territory of the Municipality of Budva: very shallow and eroded terra rossa, alpine rendzina (shallow eroded buavica), alluvial-diluvial soils and anthropogenic brown soils on terraces. Most of the area is covered by shallow, eroded terra rossa, which is typical of the Mediterranean climate. Alpine rendzina (in the conditions of the Montenegrin karst known as shallow eroded buavica) is the second most represented soils, with low productivity for forest species and a clay and powder content of up to 70%. Alluvial-diluvial soils are characterized by light mechanical composition, low water storage and relatively high air storage capacity. Water for plants is supplied from ground waters. These alluvia are predominantly carbonates, with almost negligible hummus layer. Anthropogenic brown soils on terraces appear under the deciduous forests, rich in pores and with clayey mechanical composition. Nearly 50% of the area of Budva is the terrain with a slope above 36%, where virtually no activity is possible without major investments.

3.1.3 Herceg Novi

The Municipality of Herceg Novi is a part of the Boka Kotorska Bay, belonging to the south-eastern part of the Adriatic coast. It is situated between 18°25′ and 18°42′

longitude and 42°32′ latitude. To the south, it borders Konavle, and the north-eastern part is surrounded by the Orjen massif (1.895 m a.s.l.). The southern part belongs to the Topljanski and Herceg Novi Bay and a part of the Tivat Bay, including the Luštica peninsula. To the east, the area of the Municipality of Herceg Novi is separated from the Vrmac massif (768 m a.s.l.) by the Verige Strait. The exit to the open sea is through the Boka Kotorska Door (1.6 sea miles in width), near the Oštra Cape. Population density is 132 inhabitants per km^2.

Relief The relief is characterized by a rocky coast with a close hinterland of the mountain massif Orjen, with predominantly hilly-mountainous terrain covered by vegetation, with smaller plains among which Vrbanj is the most notable in terms of size and position. The relief characteristics of the territory include mountainous terrain, covered by deciduous vegetation and macchia, while in the mountain area, there are some coniferous forests, among which karst forms have developed. The mountain tops are bare, while at the foot, the most pronounced forms are karst fields (Krusevice, Ubli, etc.), valleys (Sutorina along the Sutorina River, Kutska along the Zeleznicka River and Bijeljska along the Pijavica River) as well as a larger number of sinkholes. The Luštica Peninsula (a part belongs to the Municipality of Herceg Novi) is represented by two hills (Obosnik 584 m), with the central valley stretching between them, where most of the villages of the Luštica area have been formed. The exit to the open sea is through the Boka Kotorska Door 1.6 sea miles in width, near the Oštra Cape. The depth of the sea at the Oštra Cape is 80 m, while in the Herceg Novi Bay, it is 45 m.

Climate The climate on the territory of the Municipality, taking into account all geographical and meteorological conditions, can be characterized as a mild Mediterranean climate with warm dry summers and mild and humid winters. Average mean air temperature is about 15.1°C, average max. 20.8°C and average min. 9.5°C. The coldest month is January with mean min. temperatures around 11.8°C, and the hottest month is July with mean max. temperatures around 29.4°C. On average, there are only 3.3 days per year when the temperature drops below 0°C. In recent years, constant increases in mean min. and max. temperatures have been observed (both in winter and summer periods). July and August have average solar insolation of 328 h or 10.7 sunshine hours a day. The maximum cloudiness is in November and December. Mean monthly and annual cloudiness in 1/10 of cloud cover is 5.0/10. Yearly, there are 101.8 clear days and 102.8 cloudy days.

Gale-force gusts have been observed recently as well as the higher intensity of the winds from the north, northeast and south directions. Bura is typical in winter (from the north-west or north-east) lowering the temperature significantly, achieving high speed, even of gale force and with strong gusts. Bura is also common during the summer months when it does not last for long and is blowing usually at night, but then it is warm and humid and causes a temperature increase. Oštrijal and mistral are summer winds, but they are also blowing in other times of the year. In the summer, in night and early morning hours, a light breeze called Poljak blows as a result of the difference between the temperatures of the sea and the land.

Precipitation Mostly rain, and sometimes hale and very rarely snow, typically occur in autumn-winter-spring, when the total precipitation average is about 1.158 mm/m^2 (although it can be noted that it has slightly risen in recent years). In the winter, the precipitation is about 610 mm, in the spring around 450 mm, in the summer around 200 mm and the autumn around 550 mm. The intensity of rainfall is pronounced, causing problems in flood waters formation. The intensity of rainfall is pronounced, causing problems in flood waters formation. An analysis of short-duration rainfall of typical probability for return periods of 2 to 100 years indicates a high risk of floods during such rainfall events, taking into account all the historical information on rainfall-runoff relations in the Municipality of Herceg Novi.

Soil The soil condition in terms of the content of hazardous and harmful substances can be characterized as good, based on the monitoring carried out at the target locations selected. Elevated levels of pollutants (both organic and inorganic) have been found in the Municipality of Herceg Novi. This is the result of inadequate municipal waste disposal. Various soil types can be found from the coast towards the mountain: Mediterranean terra rossa, mountain terra rossa of the buavica type and 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. The ratio of agricultural and forest land had been distorted long ago with the 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.

3.1.4 Kotor

The ancient City of Kotor is situated in the south-eastern part of the Adriatic Sea, at the end of the beautiful Boka Kotorska Bay and below the Lovćena slopes. Area of Kotor totals 355 km^2. Population density is 67.5 inhabitants per km^2. Natural characteristics notable in the area of the Kotor-Risan Bay give particular value to the territory of the Municipality of Kotor as it is listed in the UNESCO's World Heritage list as a natural and historical area.

Relief The relief of the Boka Kotorska Bay and Kotor is of karst origin. To the south-east, Kotor is surrounded by the limestone massif of Mt. Lovćen (1.749 m) and to the north-west by branches of the Mt. Orjen (1.895 m), Radostak (1.446 m) and Dobroštica (1.570 m). Close by are two peninsulas – Vrmačko and Devesinjsko – separated by the Verige Strait. The Strait divides the Boka Kotorska Bay into two internal bays, the Risan and the Kotor Bay, and two outer bays, the Tivat and the Topljanski Bay.

Climate Kotor has a Mediterranean climate. The climate is characterized by hot, dry summers and mild winters. July is the warmest month with a mean temperature of about 25°C, while January is the coldest, with 7.5°C. In Kotor, autumn is by 2.9°C warmer than spring. The sea near Kotor is the storage of heat and a source of vapour, which is one of the most important factors in temperature fluctuations and precipitation on the whole territory.

Precipitation Mean annual precipitation is around 2.200 mm. However, in Crkvice, annual precipitation ranges from 4.500 to 5.000 mm, so this is the site with the highest precipitation in Europe. Most of the rainfall occurs in autumn (248 mm) and spring (243 mm), with the lowest in summer, slightly more than 68 mm. The most significant winds are mistral, scirocco, bura and burin. From mid-May to mid-October, the temperature of the sea varies around 22°C, allowing the bathing season to last for about 144 days.

Soil The area of the bay is surrounded by vertical Dinaric-coastal limestone slopes, extremely high and thick, one of the rare holokarst areas in the world with pronounced karst morphology and hydrology. Its formation and morphological characteristics (pronounced vertical indentation) make it the unique bay in the Mediterranean. The nature of this area is characterized by pronounced vertical indentation, as a result of the morphogenesis of the bay, which is highlighted by tectonic descent along the lines Kotor-Orahovac and Risan-Krivošije. The consequence of such characteristics is a height difference of 1.453 m measured between the deepest point in the bay (67.96 m) and the highest elevation point of the bounded area (1.385 m).

3.1.5 Tivat

Tivat is situated in the central part of the Boka Kotorska Bay, on south-western slopes of the Vrmac hill. Across lies the Tivat Bay, the biggest of the four bays in the Boka Kotorska. The Tivat Bay covers the area of 46 km^2, of which 5 km^2 has an exit to the open sea. Development of Tivat as a city began as late as at the end of the nineteenth century when the Military Maritime Port Arsenal was established. 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. Today, Tivat is a modern city relying on the development of tourism as the priority business activity.

Relief According to morphological characteristics and geological structure, three spatial micro-units are distinct on the territory of the Municipality of Tivat, as follows: the Vrmac massif, the Tivat Field and the Krtole. 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.

Climate Tivat has a typical Mediterranean climate with mild and rainy winters and clear and warm summers. This is the sunniest city of the Boka Kotorska with 2.420 sunny hours a year. The most frequent winds are bora in the winter and mistral in the summer months. One of the frequent winds is jugo, both in autumn and in winter; it is quite warm and brings in a lot of rain. Precipitation in Tivat exclusively takes the form of rain, while other forms of precipitation are very rare here. On the Tivat Riviera, the sea is clear, and the air is refreshingly mild. The maximum air temperature has a mean monthly maximum in the hottest months of about 30°C, while in the coldest ones, it ranges from 12 to 13°C.

Soil 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.

3.1.6 Ulcinj

The territory of the Municipality of Ulcinj occupies the southernmost part of Montenegro, the eastern coast of the Adriatic Sea. The area of the Municipality of Ulcinj is 255 km^2. In the continental part, the Municipality of Ulcinj borders the Municipality of Bar to the west and to the north and Albania to the east. The Municipality of Ulcinj is situated in the vicinity of the following important transport infrastructure facilities: the Port of Bar, about 25 km to the north-west, is the largest regional transport port and is connected to strategically important roads and the railway.

From the Port of Bar, passengers are transported by ferry to Ancona, Bari (Italy) and Dubrovnik (Croatia), with an average of 40.000 passengers per annum. Expansion of existing capacities is planned. Railway Bar-Belgrade is used for transport of passengers and cargo, connecting the coastal region to Podgorica and the northern region of Montenegro, as well as further through Serbia and Belgrade with other parts of Europe. This is the most important rail route in Montenegro.

Relief The main characteristic of this area is the clear division into mountainous terrain to the west, north-west and north, and the branches of foothills with the plains to the eastern and central areas of the municipality.

Relief analysis for the Municipality of Ulcinj shows that most of the terrain of the Municipality is at an elevation of up to 100 m a.s.l. – 65.2%. This lowland relief is divided by a 100 m a.s.l. isohypse because it can be seen that some hills (Briska Gora, Šasko Brdo, etc.) have a significant effect on the space. They are about 100 m high because they affect communication and climate and other physical-spatial characteristics. The limestone foothill zone is situated to the west, with altitudes of up to 500 m. Lowlands with slopes 0–5% prevail in the area covered by the plan. Except for the hills in the Ulcinj Field, raising like islands with slopes of up to 15% the entire Ulcinj Field with Ada and the Bratica Valley to towards Bar are plains.

The analysis of the terrain's solar insolation suggests that 84.18% of the terrain has a favourable exposure, while only 10.30% have unfavourable exposure. All southern slopes facing the sea, and the plains of the Municipality (Ulcinj, Briško, Alamansko Fields) have favourable sun exposure.

Climate Climatic conditions in Ulcinj are specific and have diverse climate characteristics, which are due to geographical position, altitude, relief and influence of the Adriatic Sea. The influences of warm Mediterranean and colder continental climate combine here, so it can be concluded that Mediterranean climate prevails in this area, with very warm and dry summer periods, moderate autumn periods and spring periods with relatively low precipitation, mainly in the form of rain, and with mild winters. It can be said that the area of Ulcinj has less pronounced differences in average monthly temperatures than other cities in Montenegro. The mean monthly temperature ranges from 6.9°C in January to 24.3°C in July and August with a mean annual temperature of 15.5°C. The minimum number of sunshine hours is in December 115, while July it is 349 h. The mean annual sunshine in the area of Ulcinj is 2.571 h, and in this regard, Ulcinj comes first in Montenegro.

Precipitation In Ulcinj, the driest month is July with only 298 mm rain, and the most abundant rainfall is in November 173 mm and December 154 mm. The average annual precipitation is 1.274 mm, and after Pljevlja and Berane, Ulcinj is a city with the lowest mean annual rainfall.

Soil Pedological cover of the territory of the Ulcinj is characterized by a significant presence of potentially fertile soils in comparison to other areas of Montenegro and particularly compared to the Montenegrin coastal region. Soil resources in the plains are particularly important, because Ulcinj, accounting for only 1.8% of Montenegro's territory, has about 8.500 ha of deep fluvial soils in the plains (saline and water surface excluded), which is about 14% of all the plains in Montenegro and more than 60% of the plains in the coastal area.

3.2 Natural Resources for Agriculture Development

High-quality, preserved and fertile soil contributes to the agriculture development in Montenegro. Soil is the most important natural resource for the development of agriculture. Table 12 provides an overview of agricultural land by category of use in coastal municipalities of Montenegro in 1965–2010.

In the period 1965–2010, significant changes happened in the structure of agricultural areas in Montenegro, as well as in the coastal municipalities under survey. The total agricultural area is on the decline – the sharpest was recorded in Kotor and is around 63.08%.

The areas under the arable fields and gardens decreased at the level of Montenegro by about 30%. The highest decrease in the area under arable fields and gardens was recorded in the Municipality of Bar, around 72%, and the smallest in the Municipality of Ulcinj, around 10.59%. The structure of agricultural areas in the period observed clearly shows that agriculture has become a negligible activity for the population of the coastal region.

3.2.1 Agriculture of the Coastal Region

In the field of agriculture, the basic orientation is focused on the faster development of typical Mediterranean agriculture, agri-tourism and mariculture. The concept of rural areas development starts from the fact that, apart from the attractive shoreline,

Table 12 The structure of agricultural areas (ha) in coastal municipalities, period 1965–2010

			Arable area (ha)						
		Total	Total	Arable fields and gardens	Orchards	Vineyards	Meadows	Pasture (ha)	Ponds, fishponds and reeds (ha)
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
	2010/65	88.22%	100.00%	69.33%	134.79%	311.63%	112.58	82.46	106.34
Bar	1965	21.161	12.249	4.184	7.490	130	445	15.088	4
	2010	18.480	5.322	1.141	2.441	291	1.448	13.129	9
	2010/65	87.33%	43.44%	27.27%	32.59%	223.84%	325.39%	87.01%	225%
Budva	1965	7.476	1.366	562	310	29	465	6.061	49
	2010	5.025	1.045	263	284	8	490	3.950	30
	2010/65	67.21%	76.50%	46.79%	91.61%	27.58%	105.37%	65.70%	61.22%
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
	2010/65	58.53%	80.77%	53.44%	84.42%	109.19%	98.64%	54.11%	150.00%
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
	2010/65	36.92%	91.56%	35.17%	117.43%	106.06%	227.34%	23.90%	–
Tivat	1965	2.533	1.182	420	570	113	79	1.350	1
	2010	1.712	1.166	368	510	100	188	545	1
	2010/65	67.58%	98.64%	87.61%	89.47%	88.49%	237.97%	40.37%	100.00%
Ulcinj	1965	11.456	5.661	3.893	561	66	1.141	5.661	134
	2010	11.503	6.502	3.481	800	93	2.128	4.729	272
	2010/65	110.41%	114.85%	89.41%	142.60%	140.90%	186.50%	83.53%	202.98%

Source: Statistics Office of the Republic Montenegro (1966) Agriculture – Statistical overview 1947–1965, Monstat (2012) Statistical Yearbook 2012 [6, 7]

the coastal region can offer also a valuable rural hinterland. The valorisation of these resources results in balanced development in the region, the development of agriculture and rural tourism, encourages the retention and restoration of green spaces in the coastal zone should ensure accommodation conditions of good quality, preservation of the population and reduction of pressure on urban areas and the narrow coastal zone. Food production is ensured, and habitats and natural ecosystems are preserved. Agricultural areas are intended for agricultural production only. In these areas, only facilities for agricultural land management can be built.

3.2.2 Plant Production

Table 13 provides an overview of the use of arable fields in coastal municipalities according to the 2010 Agriculture Census.

In the coastal municipalities observed, according to the 2010 Agriculture Census, the Municipalities of Ulcinj and Bar disposed of the largest areas under arable fields and gardens. In these two municipalities, vegetables prevail in the structure of areas sown.

Due to the favourable environmental conditions, coastal municipalities have favourable resources for olive and citrus fruits growing. Olive growing has a long tradition. Table 14 below gives an overview of trends regarding the number of olive and citrus trees and grapevine plants in the period 1965–2010.

Based on the analysis of the number of productive grapevine plants, it can be seen that the number has been decreasing, except in the Municipality of Bar, where the number of grapevine plants in 2010 was higher than in 1965. The highest decrease was recorded in the Municipality of Budva, as much as 90%. Yield per vine plant has increased in the municipalities of Bar, Budva and Herceg Novi.

The number of olive trees has increased in the Municipality of Tivat (3.43%) and Ulcinj (37.78%). The yield per tree rose in almost all municipalities; only Ulcinj experienced a decrease of about 6%.

The number of productive orange and mandarin trees is growing in all municipalities, and it is the highest in the Municipality of Ulcinj. The yields per three have grown in all municipalities observed.

3.2.3 Livestock Farming

Livestock farming is one of the most important branches in the Montenegrin agriculture sector. Livestock farming enables Montenegro to use less-productive areas (meadows and pastures). Table 15 shows the number of livestock in coastal municipalities.

In the period observed, significant reduction in the number of livestock took place in all coastal municipalities. Municipalities of Kotor and Tivat record the largest decline of the livestock by all categories. The data shows that livestock is not the

Table 13 Use of arable fields (ha) in coastal municipalities, according to the 2010 Census

	Arable fields and gardens	Sowed area					Flowers	Nurseries	Fallow land and uncultivated areas
		Total	Cereals	Industrial crop	Vegetables	Forage crops			
Montenegro	45.472	31.025	5.012	125	18.268	7.620	16	2	14.429
Bar	1.142	1.138	84	12	782	260	–	–	4
Budva	263	36	–	–	27	9	9	–	218
Herceg Novi	388	175	–	–	132	43	–	–	213
Kotor	636	146	11	–	85	50	2	–	488
Tivat	368	55	10	–	38	7	–	–	313
Ulcinj	3.481	3.481	1.100	–	1.581	800	–	–	–

Source: Monstat (2012) Statistical yearbook 2012 [7]

Table 14 Trends regarding the number of olive and citrus trees and grapevine plants in the period 1965–2010

		Vineyards			Olives			Oranges and mandarins		
		Number of productive grapevine 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
Bar	1965	782.959	550.7	0.7	118.761	474.2	4.0	10.225	5.4	5.0
	2010	959.500	1.018	1.1	83.500	418	5.0	93.100	1.958	21.3
	Index	122.54		157	70.30		125	910		426
Budva	1965	144.410	81.7	0.5	62.750	668.7	10.6	1.690	14.4	8.5
	2010	14.225	16.0	1.1	41.300	620	15.0	2.830	42	14.8
	Index	9.85		220	65.81		141.51	167.45		174.11
Herceg Novi	1965	574.070	438.9	0.5	120.746	229.8	1.9	8.080	77.5	9.5
	2010	322.734	336.0	1.0	71.390	343.0	4.8	10.960	198	18.1
	Index	56.21		166	59.12		252.63	135.64		190.52
Kotor	1965	292.600	350.7	1.2	61.866	62.1	1.0	1.653	3.8	2.4
	2010	261.000	183.0	0.7	40.000	172.0	4.3	28.000	268.0	9.6
	Index	89.20		58.33	64.65		430	1.693.88		400
Tivat	1965	460.600	324.2	0.7	62.842	62.7	1.0	6.529	11.2	1.7
	2010	124.500	88.00	0.7	65.000	260	4.0	11.000	106	9.6
	Index	27.02		100	103.43		400	168.47		564.70
Ulcinj	1965	158.797	405.4	2.6	76.934	358.5	5.0	66	0.30	4.5
	2010	117.000	140.0	1.2	106.000	500.00	4.7	245.000	6.150	25.1
	Index	73.67		46.15	137.78		94	3.712.10		557.77

Source: Statistics Office of the Republic Montenegro (1966) Agriculture – Statistical overview 1947–1965, Monstat (2012) Statistical Yearbook 2012 [6, 7]

Table 15 Livestock numbers in coastal municipalities, 1965–2011

		Bovine animals total	Pigs total	Sheep total	Horses total	Poultry	Bee Hives
Bar	1965	5.073	2.103	21.406	303	–	–
	2011	2.217	1.119	4.119	57	9.491	3.099
	Index	43.71	53.21	19.24	18.81	–	–
Budva	1965	909	455	1.744	93	–	–
	2011	154	11	98	–	81	406
	Index	16.94	2.42	5.61	–	–	–
Herceg Novi	1965	2.362	1.095	5.207	234	–	–
	2011	547	589	1.009	39	3.137	770
	Index	23.15	53.78	19.37	16.66	–	–
Kotor	1965	2.074	652	3.843	256	–	–
	2011	86	247	195	1	390	520
	Index	4.15	37.88	5.07	0.40	–	–
Tivat	1965	374	222	162	102	–	–
	2011	9	2	90	–	--	212
	Index	2.41	0.90	55.55	–	–	–
Ulcinj	1965	4.569	841	14.796	610	–	–
	2011	3.312	130	6.516	31	20.162	842
	Index	72.48	15.45	44.03	5.08	–	–

Source: Statistics Office of the Republic Montenegro (1966) Agriculture – Statistical overview 1947–1965, Monstat (2012) Statistical Yearbook 2012 [6, 7]

primary agricultural branch of coastal municipalities. Historically, livestock was farmed only in the peri-urban areas.

Nowadays, the share of cattle in the Municipality of Bar in the total number of cattle in Montenegro ranges from 2.59%, in the Municipality of Budva, 0.18% in the Municipality of Herceg Novi, 0.64% in the Municipality of Kotor, 0.01% in the Me Municipality of Tivat and 3.88% in the Municipality of Ulcinj.

3.2.4 Demographic Indicators by Municipalities

Based on data given in Table 16 below, it can be seen that the population in Montenegro was continuously growing in the period 1948–2011. Furthermore, the population in the coastal municipalities has increased.

In demographic terms, the coastal region is characterized by population growth in the period 1948–2011. The population growth is particularly pronounced in the municipalities of Bar and Budva, which are the most active ones in terms of economy. The population of the Municipality of Ulcinj is on the decline.

The number of households in the coastal municipalities has been growing from one census to another so that the number of households in the Municipality of Bar is higher by 168% in 2011 than in 1948, in Budva by 537%, in Herceg Novi by 219%, in Kotor by 94%, in Tivat by 227%and in Ulcinj by 132% (Table 17).

Table 16 Population by municipalities, by censuses

	1948		1971		2003		2011	
	Population	% Share	Population	% Share	Population	% Share	Population	% Share
Montenegro	377.189	100	529.604	100	620.145	100	620.029	100
Bar	21.487	5.70	27.580	5.21	40.037	6.45	42.048	6.78
Budva	3.822	1.01	6.108	1.53	15.909	2.56	19.218	3.09
Herceg Novi	12.482	3.31	18.368	3.46	33.034	5.33	30.864	4.98
Kotor	14.124	3.74	18.917	3.57	22.947	3.70	22.601	3.65
Tivat	5.030	1.33	6.925	1.31	13.630	2.20	14.031	2.26
Ulcinj	12.861	3.41	6.141	1.60	4.204	0.68	3.569	0.56

Source: Monstat (2013) Statistical Yearbook 2013 [29]

Table 17 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
Bar	5.294	6.33	6.868	5.63	12.447	6.89	14.211	7.29
Budva	1.096	1.31	1.854	1.52	5.218	2.89	6.982	3.58
Herceg Novi	3.485	4.20	5.373	4.40	11.076	6.14	11.133	5.71
Kotor	3.940	4.71	5.317	4.36	7.290	4.03	7.649	3.92
Tivat	1.484	1.77	1.997	1.64	4.502	2.49	4.862	2.49
Ulcinj	2.504	2.99	3.781	3.10	5.327	2.95	5.812	2.98

Source: Monstat (2013) Statistical Yearbook 2013 [29]

Of the total population in Montenegro, 24% live in the coastal region. In the period between 2003 and 2011, the largest population growth was recorded in the municipalities of Bar and Budva, which are also the leading economic and tourism centres. Attractive tourist sites in coastal municipalities result in the highest concentration of the population in these locations. Except for Bar, where more residents live in rural settlements, in other coastal municipalities, the population inhabited city centres and surrounding settlements. In Budva, this percentage is the highest (83.2%), and a higher share of residents in rural areas confirms the availability of resources that are sufficiently attractive to residents who stay in these areas.

In economic terms, the coastal region is the most developed part of Montenegro. Measured by the development index, four of six municipalities in the coastal region are among the most developed municipalities in Montenegro, with development index above 125% of the national average (municipalities Budva, Kotor, Herceg Novi and Tivat). Although agriculture is a significant development resource for the coastal region, only 364 agricultural producers have been registered, accounting for 8.1% of the total number of agricultural producers in Montenegro.

Limited spatial resources, the natural characteristics of the area and the orientation towards tourism development, impose future development of the coastal areas on the principles of the green economy and green entrepreneurship. Otherwise, unsustainable resource exploitation will occur, which will ultimately jeopardize the future growth and development of the economy in this region.

4 Possible Agriculture Development Directions for the Coastal Region

The main characteristic of rural areas in the coastal region is the fragmentation of agricultural holdings, negative demographic trends, underdeveloped rural infrastructure and low degree of commercialization of agricultural holdings.

The coastal region is characterized by a high population density, a dense network of settlements and concentration of population in urban areas. Furthermore, in recent years, the number of apartments built both for residence and seasonal use has been increasing.

One of the main issues is the change of purpose of agricultural land and its transformation into construction land.

In the process of planning development directions for agriculture and food production in the coastal region, apart from all agro-environmental-specific characteristics, the strategic documents adopted by the municipalities need to be taken into account.

Strengthening the competitiveness, sustainable resource management and a comprehensive rural development programme provides a logical framework for the development of agriculture in the coastal area.

In the future, it would be necessary to increase competitiveness, both in agriculture and in the field of the tourism offer. It would be necessary also to work on improvement of the system of innovations, food safety standards, product quality, etc.

Further efforts improve agricultural production and optimal use of available agricultural resources in plant and livestock production.

Biodiversity richness provides an opportunity for the development of organic agriculture.

Depopulation of the hinterland of coastal municipalities can be reduced by developing agricultural activities as main or secondary sources of income for holdings; improving regional marketing of agricultural products by strengthening links between agricultural production and tourism, within the same or a broader area; strengthening the role of agriculture as a dominant component in preserving the wealth of cultural landscapes; and sustainably managing natural resources through adequate land use and prevention of soil and water pollution.

The area surveyed should be dominated by agricultural activities and orientation focused on the production of citruses, early fruit, olives, medicinal herbs, planting materials of subtropical plants as well as greenhouse production.

In the future, it is necessary to further develop fisheries and fish farming at the level of individual production in accordance with the requirements of long-term protection of aquatorium and the landscape.

Local self-governances should encourage the production of healthy food and so-called organic farming, in particular, the production and processing of Mediterranean crops.

5 Conclusions

Agriculture has a long tradition in Montenegro. By the 1960s, agriculture was a dominant activity in the hinterland of the coastal municipalities, while other industries were at their infancy. This was followed by accelerated industrialization, resulting in migration of the population into cities. Rural areas have become areas with low population density and employment in agriculture mainly refers to senior households. The population in the hilly and mountainous area has been reducing significantly.

The analysis of the statistical data in the period 1965–2011 suggests that agriculture in the coastal region was not the primary activity. In the period analysed, the demographic system was disrupted, resulting in changes in the agricultural sector, available labour force, etc.

In the upcoming period, it would be necessary to put the existing natural resources into the function of agriculture development, primarily organic farming. Complementarity of agriculture and tourism is increasingly important, since the broad range of domestic products enrich the tourism offer, making it unique.

Tourism is a powerful generator for agriculture development through the affirmation of national cuisine and specific Montenegrin products.

Montenegro's agriculture has many opportunities for further development. This concerns an increased demand, due to economic growth, and increased income and sales through the growing tourism sector. Local population prefers domestic products, and an increasing standard of living increases the demand for labelled, quality and organic products. The uniqueness of the Montenegrin tradition offers a wealth of possibilities to label products with designations of origin (e.g. lamb meat, "Njeguška smoked ham", "Pljevaljski cheese", "Kolašinski cheese", etc.). Tourism as the driving force of Montenegro's economy is a significant market for domestic products, traditional high-quality products will enrich the tourism offer, and the linking of agriculture and tourism is also reflected in the development of rural tourism.

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Regional Climate Change of the Adriatic Montenegrin Coast

Luka Mitrović, Mirjana Ivanov, Mlađen Ćurić, and Branislav Gloginja

Contents

Abstract This study is intended to be the basis of the available data in the further analysis of the storm's impact as one of the frequent extreme events, which causes damages to properties and which is expected to be more frequent and intense as a result of climate change and variability. Storms are one of the climate factors with possible destroying bio-geophysical effects in coastal morphology. Moreover, the storms have a great impact to suddenly raising of the sea level. Therefore, the risk for the construction on narrow coastal area of Montenegro becomes greater, and the issues of minimum zone offset even more important. A lot of the coastal area are rated as moderate to high vulnerable to storms.

Keywords Climate change, Coast, Montenegro, Storms, The Adriatic Sea, Vulnerability

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1 Introduction

The aim is to use those data in analysis of the narrow coastal strip in order to determine the minimum offset zone where exists a risk for construction, i.e. coastal urbanization. Therefore, the further work instead of all characteristics of the storms that occur in any place during the year will be focused only on those storms that are characterized by a maximum wind gust at any period during the year and maximum amount of rainfall as well. So, only cyclones well developed will be analyzed and shortly called storms.

2 Climate Variability

The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change [1]. Climate variability was analyzed in the terms of IPCC definition [2]. Some of the most important weather and climate variability for Montenegro are:

- North Atlantic Oscillation (NAO) as a measure of strength of the Iceland Low and the Azores High pressure and west winds between them, mostly in the winter. There is a connection between the NAO fluctuations in the storm path, temperature, and precipitation in the direction from North Atlantic to Eurasia [2] Positive NAO index is associated with the dry winters in Southeastern Europe, while negative index is associated with warm and wet winters;
- Genoa Cyclone and Siberian Anticyclone have a particularly strong influence on the climate of Montenegro. They are characterized by high gradients of atmospheric pressure and temperature throughout the Balkans. When the Genoa Cyclone is active it does not stay long, rainfall is intense and do not last for many days. Prolonged rainfall occur when the high SW air flow is developed over Western Europe within the cyclone;
- Air depression in the Adriatic Sea during the winter season – series of depressions moving from west to east and causing maximum precipitation in the winter on the coast;
- Cyclone's path across the Mediterranean or the Adriatic Sea, and over the North Africa high air pressure;
- Impact of El Nino when is extremely strong, as was the case in 1998;
- Impact of atmospheric blocking system.

The extent to which forms of variability such as these, can be considered as the actual forms of variability in the climate system, is the subject of active research in the detection of climate change as opposed to its variability [2].

2.1 Examples of Storms in Montenegro and Their Consequences

Bearing in mind that the storms on the coast of Montenegro contribute significantly to the mean sea level rise, and that generate storm surge up to 5 m in height, that observed data indicate sea level rise during the mid-90s (Fig. 1), that projections indicate the increase in sea surface temperature (Fig. 4), and taking into account the results of sea level rise projections that are subject to special analysis on sea level rise

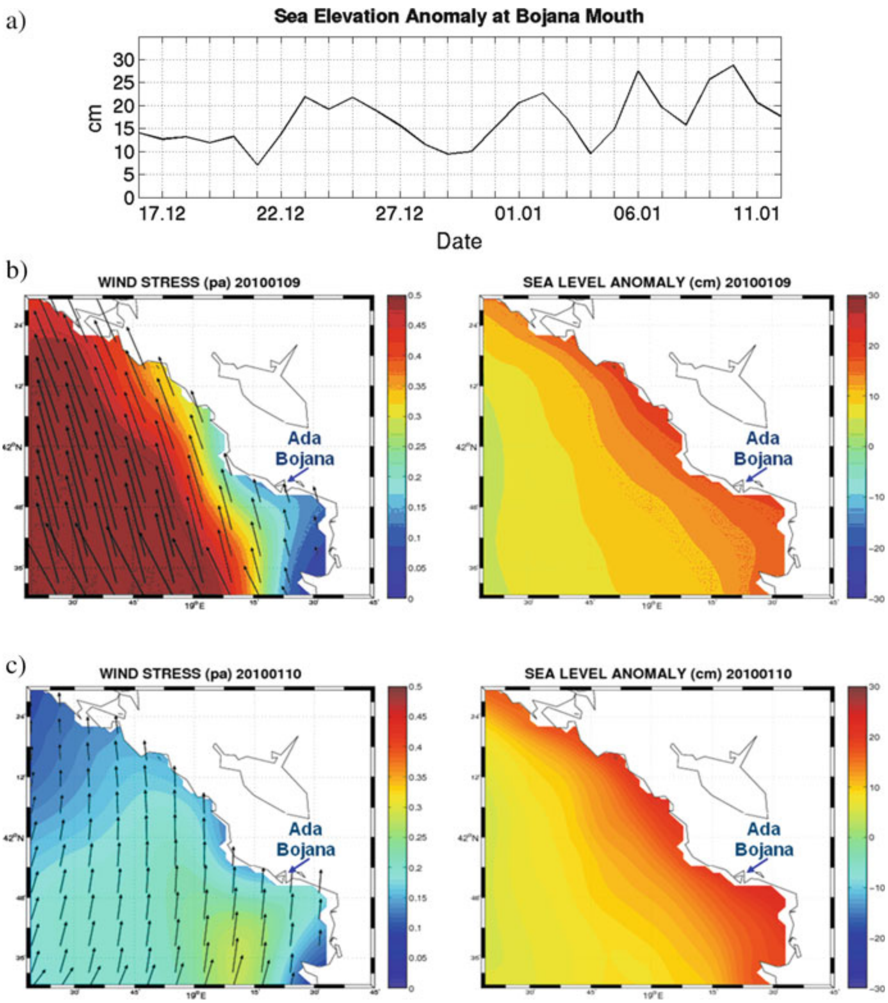


Fig. 1 The influence of wind on sea level rise along the coast, from the 9th to 10th January 2010: (**a**) sea level anomalies at the mouth of the Piver Bojana; (**b**) and (**c**) panels show wind pressure (Pa) and sea level anomalies (cm) occurred during the action

due to global warming, the risk for the construction on narrow coastal area becomes greater, and the issues of minimum zone offset from the aspect of respect and expansion even more important [3].

Storms occur in strong and relatively large atmospheric systems – cyclones. The main risks accompany them are: storm waves and their combination with astronomical tide, the so-called storm tide, then heavy rain, wind, and flooding [4].

Along the Montenegrin coast, large waves are a major threat leading to floods in the wider areas along the coast, causing damages to nearby buildings, beach furniture's, docks, etc.

Figure 1 shows a situation that occurred in the period from 9th till 10th January 2010 when Ada Bojana was flooded At that time, wind speed was more than 65 km/h and pressure in cyclone is of 0.15 to about 0.20 Pa, south to south-easterly direction, caused a sea level rise of about 28 cm (Fig. 1a, b, c). Storm surges reached the height of 4–5 m, causing blocking the outflow of the River Bojana into the sea and the discharge of the Skadar Lake very difficult.

It should be noted that during this high tidal waves and storm south wind in terms of lower rainfall, significantly increase the level of the River Bojana and Skadar Lake.

The panel 3c shows that the wind direction was perpendicular to the coast in the area of Ada Bojana and beyond, and that with the pressure of 0.15 and 0.20 Pa caused a raise of mean sea level from 15 to 28 cm [5, 6].

Observing and monitoring damages caused by the storm, it could be said that the storms in Montenegro occur more frequent and more intensely from 1998 bringing especially to the coast heavy rainfall, storm to hurricane wind gusts, high waves and flooding of the wide areas along the coast [6].

These changes coincide with an increase in sea surface temperature, Fig. 2 which follow the temperature rise on the global level and coincide with the satellite observations in which each year from 1997 was warmer than the climatological normal. However, the relationship between sea surface temperature and the intensity of the storm is not unambiguous, since there are many other environmental factors that influence the intensity and frequency of the storm. The red line at Fig. 2 indicates the 5 year variations of the SST.

A lot of missing data are evident in the Fig. 3a. However, in these incomplete data set, it can be seen that from the 90s sea level was decreasing, then increasing from the mid-nineties, and in the first decade of this century the sea level was stable [7]. It should be considered that the measurements were performed with two different instruments (OTT in Former Republic Yugoslavia and then with Thalimedes). It is noted from the graph (Fig. 3b) that the observed value of 3.4 mm/year exceeded the projected value of IPCC of 1.9 mm/year for the period 1990–2012.

However, considering the current climate it is not easy to detect sea level changes along the Montenegrin coast. The reasons are: rare stations' network for measuring wind and tidal waves, not good data quality and the poor state leveling grid, for which the zero leveling in Bar is below mean sea level. For these reasons, it should be established special anemographic and tide measurements, hydrological and

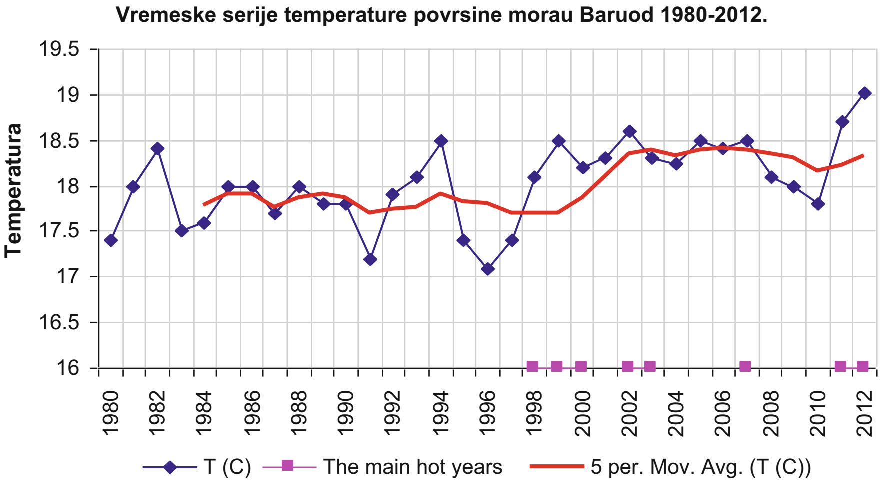


Fig. 2 Interannual variation of sea surface temperature (SST) in the Bar, in the period 1980–2012 (source: according to [6])

hydrographic observational program as the core basis for risk assessment and development of plan to reduce the consequences of disasters [8].

3 Climate Change

The largest climatic and temporal aspects of sea level influence are due to the extreme lasting several days or hours, that are associated with tropical cyclones and mid-latitude storms [2]. The appearance of all these events, at the same time raises questions about their possible links with the projected increase in the intensity and frequency of extreme events as a result of climate change. For example, the IPCC AR 52014 states that the type, frequency and intensity of extreme events change how the climate changes on the Earth [9]. In addition, their changes could occur even with relatively small mean climate changes. Changes in some extreme events are already observed, for example, increasing in frequency and intensity of heat waves and heavy precipitation [1].

Observed effects of climate change are detected on both global and regional levels. On regional level most obvious indication is a significant temperature rise in Europe during 150 years ago. Sea level rise, changes in extreme weather and climate events, and precipitation were observed in Europe during the last 50 years. Climate in Montenegro changes as well [10, 11]. Retaining for this occasion only on coastal region, it is evident that the number of very hot days and nights is in significant increase (indexes Tx90 and Tn90) while the number of very cold days and nights significantly decrease (indexes Tx10 and Tn10). Extreme annual temperature range

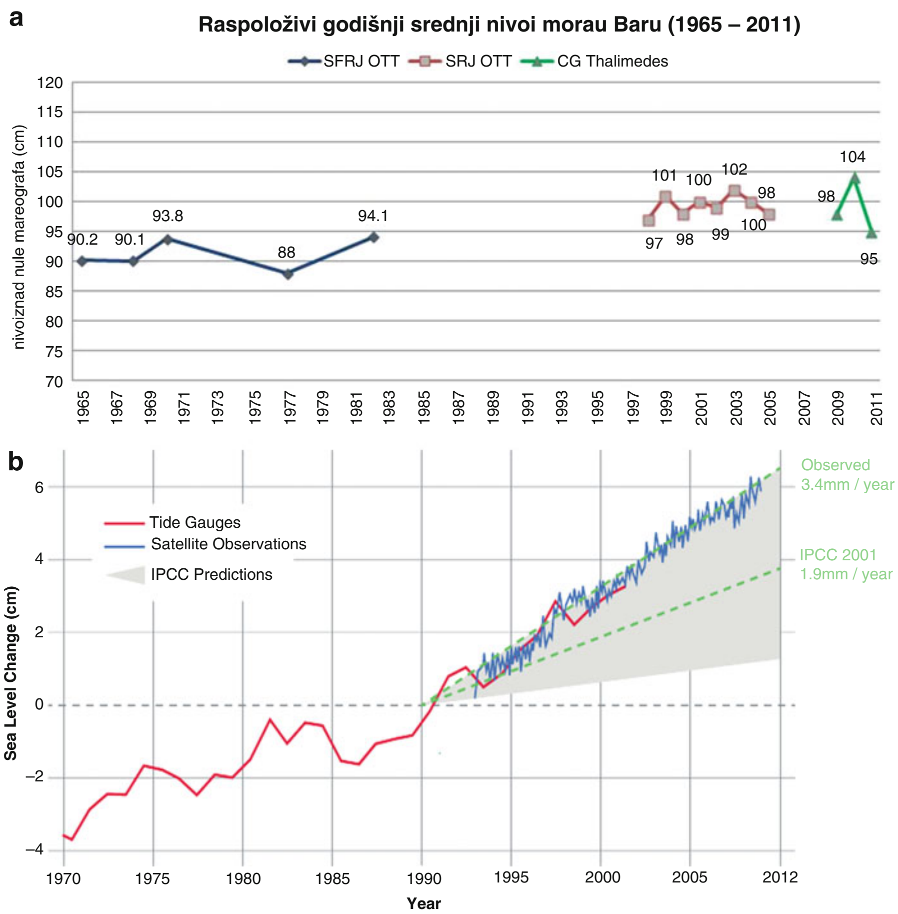


Fig. 3 (**a**) Interannual variation of sea level (cm) according to data from tide gauges in the Port of Bar. (**b**) Observed and projected changes in global sea level (red line –tide measurements, blue line – observations from satellites, dashed green line – the projected changes according to [1]

slightly decreases, and duration of heat waves (index HWDI) significantly decreases. On the other hand, indicators of precipitation extremes, such as R10 (number of days with heavy precipitation), SDII (maximum number of dry days), and R95T (ratio of extreme precipitation in the total annual amount of precipitation), have statistically insignificant trends, and high annual variability (Fig. 4).

Figure 5 shows the results of AdriCosmStar Project and according to them expected increase in sea surface temperature of about 1°C in the period 2015–2020 with respect to the period 2003–2008, and faster sea surface currents, especially in the central part of the Adriatic.

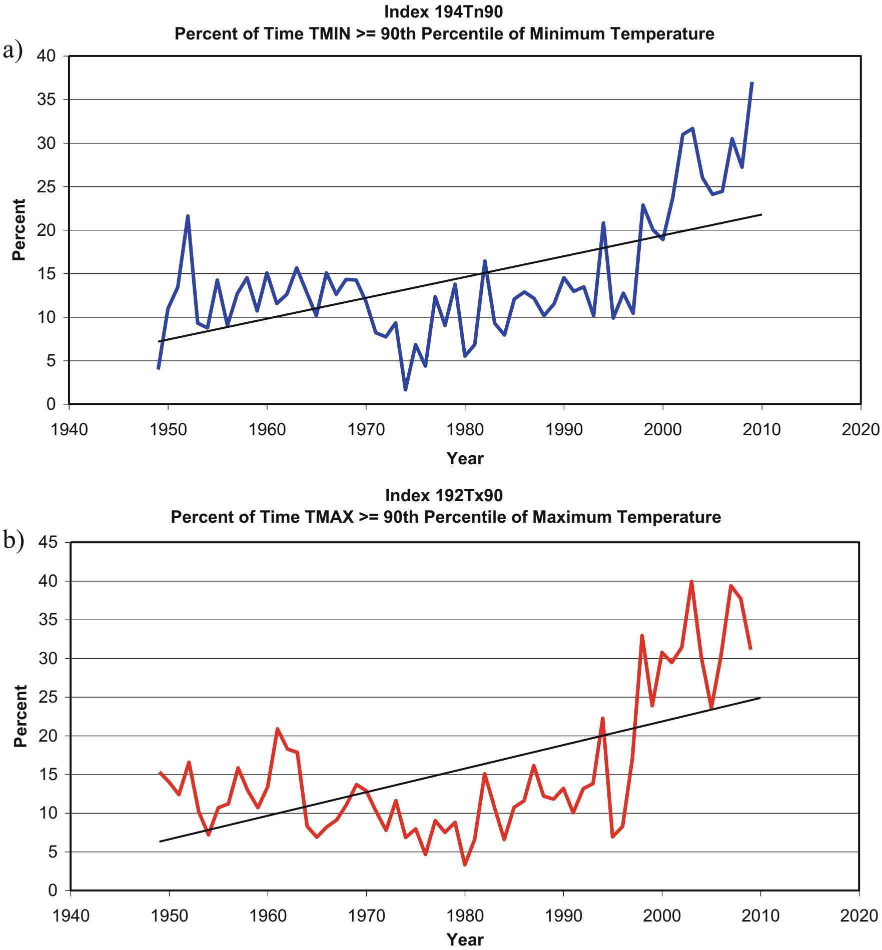
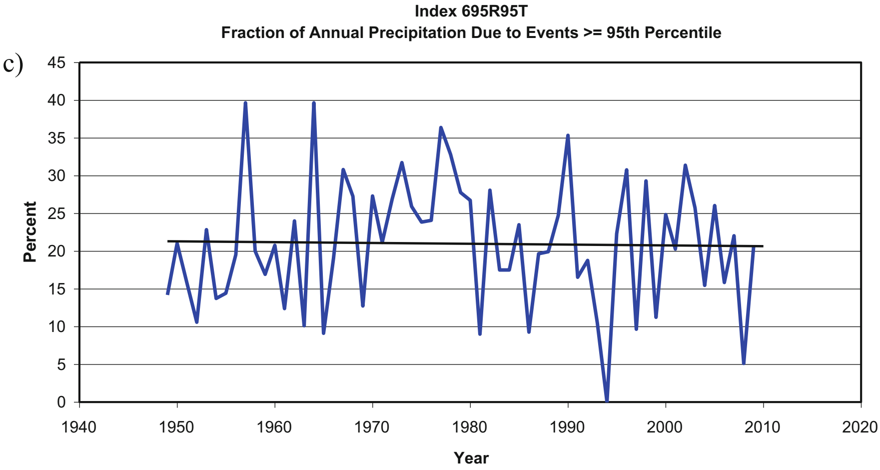


Fig. 4 Observed trends in indexes (**a**) Tn90, (**b**) Tx90, (**c**) SDII, (**d**) R95T. Source: Institute of Hydrometeorology and Seismology

When it comes to the strength and extent of the impact of the storm, research shows that they are expected to increase due to global warming which provides energy for storm intensification. Because of that many coastal areas will cope with the increasing levels of flooding, accelerated coastal erosion and mixing of seawater with fresh water and the loss of wetlands [3]. As a result, concern due to the impact that this will have on the economy, the environment, and food and energy production grows.



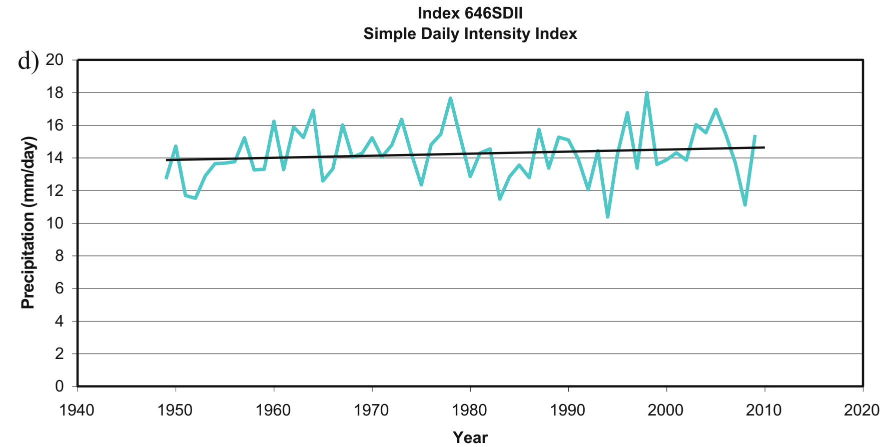


Fig. 4 (continued)

4 Storms' Classification and Vulnerability Assessment

As we mentioned before, the storms on the coast of Montenegro contribute significantly to the mean sea level rise and the increase in sea surface temperature, in this section will be analyzed existing cyclone's intensities strongly developed on the coast. Thereby, the storms are characterized through the parameters that have to be simple so that could be easily found in the data archive and data base, and that are precise enough to be classified according to their severity. Therefore, storms are classified by severity into five categories from strong to extremely strong, and together with their frequency present in the table below. Data were analyzed from three major meteorological stations located on the coast in Herceg Novi, Bar, and Ulcinj (Table 1).

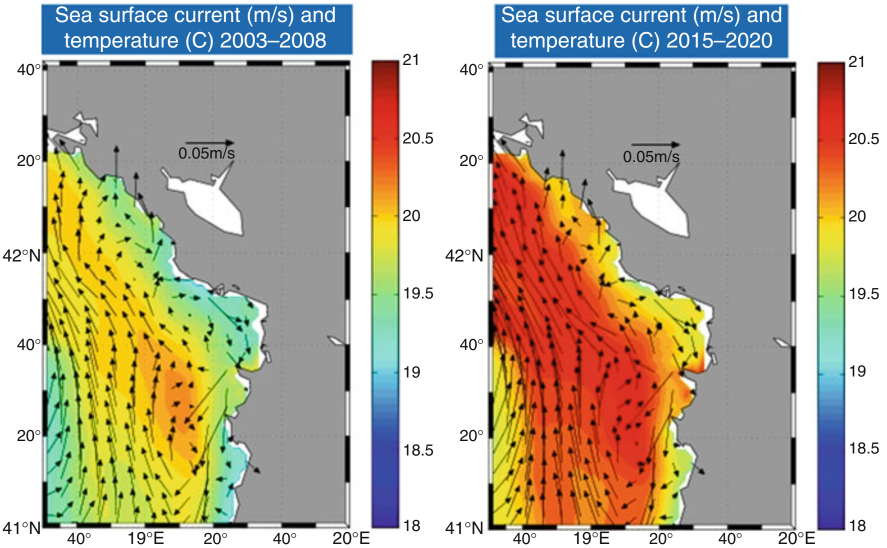
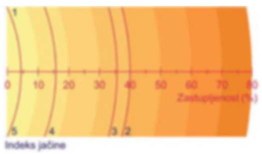
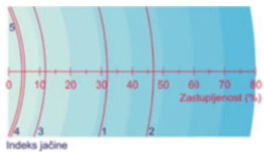
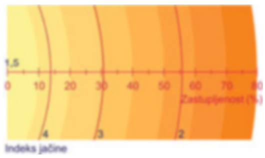
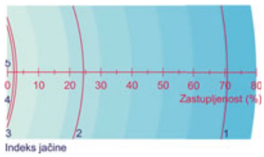
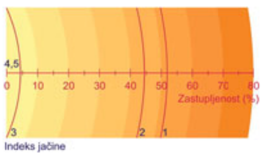
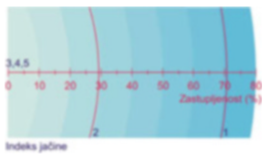


Fig. 5 Observed sea surface currents and sea temperatures for the period 2003–2008 and their projected values for the period 2015–2020 (source: according to [4])

Table 1 Data from three meteorological stations (source: according to [6])

Meteorological measurements from the land	Wind intensity index	Rain intensity index
Herceg Novi 		
Bar 		
Ulcinj 		

Waves generated by the wind and based on visual observation from the ship, as well as waves measured by instruments were considered as well and their analysis is performed in this chapter. At the end, according to this analysis, vulnerability of the coast were assessed.

4.1 Meteorological Measurements of Wind and Rain Data

Analysis of storms based on the data from three major meteorological stations indicate frequent winds from the second and third category, with maximum gusts of gale to hurricane speed. Most of the time they appear within cyclone in cold part of the year from October to April. For precipitation, category 1 and 2 are usually present indicating heavy rain which in 1 day can reach values around 150 mm.

4.2 Observation from the Ship and Instrumental Measurements of Waves

Analysis of waves generated by the wind indicates that the open sea of Montenegro has no natural protection from waves in the form of island chains of reefs. Therefore, it is entirely exposed to destructive waves. The influence of waves in larger part of Boka Kotorska Bay is moderate, while the exception is the gulf of Herceg Novi and a few locations with the fetch. Comparison of the observational data from the ship and those measured by instruments show that observational data are significantly underestimated. However, observational data may well serve to determine frequency of waves' progression in some wave's models. It should be noted that during sirocco (south wind) the maximum wave height could reach 10.8 m on the open part of the Adriatic Sea [6].

5 Vulnerability Assessment

According to intensity of the storms, their movements, impact, and geometry of the Montenegrin coast (in some places low gradient of the coast, half-closed bays and inlets, and estuaries), the following areas based on the expert opinion could be set aside and rated as moderate to high vulnerable to storms. These areas are:

1. areas for which the measurements at meteorological stations in Herceg Novi, Bar, and Ulcinj are representative – vulnerability 4 (Herceg Novi) and 3 (Bar, Ulcinj);
2. Buljarica Bay, Jaz Bay, estuary of the River Sutorina, Solila, and Kotor (especially its southern part), Čanj Bay, Ulcinj beach and the mouth of the River Bojana to the channel Port Milena – vulnerability 4;

Table 2 Flooding areas (source: according to [6])

Location	Surface (m^2)
Mouth of the river Sutorina	51,936
Solila	147,183
Bay Jaz	29,202
Bay Buljarica	159,562
Bay Čanj	61,734
Ulcinj beach	863,726
Ada Bojana beach	2,282

3. open sea coast because of no natural protection from waves in the form of islands or reefs – vulnerability 4
4. most of the Boka Kotorska Bay – vulnerability 3

In mapping vulnerability to storms, there are numerous of obstacles. Some of the most important are: insufficient number of data and information, and complexity of the terrain (e.g. the area of Ulcinj beach is a large area of low topography with beach ridges, sand dunes and depressions behind the ridges). For this reason only the coastal flooding for six locations is mapped for which the information could be found in the literature, cartographic view, and field survey. For Ulcinj beach and Ada Bojana coast, the analogy with the Buljarica Bay is used because of similarity with sandy-gravel beaches which exposure to the waves is identical to the Buljarica Bay.

Two types of polygons/areas are recognized as *current* and *potentia*l areas of flooding. The *current* polygons are those based on the specific cartographic source (which is the case for Sutorina and Solila, where the current areas of flooding are digitized from nautical map of Boka Kotorska Bay with the scale 1:25,000), the analysis of storms' intensity, hydrographic measurements (visual and instrumental) of waves driven by winds and field survey.

The *potential* areas of flooding are those based on estimates of possible flooding caused by storms. The surface of delineated areas is presented in the table below (Table 2). Those areas need to be explored in order to collect new and update existing data, using modern technology, such as satellite data, DTM, and reanalysis of wind field [2].

Overall importance for further exploring is that all eight sites are identified as highly vulnerable to sea level rise due to the increase of temperature. Thus, sea level rise due to the thermal expansion in combination with meteorological and oceanographic factors, could lead to major flooding in these areas.

6 Conclusion

The problem of coastal and marine areas can be solved if and only if we have options of adaptation applied in the process of overall spatial planning, and when they are part of plans to mitigate the consequences of disasters and land use plans.

Some of the measures that should be undertaken to reduce the damage caused by the storms are:

- Denser network of anemographic and tidal gauge stations, and improving the leveling networks.
- Establishment of local meteorological, hydrological, and hydrographic observational program as a basis for risk assessment.
- Developing an early warning system and establishment of operational services for real time monitoring the state of the coastline and waves.
- Establishment of correlation between damages and storms, their systematic monitoring, recording, and mapping.
- Improvement of drainage systems
- Set up protected barriers in critical areas including water sources from salinization.
- Existing infrastructure facilities readapt to the load according to the updated climate data and wave data.

Acknowledgments The authors would like to acknowledge the Ministry for Sustainable Development and Tourism for their support in preparation of this article.

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Trace Elements in Mussels from Montenegrin Coast: A Risk for Human Health

Ana Perošević-Bajčeta, Danijela Joksimović, Ana Castelli, Milica Peković, and Slavka Stanković

Contents

Abstract This study presents a review of available data on trace element contents in soft tissues of mussels (*Mytilus galloprovincialis*) collected from the coastal area of Montenegro, starting with the first research in this area (2005–2007) until the recent years. The aim of this review was to compare the results obtained for mussels during different research periods (autumn 2005–spring 2007, autumn 2007–autumn 2009, autumn 2014–autumn 2015) and to assess the human health risks caused by exposure to trace elements via consumption of these mussels. By two approaches for the human health risk assessment (HHRA), considering oral reference doses by the United States Environmental Protection Agency (US EPA) and provisional tolerable

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intakes by the Joint FAO/WHO Expert Committee on Food Additives (JECFA), it was shown that the levels of Co, Pb, and Cd were the limiting factors for the consumption of mussels from this coastal area during the whole investigated 10-year period. Besides these elements, during the first period As content was the limiting factor for mussel consumption as well. Also, the results obtained for Li via target hazard quotient (THQ) values in the period 2014–2015 are an indicator of possible mussel contamination by this element, which has not been previously studied in *M. galloprovincialis*. Since the consumption of seafood is one of the primary sources of human exposure to trace elements, the fact that for Boka Kotorska Bay it was noticed a decrease in average concentrations of most elements over time is particularly important.

Keywords Health risk, Human exposure, Montenegrin coast, Mussels, Trace elements

1 Introduction

Metals are probably the oldest toxins known to humans [1]. They are usually present in trace amounts in different environmental samples (ppb range to less than 10 ppm), which is the reason why they are often called trace elements [2]. Still, these toxic elements in air, soil, and water represent a global problem. Metals are naturally occurring elements in the Earth's crust and, since they have been used for thousands of years [1, 3], their sources in the environment can be both natural and anthropogenic [4]. In nature, potentially toxic trace elements originate mainly from rocks and mineral ores. Natural processes, such as weathering and volcanic eruptions, can, therefore, contribute to higher metal concentrations in the environment [1, 2, 4–6]. However, environmental pollution and human exposure to these elements are mainly the result of various anthropogenic activities, including the mining and smelting processes, industrial production and use, and domestic and agricultural use of metals and metal compounds [2]. Metals from these sources are dispersed into the environment, where they accumulate in soils, sediments, and biota. Furthermore, they directly or indirectly, through the air, water, and food, reach the human body [4].

These elements differ from other toxic substances because they cannot be made nor destroyed by man [1]. Metals are not biodegradable and they tend to accumulate in living organisms. The persistence in nature and the toxicity of these elements [4, 5, 7] make a potential threat to plants, animals, and humans. The major concerns caused by these pollutants are the ecosystem contamination and health issues of the exposed organisms. Living organisms use trace elements in various biological and physiological processes, such as stabilization of protein structure, facilitation of electron transfer reactions, and catalysis of enzymatic reactions [4]. In the human body, the so-called essential elements play a key role in achieving a balanced biological function of the cell, while non-essential elements can have toxic and carcinogenic effects [3]. However, even metals that are biologically essential and whose deficiency has an adverse effect on living organisms can be harmful if they are present in high concentrations, i.e. at high levels of exposure [4].

During the last decades, human activities increased concentrations of various trace elements in the marine environment, to the levels which could be hazardous to marine ecosystems [6, 8–11]. Such a situation is observed on the Montenegrin coast as well [12]. Marine organisms adsorb and accumulate these elements from their environments [13–15]. Since the bioaccumulation is a process that lasts several months or years, the use of living organisms in marine pollution monitoring programs, unlike classical methods of contaminants analysis, allows the determination of biologically available elements in the marine environments, as well as their concentrations over a long period [16]. The Mediterranean mussel (*Mytilus galloprovincialis*) is a sentinel species and a filter-feeding animal, known for the ability to accumulate a wide range of trace elements. Furthermore, their wide geographical distribution, sessile nature, and easy sampling make them valuable bioindicators of marine pollution [4, 8, 10, 17]. Trace elements can be accumulated in mussel tissues to concentrations much higher than those found in the environment [8, 18], and they can cause long-term harmful effects on marine organisms, but also on humans [10].

The food chain, especially the consumption of seafood, is one of the primary sources of human exposure to trace elements [19]. Besides that, the production and human consumption of shellfish are increasing all over the world [19, 20]. Therefore, in order to minimize the potential adverse health effects, the knowledge about contents of trace elements in mussels planned for consumption and the health risk assessment (HHRA – human health risk assessment) of mussel consumers is of major importance [19, 21].

Studies for the Adriatic and even Mediterranean coast done in this area were mainly focused on human exposure to different essential elements, such as Co, Cr, Cu, Fe, Mn, Zn, which can become toxic at elevated concentrations, and also to very toxic elements, such as Hg, Pb, and Cd, and not so often As [10, 11, 18, 22–32]. This was mainly the case for the Montenegrin coast as well since the first continuous research of trace elements in mussel tissues (the period from 2005 to 2009) [33] included the measurements of Co, Cr, Cu, Fe, Mn, Ni, Zn, Hg, Pb, Cd, and As [34, 35], although during the second part of this period (2007–2009) Cr and As were not examined [35]. However, one study published in 2016 [21], conducted at seven locations in Boka Kotorska Bay, investigated human exposure to 17 trace elements. Also, the research conducted in Boka Kotorska Bay during five seasons (from the autumn of 2014 to the autumn of 2015) [36, 37] examined 14 elements, including some elements which have rarely been investigated in mussels generally, such as Al and Li [38, 39]. No data related to Li concentrations in mussels *M. galloprovincialis* were found in the literature previously, although in France it was found that one of the main food groups containing Li was shellfish [38]. Data for Al contents in mussels were found only for the Ligurian Sea [40] and the coast of Turkey [41]. That means that Li concentrations in the Mediterranean mussel, as well as the concentrations of both elements, Al and Li, in mussels from the Adriatic Sea and human exposure to these elements via mussel consumption, were studied for the first time within the research mentioned above [37].

2 Trace Elements Accumulation by Mussels: The Montenegrin Coast

Since 1975, when Goldberg proposed the use of *M. edulis* or related species in the marine pollution monitoring (US Mussel Watch program) [42], mussels have been increasingly used as bioindicators of seawater pollution by trace elements. Thus, most national and international biomonitoring programs around the world include the use of mussels as bioindicators of pollution [43–46]. The regional biomonitoring program for the Mediterranean (Mediterranean Mussel Watch, MMW), developed by the International Commission for the Scientific Research of the Mediterranean (CIESM) in 2002, involves the use of the native Mediterranean mussel, *Mytilus galloprovincialis*, as a bioindicator species [45, 46]. The use of native populations of wild mussels, passive biomonitoring, showed good sensitivity, i.e. a high degree of accumulation, due to the long-term exposure [47]. Trace elements are absorbed from the water column and through the food, i.e. ingested phytoplankton and other suspended particles [9, 48, 49]. As mussels filter large amounts of seawater daily they are exposed to numerous contaminants present in the water, including trace elements [49–51].

Bioaccumulation in mussel tissues occurs if the degree of absorption is higher than the degree of excretion [52]. The process of trace elements absorption into a living organism is undoubtedly much faster than the process of excretion [53]. Moreover, mussels tolerate high concentrations of toxic elements well [4, 54], because they have a well-developed detoxification mechanism (they synthesize metallothioneins, metal-binding proteins) [55] and can survive in areas where most other organisms would die [56]. On the other hand, they do not have the ability to regulate the concentrations of individual elements, so they are also known for their bioconcentration ability [57]. Thus, the concentration of trace elements in mussel tissues is much higher than the trace elements content in the environment, from 1,000 to 100,000 times [56], which gives a long-term overview of marine pollution [57–59]. High concentrations, in comparison with seawater, allow easier chemical analysis [56]. Besides that, since mussels occur in large populations, Fig. 1, repeated sampling does not endanger their survival. The possibility of frequent sampling provides information on short-term and long-term changes in the concentration of investigated pollutants [56, 60, 61].

The first continuous research on the presence of trace elements in mussels from the Montenegrin coast was performed during the period from autumn of 2005 to autumn of 2009 [33]. The seasonal research in Boka Kotorska Bay, which included the measurement on 14 elements, was continued in the autumn of 2014 [36, 37]. From the point of environmental protection and the health risk assessment,

Fig. 1 Mediterranean mussel (*Mytilus galloprovincialis* L.) in its natural environment (Photo by Rajko Martinović)

it is essential to compare the results obtained over a longer period. This review will include the results from the period between the autumn of 2005 and the autumn of 2015, in order to assess the differences in trace element contamination of mussels during this period.

2.1 Sampling of Mussels and Chemical Analysis

Sampling of mussels from the Montenegrin coast in the period between 2005 and 2015 was mainly conducted in Boka Kotorska Bay [34–37]. However, during the period from the autumn of 2005 to the spring of 2007, two sampling locations were outside of the Bay (Bar and Rt Djeran) [34]. The whole investigated period included three independent research periods (autumn 2005–spring 2007, autumn 2007–autumn 2009, and autumn 2014–autumn 2015) and 12 sampling sites (Dobrota, Sveti Stasije, Orahovac, Perast, Opatovo, Tivat, Kukuljina, Krašići, Žanjice, Herceg Novi, Bar, and Rt Djeran) [34–37], Fig. 2.

During the sampling, around 2 kg of mussels of similar shell length was collected at each selected location. The amount of 2 kg per location is taken to obtain a representative sample. For transportation to the laboratory, mussels are placed in polyethylene bags with seawater. They are cleaned and rinsed with seawater and/or Milli-Q water and then dissected by removing byssus and shells. Soft tissues of mussels are frozen, then freeze-dried and homogenized [22, 23, 37].

Mussel samples are digested in a closed vessel microwave digestion system by adding HNO_3 and H_2O_2. For each batch of analysis, the blank and the certified

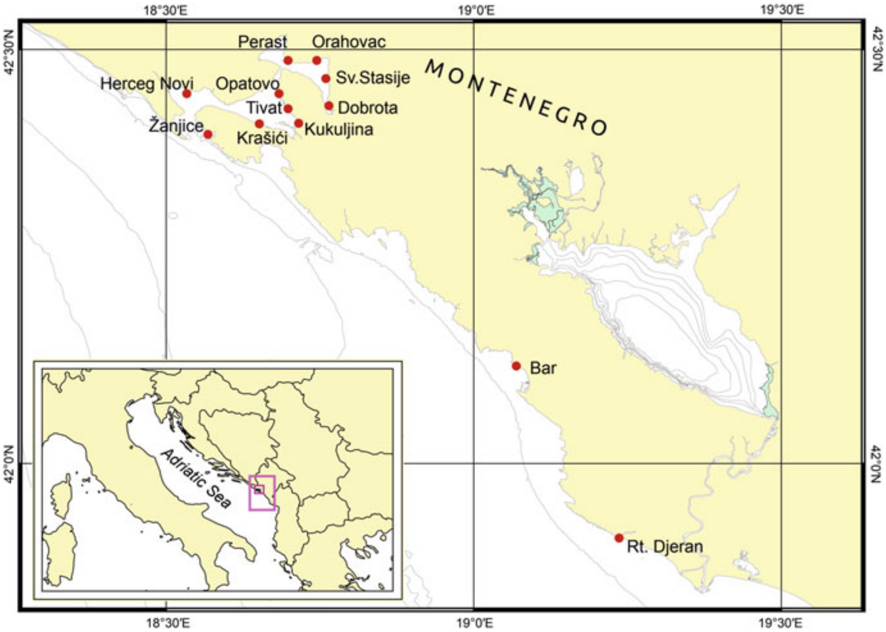

Fig. 2 Map of studied area

reference material are prepared in the same manner as the samples. The certified reference material's role is to obtain the validation of the applied analytical method for accuracy. In these analyses, the certified reference material NIST 2976 (Mussel tissue) was used [22, 23, 37].

Concentrations of trace elements in mussel samples from the Montenegrin coast in the period from 2005 to 2009 were measured by different techniques of an atomic absorption spectrometry (AAS) [22, 23, 34, 35]. For trace elements analysis during the period from autumn of 2014 to autumn of 2015, an inductively coupled plasma – optical emission spectrometer (ICP-OES) was used, except for Hg, which was determined by a direct mercury analyzer (DMA) [36, 37]. All results were expressed in mg/kg of a sample dry weight.

On the other hand, the research published by Tanaskovski et al. [21] presents concentrations of 30 trace elements in mussel tissues from seven locations in Boka Kotorska, determined by an energy dispersive X-ray fluorescence technique (ED-XRF). This study included the assessment of human health risk caused by 17 elements from mussels. Because of the fact that only one season was included in this research, as well as the different sample preparation for the XRF analysis, which implies measurements on dry samples, those results cannot be used for the comparison with other investigated periods. Actually, after freeze-drying of samples and grounding to the fine powder, they were sieved and the larger particles were discarded. This was done to reduce the particle size effect [21], but it can obviously affect the final results since in the microwave digestion the whole mussel tissues are used.

2.2 Comparison of the Results from the Montenegrin Coast

The research conducted in the period from the autumn of 2005 to the spring of 2007 included three inner shore locations (Sv. Stasije, Herceg Novi, and Žanjice) and two locations outside the Bay (Bar and Rt Djeran). Although the location Žanjice is considered an inner shore location, it is situated at the entrance to the Bay, close to the open sea. During this period, the concentrations of examined elements, expressed on a dry weight, were in the following ranges: 1.90–20.5 mg/kg for As, 1.00–3.50 mg/kg for Cd, 1.10–10.0 mg/kg for Co, 2.00–6.60 mg/kg for Cr, 4.60–17.2 mg/kg for Cu, 86.7–603 mg/kg for Fe, 1.50–85.0 mg/kg for Mn, 3.40–18.9 mg/kg for Ni, 2.30–17.7 mg/kg for Pb, 82.0–345 mg/kg for Zn, 0.03–1.06 mg/kg for Hg. The highest average concentrations for most of the examined elements (Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn) during this period were found for the locations situated outside of the Bay. More precisely, the highest average contents of Co, Cu, and Pb (5.85 mg/kg, 14.6 mg/kg and 11.5 mg/kg, respectively) were found in the mussel samples from the location Bar, while the levels of Cr, Fe, Mn, Ni, and Zn (4.97 mg/kg, 415 mg/kg, 53.0 mg/kg, 11.8 mg/kg and 210 mg/kg) were higher in the samples from Rt Djeran. However, the average contents for Ni and Zn in mussels from the location Bar (10.9 mg/kg and 206 mg/kg) were slightly lower than those found for Rt Djeran. Regarding the locations from the Bay, the highest contents of almost all elements were found in mussels from Žanjice. Only the contents of Hg (0.59 mg/kg) and As (13.3 mg/kg) were in average highest in mussel samples from Herceg Novi. The average concentration of Zn was similar in both Herceg Novi (176 mg/kg) and Žanjice (173 mg/kg) samples [34].

In the period from the autumn of 2007 to the autumn of 2009, the concentrations of examined elements varied in the following ranges: 0.90–5.05 mg/kg for Cd, 2.40–14.6 mg/kg for Co, 1.65–15.6 mg/kg for Cu, 54.4–752 mg/kg for Fe, 3.15–28.7 mg/kg for Mn, 1.35–11.0 mg/kg for Ni, 1.50–14.5 mg/kg for Pb, 34.4–566 mg/kg for Zn and 0.12–2.65 mg/kg for Hg. For the majority of elements, a wider range of concentrations was found during the period 2007–2009 [35], in comparison with 2005–2007 [34], although the second period included only locations from Boka Kotorska (Sv. Stasije, Perast, Opatovo, Tivat, Kukuljina, Krašići, Herceg Novi). The reason can be the fact that some of the locations investigated during the period 2007–2009 were in Tivat Bay (Opatovo, Tivat, Kukuljina, Krašići), close to the pollution sources different from those in other parts of the Bay. The highest average contents of all examined elements, except Cd, were found in mussel samples from Tivat Bay (the locations Tivat and Kukuljina, as well as Krašići in the case of Hg). Mussel samples from the location Tivat had the highest average contents of Cu (7.34 mg/kg), Mn (14.4 mg/kg), Pb (6.41 mg/kg), and Zn (254 mg/kg), while the samples from Kukuljina had the highest average contents of

Co (7.09 mg/kg), Fe (402 mg/kg), and Ni (5.93 mg/kg). The highest average content of Hg was 0.717 mg/kg (location Krašići). Due to the one extreme concentration, measured in the winter of 2008, the highest average concentration of Cd was found in mussel samples from Perast (2.40 mg/kg) [35].

Although the military shipyard in Tivat is now replaced with the luxury marina, high contents of metals in this area can still be the consequence of the past industrial activities [62], as well as the vicinity of examined locations to the Tivat airport. Besides that, during the first period, only spring and autumn samples were analyzed, while the period 2007–2009 included autumn, winter, and spring samples, which can also contribute to higher average concentrations. However, the average concentrations of most elements were lower during the period 2007–2009 compared to 2005–2007 [34, 35].

Newer research (autumn 2014–autumn 2015) studied the concentrations of 14 elements at three locations in Boka Kotorska (Dobrota, Orahovac, Žanjice). The results were in the following ranges: 48.0–830 mg/kg for Al, 0.40–6.76 mg/kg for Ba, 0.77–2.87 mg/kg for Cd, 0.40–2.88 mg/kg for Co, 0.72–4.05 mg/kg for Cr, 6.08–11.2 mg/kg for Cu, 107–659 mg/kg for Fe, 1.54–6.57 mg/kg for Li, 6.36–22.2 mg/kg for Mn, 1.27–6.57 mg/kg for Ni, 1.37–3.50 mg/kg for Pb, 29.8–162 mg/kg for Sr, 85.6–241 mg/kg for Zn and 0.083–0.263 mg/kg for Hg. During this period, the highest average concentrations of all examined elements, except Pb, were measured in samples of wild mussels from Žanjice. Except for Cu, whose average concentrations in samples from other locations (Dobrota – 7.82 mg/kg, Orahovac – 6.79 mg/kg) were close to the average concentration in mussel samples from Žanjice (8.46 mg/kg), concentrations of all other elements were significantly higher in the samples from Žanjice. Only the average concentration of Pb was higher in mussel tissues from the location Dobrota (2.54 mg/kg on average) than in the samples from the other two locations. Although situated near the open sea, there are many restaurants and cottages at the Žanjice beach, with a discharge of wastewater directly into the sea. This is especially increased during summer season [63]. Also, the adsorption of metals by sediments causes a reduction in metal concentrations in seawater [32], and, consequently, lower uptake of these metals by mussels. Since the rate of absorption is higher in the case of fine-grained sediments, present at the locations Dobrota and Orahovac, in comparison with sandy sediments at the location Žanjice, [64], the higher concentrations of trace elements in seawater at Žanjice, as well as in mussels from this location were expected [36].

A wide concentration range for individual elements was found in this last period, as there were significant differences between concentrations of the majority of the measured elements in different seasons. The highest differences were recorded between the winter and summer samples [36, 37]. There is an increase in metabolic rates at higher temperatures, which can contribute to metal accumulation in these organisms due to a higher energy demand [65]. Therefore, differences in element concentrations found in mussel samples from different seasons were expected. However, an increase in concentrations of some elements during cold seasons, which were noticed during the last period, but also during the period 2007–2009 [35], corresponds to the period of high storage of energy reserves, before the

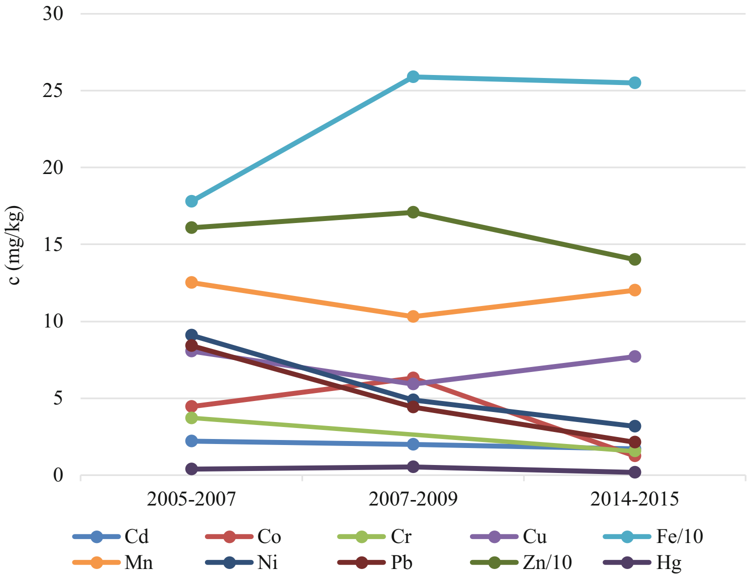

Fig. 3 Change in the average concentrations of trace elements in mussels from Boka Kotorska Bay over time

reproduction period [31]. High concentrations of some elements in winter can be also explained by a low nutritional status, i.e. reduced weight of the mussels' soft tissues during the winter. While body mass decreases, the metal content remains the same, so the concentration expressed in relation to body mass increases [66].

Comparing the metal concentrations in soft tissues of mussels from Boka Kotorska Bay during the 10-year period (from 2005 to 2015), which included three independent studies (autumn 2005–spring 2007 [34], autumn 2007–autumn 2009 [35], and autumn 2014–autumn 2015 [36, 37]), it can be noticed a decrease in the concentration of most elements over time. The decrease in the average concentration in particular refers to the period 2014–2015 [36, 37] in relation to the period 2005–2007 [34]. This can be seen in Fig. 3, which represents the change in the average concentrations of individual elements in the soft tissues of mussels from the Bay over time.

Although the average concentrations of some elements (Co, Zn, Hg) were higher in the period 2007–2009 (6.31 mg/kg, 171 mg/kg, and 0.52 mg/kg, respectively) [35] than during 2005–2007 (4.45 mg/kg, 161 mg/kg, and 0.402 mg/kg, respectively) [34], the concentrations of these elements in the period 2014–2015 (1.24 mg/kg, 140 mg/kg, and 0.156 mg/kg) were lower than the concentrations from both previous research periods [36, 37], Fig. 3. The increase of these concentrations in the second period can be explained by higher concentrations in mussels from Tivat Bay [35]. Other periods did not include the locations from this part of the Bay.

On the other hand, in the period 2007–2009 the average concentrations of Cu (5.92 mg/kg) and Mn (10.3 mg/kg) [35] were lower than during the first period

(8.07 mg/kg for Cu and 12.5 mg/kg for Mn) [34], while in the period 2014–2015, the concentrations of these two elements were increased (7.69 mg/kg and 12.0 mg/kg) [36, 37], but remained lower than during the period 2005–2007 [34]. Of all the examined elements, only the concentration of Fe increased during the period 2014–2015 (255 mg/kg) [36, 37] compared to the period between 2005 and 2007 (178 mg/kg) [34], but the average concentration during the most recent period was almost identical to the average concentration during the period 2007–2009 (259 mg/kg) [35], Fig. 3.

Based on these comparisons, it can be concluded that the environmental state of the Bay has improved over the years. However, in different periods of the research, samples were not taken from identical locations. It is also necessary to emphasize the significant impact of seasonal variations in metal concentrations and the fact that during the period 2005–2007, the sampling was performed only in spring and autumn [34], and during the period 2007–2009 in spring, autumn, and winter [35]. As during the latest period (2014–2015) the most considerable variations in concentrations were observed between summer and winter seasons [36, 37], we can assume that the average concentrations obtained by previous studies could be different, if they included all seasons [34, 35].

3 Mediterranean Mussel (*Mytilus galloprovincialis*) as a Seafood: Benefits and Risks

World's growing population consumes seafood as major dietary food [22]. During the following decade (2020–2029), world fish and seafood production is projected to grow at a rate of 1.3% per year. Although at a slower pace than over the previous decade (2.3% per year), fish and seafood production, especially aquaculture in comparison with capture fisheries production, is expected to grow on all continents. Accordingly, per capita fish consumption will continue to grow, with an expected increase of 0.5% per year during the following period. These are the projections of the OECD-FAO Agricultural Outlook 2020–2029 (Organization for Economic Co-operation and Development – Food and Agriculture Organization of the United Nations), which provides a scenario of the 10-year prospects for agricultural and fish commodity markets at global level [67]. Fisheries and aquaculture already represent very important sources of food, nutrition, income, and livelihoods for hundreds of millions of people around the world [68], and based on the OECD-FAO projections, they will become even more significant in the following decade.

Bivalve farming in Montenegro is still at a relatively low level. There are only 20 farming sites on the Montenegrin coast, and all of them are situated in Boka Kotorska Bay. However, it is expected that mariculture, along with fisheries in developing countries such as Montenegro, will become one of the most important development sectors in the following years [69]. Besides that, people often consume wild mussels from the seashore. So, it is crucial to include not only farmed, but also mussels from wild populations in the studies about the consumption of these bivalves [22].

Seafood products are rich in proteins, vitamins, minerals, and in omega-3 fatty acids [70, 71]. Some studies have shown that seafood was the largest source of vitamin B6 (16–23% of the total intake) and B12 (77–84%) in the diet [72]. Benefits associated with the consumption of seafood products are particularly significant for vulnerable groups such as pregnant women, infants, and children [20, 68]. Among various seafood products, mussels are very important since they are a good source of proteins of high biological value, essential elements, and vitamins, all significant for human consumption [20]. Proteins contribute about 60% to the dry weight of the soft tissues in *M. galloprovincialis* [73]. Also, mussels contain almost all elements required to maintain normal physiological functions, including metals [21, 74].

However, due to the high degree of accumulation of trace elements, mussel consumption brings potential risks. Various metals, such as Cr, Cu, Mn, Fe, are essential at small quantities and their lack can cause diseases, but at higher concentrations they can be toxic [7, 75]. These so-called essential metals or micronutrients are mostly present in traces, and their required amounts are defined for each species. Unlike macronutrients, such as Ca, Mg, Si, Na, K, P, and S, which are required in higher concentrations (100 mg per day or more), daily needs for micronutrients are a few milligrams or micrograms [4]. This means that even biologically essential elements, through the increased accumulation, can negatively affect the psychophysical development of the organism [4, 76]. The range of concentrations between the beneficial and harmful effects of individual elements can be quite narrow [2].

On the other hand, some elements, such as Hg, Pb, Cd, As, are very harmful even at low concentrations [3, 7, 71, 75]. Those trace elements without a significant biological role, known as non-essentials, can also be found in mussels [74]. Metals are contaminants with a long biological half-life in these organisms, so they cannot be removed quickly and completely by autopurification [77]. Being non-biodegradable substances, they cannot be metabolized into harmless forms [24, 78] and they are bioaccumulated and concentrated through the food chain [20, 79, 80]. Mussels, with their well-developed detoxification mechanism, tolerate much higher concentrations of metals than other living organisms. Still, very low concentrations of these elements can cause severe disorders in humans, including mutagenic and carcinogenic effects [20, 81].

In human body metals form complexes that can inactivate enzyme systems or modify critical protein structures, leading to cellular dysfunction or even death [3]. Besides the inhibition of enzyme activity and protein synthesis, mechanisms of metal toxicity include alternations in nucleic acid function and changes in cell membrane permeability [76]. The most affected organ systems are the central nervous, gastrointestinal, cardiovascular, hematopoietic, renal, and peripheral nervous system, but generally, almost all organs can be affected. The nature of toxicity varies depending on different factors, such as the degree and route of exposure to the certain element, chemical (organic or inorganic) and valence state, sex and age, distribution in tissues, concentration and excretion rate [2, 3, 76]. Children are particularly sensitive to metal poisoning, especially Pb, since their nervous system is not completely developed [3]. In persons who have been exposed to Pb in childhood, a lower IQ has been reported [1]. Any toxic effect of metals in the critical period of organism development may lead to long-term consequences in the form of irreversible damage to the structure and function of individual organs. Also, conditions with increased nutritional demands (pregnancy, lactation, perinatal period, and adolescence) may result in essential element deficiencies, which can enhance an accumulation of toxic metals [76].

One of the primary sources of human exposure to different trace elements is the food chain, especially seafood consumption. Therefore, the measurements of trace element contents in mussels planned for consumption and the assessment of human health risks are of major importance for public health [19–21, 24].

4 Human Exposure to Trace Elements via Consumption of Mussels

To assess the potential human health risks via exposure to trace elements through mussel consumption, the concentrations of trace elements have to be expressed in mg/kg wet weight. Therefore, the concentrations expressed in mg/kg of a sample dry weight are converted from dry into the wet weight using the conversion index ($i = 5.78$). This coefficient was determined from data from several authors, as the mean value of water content in samples of mussels *Mytilus galloprovincialis* from the Adriatic Sea [22]. The concentrations of trace elements in mussels from Montenegrin coast (mg/kg wet weight), obtained for three independent periods (autumn 2005–spring 2007, autumn 2007–autumn 2009, autumn 2014–autumn 2015), are presented in Table 1.

A wide range of concentrations for individual elements was found in the examined mussel samples. This is largely due to the significant seasonal variability in the concentrations of most elements, as it was already explained in Sect. 2.2. Therefore, human exposure to trace elements via mussel consumption will not be the same in different seasons, even though the consumption rate is the same. According to that, it can be concluded that in the calculations for the human health risk assessment, it is necessary to use average concentrations of elements in mussel samples taken in different seasons over a longer period [37].

Table 2 provides an overview of the limits on permissible concentrations of trace elements in mussel tissues, set by different regulations. These limits are not prescribed for all elements examined in mussels from the Montenegrin coast, but usually only for non-essential, extremely toxic elements, Cd, Pb, and Hg. Comparing the concentrations of trace elements in mussels from the Montenegrin coast with legal limits on permissible concentrations presented in Table 2 [82–85], it is evident that all the values obtained for Hg and Cd [34–37], Table 1, in the period from 2005 to 2015 were lower than the prescribed limits.

Table 1 Range and average trace element concentrations (mg/kg ww) found in mussels from the Montenegrin coast

Element	2005–2007 [34]	2007–2009 [35]	2014–2015 [36, 37]
Al	/	/	8.31–144 48.6
As	0.33–3.55 1.34	/	/
Ba	/	/	0.07–1.17 0.40
Cd	0.17–0.61 0.37	0.16–0.87 0.34	0.13–0.50 0.30
Co	0.19–1.73 0.80	0.42–2.53 1.09	0.07–0.50 0.21
Cr	0.35–1.14 0.66	/	0.13–0.70 0.27
Cu	0.80–2.98 1.70	0.29–2.70 1.02	1.05–1.94 1.33
Fe	15.0–104 40.2	9.41–130 44.7	18.4–114 44.2
Li	/	/	0.27–1.14 0.49
Mn	0.26–14.7 3.53	0.54–4.96 1.78	1.10–3.85 2.07
Ni	0.59–3.27 1.71	0.23–1.90 0.84	0.22–1.14 0.55
Pb	0.40–3.06 1.50	0.26–2.51 0.77	0.24–0.61 0.37
Sr	/	/	5.16–28.0 12.0
Zn	14.2–59.7 30.8	5.95–98.0 29.7	14.8–41.8 24.2
Hg	0.004–0.183 0.064	0.021–0.458 0.090	0.014–0.046 0.027

Table 2 Regulations on limit concentrations of trace elements in soft tissues of mussels (mg/kg ww)

Regulation	Cd	Pb	Hg
European Commission Regulation (EC) [82]	1.0	1.5	0.5
JECFA [83]	2.0	/	0.5 (MeHg)
US FDA [84]	4.0	1.7	1 (MeHg)
Regulation of the Government of Montenegro [85]	1.0	1.5	0.5

Regarding Pb, the concentrations measured in mussels from the locations Sv. Stasije, Žanjice, and Bar in the autumn of 2005 and the spring of 2006, as well as the concentration measured in mussels from the location Bar in the spring of 2007 [34], were higher than the limits set by the European Commission (EC) [82] and the

Government of Montenegro [85]. The concentrations of Pb in all of these samples, with the exception of the samples from Sv. Stasije taken in the autumn of 2005 [34], were higher than the limit prescribed by the US Food and Drug Administration (US FDA) as well [84]. During the second period (2007–2009), only four samples taken in Tivat Bay were found with the concentrations of Pb higher than the limits set by the EC [82] and the Government of Montenegro [85]. Still, Pb content higher than the limit set by the US FDA [84] was measured only in samples from the location Tivat (2.51 mg/kg), taken in autumn of 2007 [35], Table 2. However, the average content for this period (0.77 mg/kg) was lower than the prescribed limits and the average content for the first period (1.5 mg/kg) was at the limit set by the EC [82] and the Government of Montenegro [85], but lower than the limit set by the US FDA [84], Tables 1 and 2. Regarding the third period (2014–2015), Pb contents were lower than the prescribed limits in all examined samples, Tables 1 and 2. In comparison with the EC [82] and US FDA [84], the Joint FAO/WHO Expert Committee on Food Additives (JECFA) [83] has not set the limit for Pb in bivalves or shellfish especially, but for fish in general. Therefore, that value was not considered here. US FDA [84] has also set the limits for Cr, Ni, and As in molluscan shellfish, which are 13 mg/kg, 80 mg/kg, and 86 mg/kg ww, respectively. All results obtained in this study were under the limits for Cr, Ni, and As, Table 1.

To prevent the potential harmful effects of different trace elements on human health, it is extremely important to use different approaches of the human health risk assessment (HHRA) [19, 21]. It is not enough to compare the concentrations of elements in mussel tissues with the prescribed limits on permissible concentrations, because in some cases, although the concentrations do not exceed the permitted values, they can pose a risk to human health [37]. There are several methods used to assess the human health risk assessment. Nowadays, the target hazard quotient (THQ) [59], as well as the comparison with the provisional tolerable weekly intake (PTWI), prescribed by JECFA, are commonly used [86]. Regardless of the method, the final goal is to determine the amount of food (mussels) that can be consumed without adverse health effects.

4.1 Target Hazard Quotient and Hazard Index

Target Hazard Quotient represents the ratio between exposure and the reference dose (RfD) [87]. RfD is an estimate of daily exposure of the human population that is likely to be without considerable risk of adverse effects during a lifetime [88]. When the level of exposure is higher than the RfD, then the THQ is above 1, which indicates that the exposed population could experience a health risk [87]. Therefore, the THQ is calculated using the equation [87, 89]:

$$\mathrm{THQ} = \frac{\mathrm{EF} \cdot \mathrm{ED} \cdot \mathrm{MS} \cdot \mathrm{C}}{\mathrm{RfD_o} \cdot \mathrm{BW} \cdot \mathrm{AT}} \cdot 10^{-3},$$

where EF is an exposure frequency (350 days/year); ED is an exposure duration (average human lifetime – 70 years) [90]; MS is a mussel meal size (17.86 g/day and 35.7 g/day, for average and high-level mussel consumers); C is a trace element concentration in the edible portion of mussels (mg/kg ww); RfDo is an oral reference dose (mg/kg of body weight per day) provided by the US EPA [91]; BW is a body weight of an adult (70 kg) and AT is an averaging time (ED x 365 days/year). The EF of 350 days/year [89, 90] represents the most frequent exposure that is reasonably expected to occur at a site with 2 weeks of vacation or travel [89]. For the mussel meal size two consumption rates were considered: 125 g per week for the average consumers (mussel meal of 250 g once every 2 weeks) and 250 g per week for high-level mussel consumers, i.e. for the population living in the coastal areas [22].

Since there is no evidence of a threshold below which a non-harmful intake of Pb could be allowed, the US EPA has declined to set an RfD_o for Pb [92]. So, the THQ for Pb can be calculated using the equation [19, 22, 26, 93]:

$$\mathrm{THQ} = \frac{\mathrm{C}}{\mathrm{ML}} \ ,$$

where C is the metal concentration in the edible portion of mussels (mg/kg ww) and ML is the maximum permitted level of the contaminant, set by the Regulation (EC) No 1881/2006 [82].

For the risk assessment of multiple trace elements contained in mussels, a total hazard index (HI) is employed. HI is obtained by summing all the calculated THQ values for the determined elements [19, 21, 22, 26, 89]:

$$\mathrm{HI} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{THQ_i},$$

where THQi is the target hazard quotient of an individual element and n is the number of examined elements. When the HI value is above 1, there might be a concern for potential health effects [87].

The calculated THQ values of individual elements in different research periods, as well as the values of HI, which evaluates the combined effects of all the examined elements, are given in Table 3. To calculate the THQ values, the average concentrations of measured elements in mussels from different research periods were used. Since RfDo for Hg was estimated for its methyl form (MeHg), a concentration of 36% of the total Hg concentration was used to calculate the THQ value. This percentage presents the average of the values reported for *M. galloprovincialis* from the Croatian (average MeHg content in total Hg about 40%) [94] and Italian coast (average content 32%) [95].

Although all THQ values obtained for the last examined period (2014–2015) were lower than 1, it was not the case for the earlier periods. Actually, during both periods, autumn 2005–spring 2007 and autumn 2007–autumn 2009, it was noticed that Co concentration in mussels could be the limiting factor for their consumption.

Table 3 THQ values for the individual elements during different research periods for average (AC) and high-level mussel consumers (HC)

		Target hazard quotient (THQ)					
		2005–2007		2007–2009		2014–2015	
	RfD_o [91] (mg/kg-day)	AC	HC	AC	HC	AC	HC
Al	1.000	/	/	/	/	0.012	0.024
As	0.0003	1.093	2.184	/	/	/	/
Ba	0.200	/	/	/	/	0.000	0.001
Cd	0.001	0.091	0.181	0.083	0.166	0.072	0.145
Co	0.0003	0.652	1.304	0.889	1.777	0.175	0.350
Cr	0.003	0.054	0.108	/	/	0.022	0.044
Cu	0.040	0.010	0.021	0.006	0.012	0.008	0.016
Fe	0.700	0.014	0.028	0.016	0.031	0.015	0.031
Li	0.002	/	/	/	/	0.060	0.121
Mn	0.140	0.006	0.012	0.003	0.006	0.004	0.007
Ni	0.020	0.021	0.042	0.010	0.021	0.007	0.013
Pb	1.500[a]	1.000	1.000	0.513	0.513	0.244	0.244
Sr	0.600	/	/	/	/	0.005	0.010
Zn	0.300	0.025	0.050	0.024	0.048	0.020	0.039
MeHg	0.0001	0.056	0.113	0.079	0.158	0.024	0.048
Hazard index (HI)		3.023	5.043	1.624	2.733	0.669	1.093

[a]ML for Pb 1.5 mg/kg ww as set by the Regulation (EC) No 1881/2006 [82], amended by the Regulation (EU) 2015/1005 [96]

In other words, THQ values were higher than 1 for high-level consumers in both periods, i.e. these values were 1.304 and 1.777, respectively, Table 3. The similar observation for Co was noticed by Jović and Stanković [22] in the paper which studied the part of the results from the period 2007–2009, obtained for mussels taken during winter, spring, and autumn of 2009. Besides Co, during the period 2005–2007 the THQ value for Pb was 1, which is at the limit of the value considered safe from the point of the health risk assessment. The highest THQ values in the first period were found for As in mussel samples, 1.093 and 2.184 for average and high-level mussel consumers, respectively, Table 3. Since during other periods As concentration was not determined, it can be assumed that As content in mussels from Montenegrin coast can generally be the limiting factor for their consumption.

Regarding HI values, they were higher than 1 during the first and second research period for both, average and high-level mussel consumers, meaning there might have been potential human health risks, caused by mussel consumption from this area. Although during the period 2014–2015, the highest number of elements was examined, HI values for this period showed better results. It was to a certain extent expected according to the obtained trace element concentrations in this period, which for the majority of elements were lower than in earlier periods, Table 1. HI value for average mussel consumers in the last examined period was lower than 1, while HI for high-level consumers was almost at the limit, 1.093, Table 3. These results, in comparison with earlier periods, indicate better conditions in the marine environment of the Montenegrin coast, which is especially important from the public health point of view. However, it was noticed that for multiple chemical exposures, the HI can be above 1 even if no single chemical exposure exceeds its RfD [87], which was the case during the second period (2007–2009) for average consumers and during the third period (2014–2015) for high-level mussel consumers, Table 3. Consequently, it might be a concern for the potential public health risks caused by mussel consumption in this area.

4.2 Maximum Allowable Mussel Consumption Rate

Provisional tolerable intakes (PTI) prescribed by the JECFA can also be used for the human health risk assessment via exposure to individual elements from mussel tissues. These values are defined as estimates of the amount of a substance in air, food, soil, or drinking water that can be taken in daily, weekly, or monthly per unit of body weight over a lifetime without appreciable health risk [97]. The weekly trace element exposures via consumption of mussels from the Montenegrin coast, sampled during the three different periods (autumn 2005–spring 2007, autumn 2007–autumn 2009, autumn 2014–autumn 2015) were compared with PTI values. JECFA has not prescribed these values for all elements studied in mussels from the Montenegrin coast [86, 98]. So, only seven elements were estimated from the point of PTI: Al, Cd, Cu, Fe, Zn, and MeHg. Provisional tolerable weekly intakes (PTWI) for Al and MeHg are 2 mg/kg body weight (bw) [99] and 1.6 μg/kg bw, respectively [100]. For Cu, Zn, and Fe, the prescribed values are given as provisional maximum tolerable daily intakes (PMTDI), and they are 0.5 mg/kg bw, 1.0 mg/kg bw [101], and 0.8 mg/kg bw [102], respectively. The estimated value for Cd is given as the provisional tolerable monthly intake (PTMI), 25 μg/kg bw [103].

Using the obtained THQ values and the prescribed PTI values for individual elements, it is possible to calculate the amount of mussels that can be consumed without danger of harmful effects for the human health over time. The maximum allowable mussel consumption limits (meals/week) for the Montenegrin coast calculated using THQs and PTI values for individual elements are given in Table 4. These limits refer to the number of mussel meals that can be consumed per week, relative to the individual elements. In order to obtain the maximum allowable mussel consumption limits, it was taken into account that the THQ for individual elements cannot exceed 1, so the number of meals was obtained by dividing 1 with the given THQ value. In the case of PTI, for calculating the limits on meals number, the prescribed PTI values were not exceeded, while the average weight of an adult (70 kg) was used, as well as the average concentration of individual elements for the selected research periods and the mussel meal size of 250 g.

The number of meals was limited during all research periods according to Co, Pb, and Cd, as well as As in the period 2005–2007, although only Pb contents at some locations during the periods 2005–2007 and 2007–2009 were higher than the limits on permissible concentrations, while the average Pb contents were equal or lower

Table 4 Maximum allowable mussel consumption rates (meals/week) for adults during different research periods at the Montenegrin coast (meal = 250 g)

	Target hazard quotient (THQ)					
	2005–2007		2007–2009		2014–2015	
	THQ	PTI	THQ	PTI	THQ	PTI
Al	/	/	/	/	>7	>7
As	0.46	/	/	/	/	/
Ba	/	/	/	/	>7	/
Cd	5.53	4.41	6.01	4.80	6.91	5.52
Co	0.77	/	0.56	/	2.85	/
Cr	>7	/	/	/	>7	/
Cu	>7	>7	>7	>7	>7	>7
Fe	>7	>7	>7	>7	>7	>7
Li	/	/	/	/	>7	/
Mn	>7	/	>7	/	>7	/
Ni	>7	/	>7	/	>7	/
Pb	1.00	/	1.95	/	4.09	/
Sr	/	/	/	/	>7	/
Zn	>7	>7	>7	>7	>7	>7
MeHg	>7	>7	>7	>7	>7	>7

than the prescribed limit, Tables 1 and 2. The lowest allowable consumption rates for Cd and Pb were recorded for the first investigated period (2005–2007), while the lowest allowable consumption rate for Co was found for the second period (2007–2009). According to the rest of the elements, mussels could be consumed every day in portions of 250 g or more, Table 4. The same observation for Pb, Co, and Cd as the limiting factors for mussel consumption was also noticed by Jović et al. for the results obtained during 2009 [22]. Furthermore, during four different seasons in 2015, an allowable consumption rate lower than seven meals per week was recorded for mussels from the location Žanjice, according to THQ value for Li [37]. The result for Žanjice obviously had an impact on the average allowable mussel consumption rate in relation to Li, which for the period autumn 2014–autumn 2015 was 8.29 meals per week.

According to THQ values for all the examined periods at the Montenegrin coast, Co was the primary limiting factor for the consumption of mussels, Table 4. Although Co has both beneficial and harmful effects on human health, it has not been evaluated as a food contaminant by JECFA [86]. However, Co and its compounds are classified into group 2B (possibly carcinogenic to humans) by the International Agency for Research on Cancer (IARC) [104]. Elevated intake of this element can cause heart and thyroid issues, as well as overproduction of erythrocytes, lung damage, and asthma [105–107]. As Co is mostly ingested through dairy products, fish and crustaceans, condiments, oil and sugar [108], the consumption of mussels must be limited in order not to exceed threshold concentrations for this element.

Lead was also one of the main limiting factors for mussel consumption during all research periods, Table 4. This element is toxic at a very low level of exposure and has acute and chronic effects on human health [109]. It is accumulated in soft tissues, as well as in bones over time, and children absorb it more than adult organisms [110]. Due to the long half-life in the human body and slow excretion, Pb can cause neurological, cardiovascular, renal, gastrointestinal, hematological, and reproductive issues [109]. It is also associated with adverse pregnancy outcomes and even mortality, caused mainly by cardiovascular diseases. There is no established PTI for Pb since JECFA withdrew the previously prescribed PTWI and concluded that it is not possible to establish a new PTWI that would be considered health protective [98]. Also, inorganic Pb compounds are classified into 2A group (probably carcinogenic to humans) by the IARC [111].

Among the elements found to be the limiting factors for the consumption of mussels from the Montenegrin coast, Cd is the only element that could be evaluated from the point of both THQ and PTI values. It was noticed that the lower consumption rates would be acceptable according to PTI values, in comparison with THQ values, Table 4. Cadmium is classified in group 1 (carcinogenic to humans) by the IARC [112]. However, US EPA has determined that Cd is a probable human carcinogen by inhalation, but it is not considered a carcinogen by ingestion [113]. Nevertheless, when ingested, soluble Cd salts are accumulated and can be toxic to the kidneys, liver, lungs, brain, heart, and central nervous system [114], but the adverse health effects are primarily manifested in the form of kidney and skeletal damage [115, 116]. Cadmium is accumulated in bones, which can serve as a secondary source of exposure during the lifetime [117]. People with a high intake of shellfish are at risk of high exposure to Cd [83], as it was the case for all three research periods conducted at the Montenegrin coast.

Besides Co, Pb, and Cd, which were the limiting factors for the consumption of mussels taken in all the examined periods, during the first period As was the major limiting factor for the mussel consumption, Table 4. This was expected since among the different foodstuffs, the highest contents of As have been found in seafood [118]. According to that, it can be assumed that it is a limiting factor for mussel consumption in general, but during other periods As was not measured, Table 1. Arsenic and its inorganic compounds are classified in group 1 (carcinogenic to humans) by the IARC. Inorganic As compounds can cause cancer of the lungs, urinary bladder, and skin. Also, exposure to As and its inorganic compounds is associated with cancer of the kidneys, liver, and prostate. However, organic As, e.g. arsenobetaine, is the predominant form of As found in seafood and these organic compounds that are not metabolized in humans, are not classifiable to their carcinogenicity to humans [118]. JECFA also noted that there had been no reports of ill-effects caused by exposure to As among populations consuming large quantities of fish and concluded that the organic forms of As present in seafood needed different consideration from the inorganic As [119].

The measuring of Li was conducted only during the last examined period, Table 1. It was recorded that the allowable mussel consumption rate from the point of Li was limited at 8.29 meals per week. This was mainly the consequence of the limited allowable mussel consumption rate at the location Žanjice [37]. Lithium was not evaluated from the point of PTI values, as JECFA has not classified it as a food contaminant [86], but the results obtained via THQ values are an indicator of possible contamination of mussels from Boka Kotorska by this element. Although Li is used in the treatment of depression [1, 107], the therapeutic index is very narrow, and if exceeded, it can produce toxic responses, including neuromuscular, central nervous system and cardiovascular changes, and renal damage [1]. Since no data were found in the literature on Li concentrations in *M. galloprovincialis*, nor in mussels from the Adriatic Sea in general, these results on possible contamination of mussels by Li are of special importance.

5 Conclusion

The research presented in this study has revealed that the concentrations of Co, Pb, and Cd were limiting factors for the consumption of mussels from the Montenegrin coast during the whole 10-year period. During the first research period (2005–2007), it was noticed that mussel consumption on a regular basis can also contribute to high As intake. The results obtained for Li in the last examined period (2014–2015) indicated possible mussel contamination by this element. These data are especially important since Li has not been previously studied in *M. galloprovincialis*. The results obtained for 10 years showed that even when the contents of trace elements do not exceed the prescribed limits for mussels, they can be limiting factors for the consumption of these mussels. However, for Boka Kotorska Bay it was noticed a decrease in average concentrations of most elements over time, which is especially significant from the aspect of human health.

In the end, it can be concluded that moderate mussel consumption is of crucial importance to prevent excessive intake of certain elements. It has to be emphasized that all the examined elements can reach the human body through other sources too and that the limits on the mussel consumption rates, obtained by our research, cannot be taken as a general recommendation. These values should be reduced according to the degree of exposure to other sources of the same elements. Also, due to the significant seasonal variability in trace element contents in mussel tissues and the fact that only during the period 2014–2015 mussel sampling was conducted during all four seasons, further research in this area should include all seasons of the year and the same locations during a longer period.

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Tetrodotoxin in Invasive Silver-cheeked Toadfish *Lagocephalus sceleratus* (Gmelin, 1789) in the Adriatic Sea

Ivana Ujević, Romana Roje-Busatto, Branko Dragičević, and Jakov Dulčić

Contents

Abstract It is commonly thought that toxic compounds come only from anthropogenic sources; however, toxic compounds can be of natural origin; hence, we call them natural toxins. In the marine environment, some molluscs and crabs contain natural toxins produced by symbiotic bacteria. Shellfish in addition to the accumulation of natural toxins (biotoxins) may produce toxic secondary metabolites. Some species of phytoplankton are known to produce potent natural toxins, which is also the case with some species of fish, especially pufferfish. The main feature of such toxins is thermostability, meaning they do not get destroyed through thermal food processing at any temperature and their toxicity remains unchanged. Here are presented the results of tetrodotoxin investigations in silver-cheeked toadfish *Lagocephalus sceleratus* (Gmelin, 1789) from the Adriatic Sea. It is a poisonous marine pufferfish that has reached the Mediterranean from the Red Sea through the Suez Canal (Lessepsian migration). Owing to its exceptional biological features such as rapid growth, high reproduction potential and lack of natural predators, it soon established large self-sustainable populations mostly in the Eastern Mediterranean Sea. This species has also been recorded in the Adriatic Sea; however, its presence is still of periodic nature, and currently there is no evidence which would suggest

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permanent population establishment. Tetrodotoxin is a very potent toxin that has been detected in organs such as the skin, muscle, liver and gonads of the pufferfish specimens collected in the Adriatic Sea.

Keywords Adriatic Sea, Invasive species, LC-MS, Pufferfish, Tetrodotoxin

1 Introduction

Phenomenon of Lessepsian migration, an influx of species from the Red Sea to the Mediterranean Sea through the Suez Canal, has been reshaping the ecosystem of the Mediterranean Sea for over a century. Effects of such migrations have particularly affected the area of the Eastern Mediterranean where some of the Lessepsian species have established large populations threatening its native ecosystems [1]. In the recent years, the Adriatic Sea is also being invaded by the Lessepsian species whose effects are still not evaluated, but it can be expected that in the case of establishment of certain species, it could have severe consequences [2]. Some of such species are extreme predators and thus can directly affect the food web in the Adriatic Sea ecosystem, in particular decreasing the fish population of sardines, anchovies, bogue and pickerel because of their intense predation on these species. Next to the ecological effects, there is also a concern about the human health as some of Lessepsian species are either venomous or highly toxic. Such is the case of silver-cheeked toadfish *Lagocephalus sceleratus* (Gmelin, 1789) (Fig. 1), a pufferfish species which contains tetrodotoxin (TTX), a potent toxin which, if consumed, can exhibit severe health effects and also lead to death of a consumer. In some cases, deaths have been reported from 10 min to 15 h after consumption of this pufferfish [3].

Fig. 1 Invasive fish species *Lagocephalus sceleratus* (Gmelin, 1789), silver-cheeked toadfish, caught in the Adriatic Sea. (Photo by Branko Dragičević)

Tetrodotoxin (TTX) is one of the strongest marine toxins that cause paralysis of the nervous and respiratory systems by binding to the sodium channels and inhibition of sodium ions through the channels [4]. This toxin is not destroyed by heat treatment of cooking, and there is no known antidote for it. Interesting fact is that the fishes of family Tetraodontidae (a member of which is *L. sceleratus*) are also known as 'fugu' in Japan which means inflatable fish; but it is also the name for a dish prepared from this type of fish. It should be noted that majority of 'fugu' fishes belong to the genus *Takifugu*, *Lagocephalus*, *Sphoeroides* and *Diodon* which contain many toxic species, but not all are used for human consumption (e.g. *L. sceleratus* is not considered as a food fish due to its extreme toxicity). All of these fish species live naturally in the waters of the Indian and Pacific Oceans. However, the silver-cheeked pufferfish is an intruder in the Mediterranean Sea which migrated from Indo-Pacific waters to the Mediterranean via the Suez Canal. The pufferfish species have, so far, been caught in the waters of Israel [5], Turkey [6], Cyprus [7] and Greece [8], as well as in the Eastern Adriatic Sea waters [9]. In the Southern Adriatic Sea, in 2008, Joksimović and Mandić [10] have recorded a pufferfish species (*Sphoeroides pachygaster*) near Budva in the Montenegrin waters, while *Lagocephalus sceleratus* was reported in 2012 near the Island of Jakljan (Croatian waters) [11], and at least five subsequent records have been reported from the Central Adriatic Sea near Tribunj, Vodice and Rab Island (Croatia), in years 2013, 2014 and 2015, respectively (Fig. 1) [12].

2 The Entry of Invasive Species into the Mediterranean Sea

The Mediterranean Sea is an intercontinental sea between the coasts of Southern Europe, Northern Africa and Southwest Asia (Middle East). It is connected to the Atlantic Ocean by the Gibraltar Strait, while opening of the Suez Canal in 1869 provided a connection with the Indian Ocean via the Red Sea, as well. The Suez Canal is 163 km long, and it virtually separates Africa from the Asian continent (Fig. 2).

Fig. 2 Map of the Mediterranean Sea with Suez Canal and Adriatic Sea denoted

It is the most important tanker waterway to supply Europe with Middle Eastern oil. The canal is named after the Egyptian City of Suez, which is located at the southern entrance to the canal. With the construction of the canal, the region was significantly changed and became one of the most important economic areas of Egypt. The opening of the Suez Canal unlocked the way for many invasive species, including toxic pufferfish from the Red Sea that inhabited the Mediterranean Sea [13–15].

New invasive species have arrived in the coastal areas of the Eastern Mediterranean Sea and caused many problems for native flora and fauna which, in many cases, get outcompeted and replaced by new, highly adapted species. It should be mentioned that once they manage to establish stable populations in the new environment, invasive species can hardly be eradicated and therefore early detection of potentially invasive species in the ecosystem and urgent action in the form of control of spread and removal are very important, as these are often the only effective methods in combating their harmful effects.

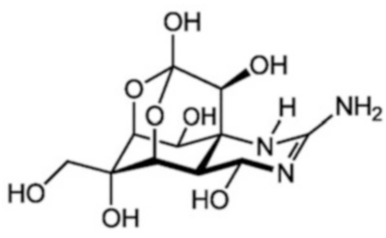
3 Pufferfish Toxicity

Pufferfish *Lagocephalus sceleratus* is characterized by the ability to inflate, as they can inflate their body to be several times larger than their normal size by swallowing large amounts of water. Of course, this ability to inflate is very effective in self-defence as it appears larger and as such easily avoids predators. But this fish has another effective defence, that is, the toxin (poison). This species of fish is considered one of the most poisonous fish in the world, and tetrodotoxin (TTX) which they contain (produced by marine bacteria *Pseudomonas* and *Vibrio*) is as much as 1,200 times stronger than the known cyanide poison [16].

Almost whole fish is poisonous, including its skin and internal organs, especially the liver, genitals (ovaries and testes) and intestines. TTX belongs to the group of nonprotein powerful neurotoxins, and it acts equally on the central and peripheral nervous system (Fig. 3).

The name tetrodotoxin comes from the name of the family of fish from which it was first isolated, Tetraodontidae. Tetrodotoxin was first isolated by Japanese

Fig. 3 The chemical structure of tetrodotoxin (TTX)



scientist Dr. Yoshizumi Tahara in 1894 [17], while the first confirmed record in the Mediterranean Sea was from the Gökova Bay (the Southeastern Aegean Sea, Turkey) in February 2003 [18]. Every year, there are 30–50 cases of intoxication for which TTX is responsible [19].

For now, maximum permitted limit for TTX in food is not defined in the European Union. The European Food Safety Authority (EFSA) stated a concentration of 44 μg/kg of TTX and its analogues in shellfish meat as one that should not result in toxic effects in humans [16].

3.1 Analysis of Tetrodotoxin in Pufferfish Tissue of the Adriatic Sea Specimens

The analysis of silver-cheeked toadfish Lagocephalus sceleratus, a pufferfish caught in the Southern Adriatic Sea, started by weighing 2 g of the muscle, liver, gonads and skin tissues followed by the extraction with 7.5 ml of 1% acetic acid. The extract was homogenized at 650 g for 10 min (Ultra Turrax Homogenizer, Cole-Parmer, GEN 700, USA) and held in ultrasonic water bath for 10 min (35 kHz, DT 100 H, Bandelin Sonorex Digitec, Germany). Then the tubes containing extracts were placed in a boiling water bath (100°C) for 10 min. After cooling at room temperature and volume adjustment at 7.5 mL, the extract was centrifuged at 3000*g* for 20 min, at 4°C (Hettich Zentrifugen, Rotina 420, Germany). The supernatants were filtered through 0.2 μm nylon syringe filters and placed in vials for LC-MS/MS analysis.

The TTX extracts were analysed using Agilent Technologies LC-MS/MS analytical system coupled with Triple Quad 6,410, Degasser 1,200, Quaternary Pump 1,200, Auto Sampler 1,290 and Thermostatted Column Compartment 1,290.

The HPLC was equipped with Poroshell 120 EC-C18 column (2.1 × 50 mm, 2.7 μm) and Poroshell 120 EC-C18 Guard pre-column (2.1 × 5 mm, 2.7 μm) and column oven maintained at 25°C. The mobile phase consisted of 100% deionized water in channel A and 95% acetonitrile (ACN) in channel B, both containing 2 mM ammonium formate and 50 mM formic acid. An isocratic elution was employed with a flow rate of 0.3 mL/min at a ratio of 35% A and 65% B and injection volume of 5 μL.

The mass spectrometer was operated in multiple reaction monitoring (MRM) mode, with the ESI interface in the positive mode using parameters that have been previously optimized by TTX toxin standard purchased from the Laboratorio CIFGA S.A., Spain. In the MS, a protonated molecular ion peak $(M + H)^+$ appeared at *m/z* 320.1 showing a molecular weight for the TTX (319.1; Fig. 4). The spectrometer analysed two product ions (Fig. 5), and the transitions were *m/z* 320.1/302.0 and *m/z* 320.1/161.9. The collision energy (CE) has been determined in MRM mode to increase product ion intensity (Figs. 6 and 7).

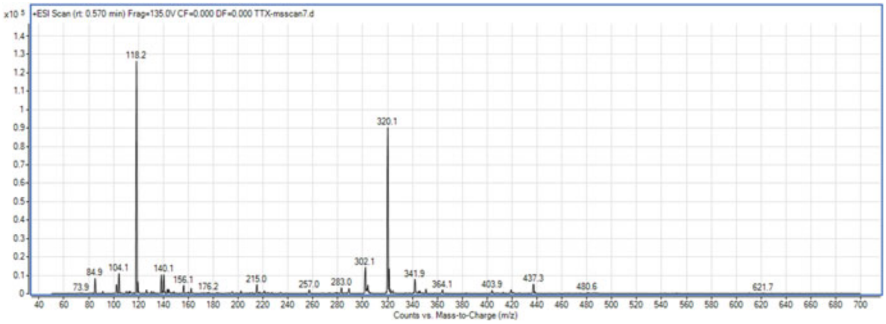


Fig. 4 The positive mass spectra of TTX in scan mode, protonated molecular ion peak at *m/z* 320.1

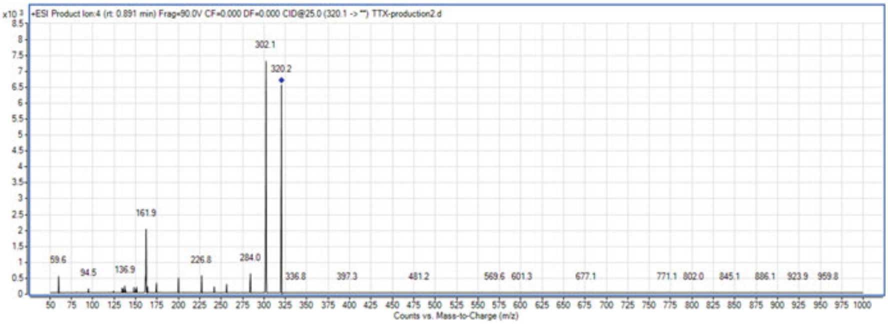


Fig. 5 The positive mass spectra of TTX in product ion mode show two product ions at *m/z* 302.0 and 161.9

For the calibration curves, a series of dilutions of the certified TTX standard solution were performed using 1% acetic acid in methanol to provide six calibration standard ranges from 20 to 1,000 ng mL^{-1}.

The gonads, liver, skin and muscle tissues were analysed from the two specimens caught in the Central Adriatic Sea in Tribunj and Vodice (Croatia) in 2013 and 2014, respectively. Among the four types of pufferfish tissue analysed, the highest average toxin level in fish caught in Vodice was found in gonads (48.7 μg g^{-1}), and the lowest average was in the muscle tissue (0.8 μg g^{-1}). The average TTX concentration in the skin was (1.5 μg g^{-1}) slightly higher than in the muscle tissue, while in the liver, it was 30.6 μg g^{-1} (Fig. 8). Concentrations of TTX in tissue samples of pufferfish from Tribunj were similar to those from Vodice for the skin and muscle, while in the liver tissue, it was lower (average concentrations 20.28 μg g^{-1}), but in the gonads, it was significantly lower (9.08 μg g^{-1}, Fig. 9).

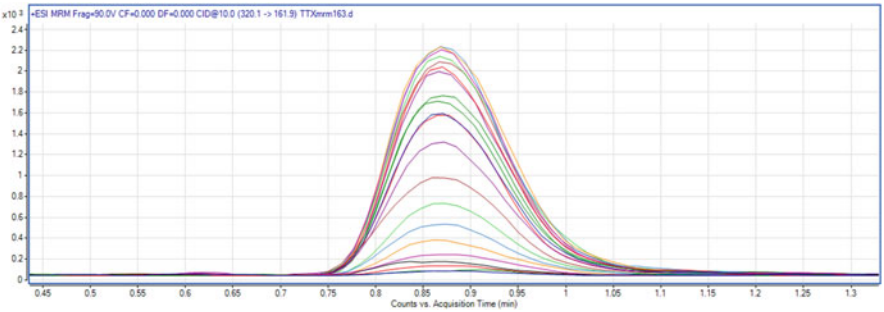


Fig. 6 Finding collision energy (CE) in MRM mode for product ion 161.9

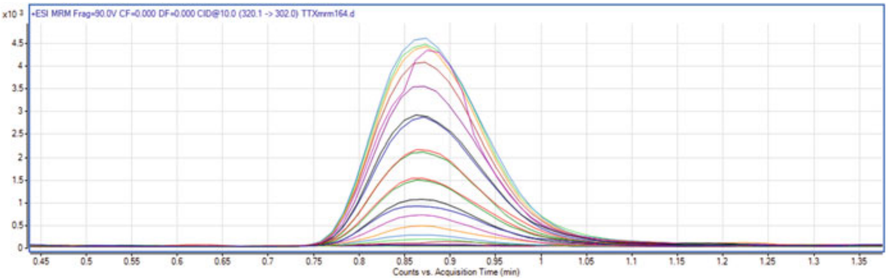


Fig. 7 Finding collision energy (CE) in MRM mode for product ion 302.0

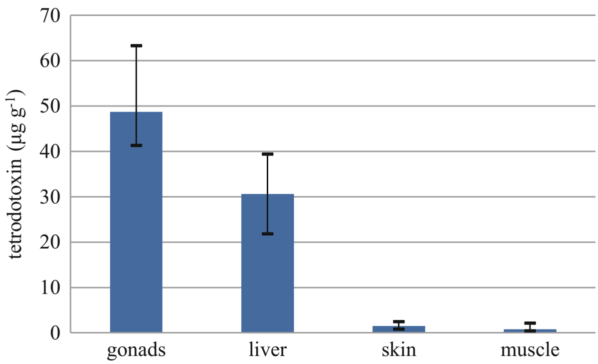


Fig. 8 TTX concentrations (average, min. and max.) in tissues of silver-cheeked toadfish *L. sceleratus* from Vodice area, caught in 2014 in the Adriatic Sea

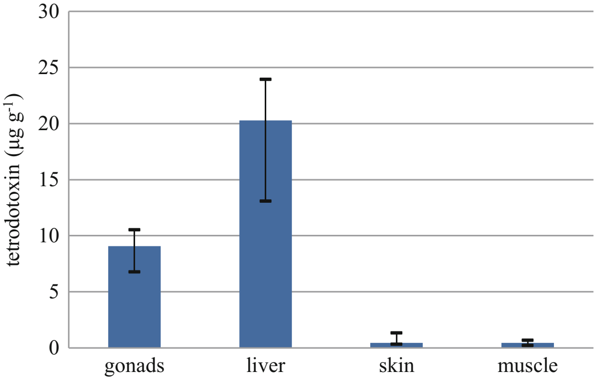


Fig. 9 TTX concentrations (average, min. and max.) in tissues of silver-cheeked toadfish *L. sceleratus* from Tribunj area, caught in 2013 in the Adriatic Sea

4 Conclusions

Marine species are increasingly migrating out of domestic habitats to the new areas. The non-native species can be introduced into new areas through a variety of vectors, including shipment, canal constructions, aquaculture and fishery and ornamental species trade, and in other ways of escape or release. The repercussion of invasive marine species introduction can be dramatic and irreversible; disruption of the natural balance through the biodiversity loss evokes various ecological consequences for the ecosystem, in addition to detrimental effects on the economy and human health. The toxicity and danger of consumption of such species is of great concern as it poses a very high risk to human health, leading to death.

The population of invasive and poisonous pufferfish in the waters of the Southern Adriatic (including the Montenegrin and Croatian waters) has not been fully established, but research indicates the spread and expansion of toxic and invasive pufferfish species through the Suez Canal.

Preventing and controlling the spread of invasive species and reduction of their impact on native species and entire ecosystems is one of the biggest nature protection challenges in Europe today. There is a need for early detection of the presence of these species in the ecosystem followed by an international collaboration and sharing of the existing scientific knowledge on their ecology and geographical distribution, as well as education of fishermen and citizens on the health risk that they present and how people may contribute to prevention of their further spreading.

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Some Results of Air Pollution from Passenger Ferries in the Boka Kotorska Bay

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Contents

Abstract Emission from passenger ships represents a threat especially for a population in the coastal area that is exposed to air pollution due to the port traffic throughput and other frequent activities at the seaside. Passenger ferries are one of the marine small vessels that have a primary role in connecting domicile inhabitants and serves as a favorite mode of transport for short tourist visits. In this chapter, the

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estimation of emission inventories produced by passenger ferry services that are transporting tourists inside the Boka Kotorska Bay in Montenegro is presented. The emission inventories of NOx, PM, SO_2, and CO emitted by four different ferries assigned at four routes are investigated. While quantifying the level of emissions, we first start with the necessary regulatory requirements at the international and national levels. Second, the identification of the bottom-up method for analyzing the status of engines onboard ferries and the sulfur limit content in diesel fuel was a foundation for the determination of emission factors of air polluters. The results showed that the largest of all ferries with respect to gross tonnage, capacity, engine power, and with the longest route emitted the largest amounts of NOx, SO_2, PM, and CO in total. On the other side, it showed best emission performances when emission of pollutants was brought down per passenger-mile.

Keywords Air pollution, Analysis, Boka Kotorska Bay, Ferries, Montenegro, Regulation, Tourists

1 Introduction and Background

The Mediterranean Sea is the largest region encompassing more than 50% of the total number of ferry routes in Europe with the presence of active regular lines in the domestic cabotage regime and between different countries [1]. Some regions are using this mode of transport only in a specific period of a year (mostly during summer) for touristic purposes. The extension in route connecting and the increase in total throughput led to a more active role of ferry operators to define a strategy of including new-constructed ships with emission-reduction technologies while satisfying the environmental requirements.

The current situation in the Boka Kotorska Bay in Montenegro (with Kotor as the third cruise port in the Adriatic Sea in total number of port calls) implies maritime services that are focused on passenger transportation only, mostly from March to October. The presence of air pollution from cruise ships and ferries are affecting these areas, as well, and negatively impacts the quality of the air and life of people in the coastal zones. Therefore, we determine four air polluters emitted from passenger ferries that transport tourists during the season, in order to estimate their level of air pollution in the bay. Some of the biggest air pollutants from the literature, and also considered here are nitrogen oxides (NOx), particulate matter (PM), sulfur dioxide (SO_2), and carbon monoxide (CO), with all of them being products of the combustion process in internal combustion engines. There are indications that all of these polluters are causing the health issues of the local population [2].

Investigating the relevant literature, we gave the advantage to the newly published references but incorporating it with the traditional ones related to passenger ships (cruise and other than cruise-ferries). Several timeless studies of the status of passenger ferry transport in the area of San Francisco Bay were motivational to quantify the exhaust emission from ships. Having in mind the air pollution inventories caused by the ferries and its advantage as an alternative mode of transport versus road transport, Corbett and Farrell [3] showed solutions (as advanced technologies) in the reduction of the former emission estimation to be comparable with road transport. At times, Farrell et al. [4] analyzed the implications of seven technological solutions for three urban passenger ferries that are in operation in the San Francisco Bay, in order to estimate the emission and costs of emission control strategies. The outputs show that ferries engines of the Tier II emission standard provided the lowest costs in reducing the total level of emissions (NOx and PM). The general recommendation of the study was directed to the state in the sense of adoption of regulatory requirements. Later, Farrell et al. [5] made a comparison between emission inventories from three passenger ferries and road transport in the San Francisco Bay area. The results showed that even passenger ferry transport indicated better performances in the level of emissions, still, NOx results were very high. They proposed solutions and implications.

Developing an appropriate mathematical tool to model the optimal passenger ferry fleet in the case of New York–New Jersey Port was presented in [6]. The authors advanced the mixed-integer nonlinear programming model to reduce the emission of NOx and PM in the case of 45 commuter ferries in the port. One of the comprehensive overview research on the impact on atmosphere and climate in maritime transport is done in [7]. Besides other topics and conclusions on the air quality problems, the study addresses the concentration of ship emissions in the coastline area due to heavy traffic and the presence of the high concentration of sulfur oxides (SOx) and PM emissions. The ship emissions harm climate change and produce a high level of carbon dioxide (CO_2), ozone, and radiative forcing (RF). Referring to NOx and SO_2, they discussed the chemistry in the marine boundary layer specifying its important chemical reactions producing the NOx-catalyzed formation of ozone, and the gaseous and aqueous oxidation of SO_2 to sulfate aerosol. The retrospective of methodologies for estimating fuel consumption correlated with emissions is given in [7]. The authors also reported the mitigation mechanisms of emissions in the air, starting with the technology options, alternative fuels, and energy optimization together with CO_2. Methodologies for reducing NOx, SO_2, and PM emissions are described. Second, control emission measures are globally presented together with policy strategies and instruments. Third, possible improvements in 16 emission scenarios are presented and discussed. At the end, current legislation and directions for near future regulations are described and analyzed.

Tichavska and Tovar [8] developed an AIS-based model for quantifying exhaust emission in the Port of Las Palmas but emphasizing maritime passenger transport including cruise ships and ferries operations. They provided results for the level of emissions for NOx, SOx, $PM_{2.5}$, CO, and CO_2 and concluded that the hoteling mode of cruise ships is predominant operative type while in the case of ferries, the situation is quite different and related to “at sea” operation. This study has been extended and related to external cost estimation applying bottom-up model for the same case study of the Port of Las Palmas, as described in [9]. They proposed eco-efficiency solutions referring to different parameters calculation of costs per passenger, tons of cargo, and port revenue. The experimental analysis of fuel additive for calculating the level of ferry emissions has been studied in [10]. The authors reported the technology on combustion performances and results showed a decrease in emission levels of the engines. They also gave an overview of the advantages of using modified physical and chemical content of fuels with the application of different methodologies elaborated in relevant publications.

In a recent paper, Toscano and Murena [11] did a deep review analysis for 38 ports concentrating on the emission estimation of NOx and PM_{10} during different ship regimes (hoteling and maneuvering) in the port area and their correlation with traffic performances. In the analysis, they summarized the regression equations for cruise ships, other passenger ships, and commercial ships. Similar methodologies and surveys have been reviewed and categorized in the view of the field of research.

Different new power solutions for reducing the pollutant emissions from ferries and increase the air quality while minimizing the operation costs and optimizing their performances are considered in [12]. The focus of the study is to hybrid management energy system of the ferries and related Zero emission concept. Besides, the authors presented the operational background of electrical ferries. Mocerino et al. [2] elaborated a methodology for determining appropriate passenger ship emission (i.e., cruise ships, ferries, and hydrofoils) monitoring network in the port areas. The case study was related to the Port of Naples and two observed periods of ship traffic in 2012. The emission calculation observed three phases of passenger ships: navigation in port, maneuvering, and hoteling. Nikolić et al. [13] indicated that the use of second-generation biodiesel could reduce gaseous pollution from maritime shipping. The research investigates the influence of the second-generation biodiesel on the characteristics of gaseous emissions of NOx, SO_2, and CO from marine diesel engines. The marine diesel engine that was used, installed aboard a ship, was a small reversible low-speed two-stroke engine used for training ship “Jadran”, without any after-treatment devices installed or engine control technology for reducing pollutant emission. The engine was fueled by diesel fuel and blends containing 7% and 20% v/v of three types of second-generation biodiesel made of olive husk oil, waste frying sunflower oil, and waste frying palm oil. A base-catalyzed transesterification was implemented for biodiesel production. According to the results, there are trends of NOx, SO_2, and CO emission-reduction when using blended fuels. Biodiesel made of olive husk oil showed better gaseous emission performances than biodiesel made from waste frying oils.

The maritime passenger service in the Boka Kotorska Bay (Montenegro) has been studied to a great extent during the last decade. In the beginning, the whole attention of the authors was related to the cruise activities within Port of Kotor. In Kofjač et al. [14], an analytical approach and simulation modeling of cruise ships traffic in the Kotor Bay is used, first to estimate the port revenue. Moreover, the results of the analysis indicated a new scenario in the operational policies in the Port of Kotor. A similar but more comprehensive study of the Kotor cruise port performances has been done in [15]. In the paper, assuming that there will be an increase in the number of port callings, the authors considered a quay extension with relevant indicators including the simulation modeling of ship traffic.

The first study on the Boka Kotorska Bay in the sense of air pollution implications has been done in [16]. The estimation of cruise ship exhaust emission at cruising, maneuvering, and hoteling regimes (more precisely for: NOx, CO, CO_2, volatile organic compound (VOC), PM, and SOx) with the relevant methodology adopted by Vaccaro et al. [17] has been reported. The results showed that more than 70% of the total emission from cruise ships was related to the hoteling mode. A comparative analysis in the level of emission from cruise ships and their externalities between Port of Dubrovnik (Croatia) and Port of Kotor was reported in [18]. The estimation of air pollution indicated that the infrastructure solutions (such as extension of the main berth's length) in the reduction of the emission inventories should be concretely implemented. Škurić et al. [19] proposed a model formulation for optimizing the size and structure of the passenger ferry fleet while minimizing the total emission of NOx, SO_2, and PM for a specified time. It is assumed that this mode of transport has its advantages for local inhabitants and touristic purposes inside the Boka Kotorska Bay. Considering the establishment of a regular passenger ferry service for local inhabitants and tourists in the bay by maximizing the profit of local operators, Škurić et al. [1] developed a deterministic mixed-integer linear programming model and used three types of matheuristics (Variable Neighborhood Branching – VNB, Variable Neighborhood Decomposition Search for 0–1 MIP – VNDS 0–1 MIP, and Variable Intensity Neighborhood Search – VINS). The results showed that the optimal allocation of ferries to routes implies the cost-effectiveness of the service.

Observing the frequent number of tourists' visits and cruise port callings in the Kotor port for a period 2011–2018, from the legislative point of view, Nikčević [20] stipulated that the local authorities should pay more attention to avoid the possible intensive pollution and constitute sustainable tourism. The author underlined the recommendations for pollution of air and seawater from maritime activities aiming at more comprehensive legislative, administrative, technical, and financial resources for the prevention of the pollution at the UNESCO site.

A part of the investigation in this chapter reviews the national legislative framework according to the international one. It focuses on the standards and provisions in the prevention of air pollution from ships applicable for passenger ferries. The second part addresses three main goals – collecting data, the definition of the appropriate methodology for exhaust emission inventories, and calculation of air pollutions from passenger ferries at the observed routes. The input parameters for sulfur content lead to the importance of legislative framework, sulfur on-field control, and future investigations, especially after new standards and IMO requirements started its implementation from January 1, 2020.

This chapter is structured as follows. Regulatory achievements at the international and national levels referring to air protection from ship emissions are provided in Sect. 2. In Sect. 3, an observation on the bottom-up methodology for calculating emission in the case of passenger ships is given. Applying this activity-based method, a formulation for quantification of passenger ship emissions used for touristic purpose in the Boka Kotorska Bay is presented in Sect. 4. The results of calculating emission parameters of NOx, PM, SO_2, and CO observed for four routes are shown in Sect. 5. Concluding remarks with future directions are specified in Sect. 6.

2 Regulatory Achievements

2.1 International Legislative Framework

Considering that more than 3/4 of world trade is carried out by sea, the International Maritime Organization (IMO) adopted resolution MEPC.304(72) on the *Initial IMO Strategy on reduction of GHG emissions from ships* in April 2018. This document consists of two annexes aiming at actions that need to be taken into consideration to decrease Greenhouse Gas (GHG) emissions from international sea transport [21]. The Strategy emerged as a result of the first, second, and third IMO GHG studies published in 2000, 2009, and 2014, respectively. Precisely, *Initial IMO Strategy on reduction of GHG emissions from ships* encompasses the concrete actions (mainly related to carbon dioxide) in the monitoring of GHG emissions from international shipping in avoiding climate changes and its negative impacts. This is another attempt of the IMO besides the continuous work in the prevention of air pollution from 1997 that was undertaken. Generally speaking, ship engines are designated as major producers of harmful substances in the air, so many standards adopted in their legislation are with an aim to control and reduce emissions from ships.

Referring to that, the IMO's *International Convention on the Prevention of Pollution from Ships* – MARPOL 73/78 regulates the pollution caused by ships, especially Annex VI from 1997 which states the limits on NOx and SOx standards for ship capacity of 400 gross tonnages and above [2]. By the time, following the development of new technologies in maritime shipping, the revisions of Annex VI were made with the only aim, i.e., prevention of harmful air pollution from ships and minimizing the total emission. The concept of emission control area (ECA) has been adopted with the specified limits and standards in the emission. On the other side, data on the year of ship construction and engine parameters referring to Regulation MEPC.177(58) [22], limits known as Tiers I, II, and III have been accepted and implemented at the global level. According to Livanos et al. [23], IMO in its Regulations 13 and 14 determined the characteristics for NOx and SOx by establishing the upper limits of ships sulfur content in the fuel inside and outside ECA and limits of Tiers. Tier II required 15% reduction of NOx compared to Tier I while Tier III imposes 80% reduction in NOx (also compared to Tier I) and was active from 2016 (Table 1).

As stated in [2] another novelty was referred to the sulfur content (in %) in the fuel accordingly with the global standard changed over years (from January 1, 2020, the sulfur content in fuel has to be reduced from 3.50% to 0.50% m/m – that is by mass as adopted by IMO resolution MEPC.280(70) [24]). At the local level, it is

Table 1 Standards in nitrogen oxides (NOx) – regulation 13 of IMO [25]

Tier	Ship construction date on or after	Total weighted cycle emission limit (g kWh^{-1}); n = engine's rated speed (rpm)		
		$n < 130$	$n = 130–1999$	$n \geq 2000$
I	1 January 2000	17.0	$45{\cdot}n^{(-0.2)}$; e.g., 720 rpm – 12.1	9.8
II	1 January 2011	14.4	$44{\cdot}n^{(-0.23)}$; e.g., 720 rpm – 9.7	7.7
III	1 January 2016	3.4	$9{\cdot}n^{(-0.2)}$; e.g., 720 rpm – 2.4	2.0

Table 2 Standards in SOx and PM – regulation 14 of IMO [26]

Outside an ECA established to limit SOx and PM emissions	Inside an ECA established to limit SOx and PM emissions
4.50% m/m prior to 1 January 2012	1.50% m/m prior to 1 July 2010
3.50% m/m on and after 1 January 2012	1.00% m/m on and after 1 July 2010
0.50% m/m on and after 1 January 2020	0.10% m/m on and after 1 January 2015

more relevant to quantify the emissions of NOx, SO_x, and PM as the most important pollutants from ships. More can be seen in Table 2.

Referring to ferries, it is significant to emphasize that the requirements specified in Table 1 are typical for marine diesel engines of over 130 kW output power. It is especially important in the regions where ferry service represents an alternative mode of transport and serves for the transportation of a small number of users. Special attention is given to Tier III NOx standard that is applicable for the ECAs outside the Tier II control; for North American and United States Caribbean Sea ECAs from 2016 while in the case of the Baltic Sea and the North Sea ECAs will be in operation from 2021.

As indicated in Table 2 [26], the ECAs established are:

1. The Baltic Sea area – as defined in Annex I of MARPOL (SO_x only);
2. The North Sea area – as defined in Annex V of MARPOL (SO_x only);
3. The North American area (entered into effect 1 August 2012) – as defined in Appendix VII of Annex VI of MARPOL (SO_x, NO_x, and PM); and
4. The United States Caribbean Sea area (entered into effect 1 January 2014) – as defined in Appendix VII of Annex VI of MARPOL (SO_x, NO_x, and PM).

Looking back at research from the beginning of this century regarding maritime air emissions and regulations, Corbett and Farrell [3] compared the standards of emission factors for rail, road, and marine engines, fuels, and their operations. Also, the authors emphasized that previous investigations were not quite relevant to passenger ferries, especially to high-speed ships.

Winebrake et al. [6] showed that ferry operators were not keen to pay attention to environmental impacts of employed diesel engine ships but were more concentrated on ship optimal performance even though the legislation adopted the limits of Tier I that were widely recognized. They announced the strategy for developing ship engine and emission limits for Tier II as well as a new eco-efficient fleet. Moreover, in the case of ferries propulsion plant in ECAs regions, Livanos et al. [23] investigated different aspects of alternative propulsions and calculated the Energy Efficiency Design Index (EEDI) values for two propulsion system cases, suggested in the latest IMO resolution for reducing the level of GHG emissions from ships.

2.2 National Legislative Framework

Recent work of Nikčević [20] gave a retrospective into the actual laws and bylaws in Montenegro, concentrating more on the cruise sector and the trends in traffic volume for the Kotor cruise port. Here, we present a very important legislative overview applicable also to passenger ferry transport.

Since Boka Kotorska Bay is under the UNESCO protection heritage, there is a different legislative framework that indicates the reduction of negative effects of the environment. First of them is the Law on Protection of the Natural and Cultural-Historical Region of Kotor ("Official Gazette of Montenegro", Nos. 56/13 and 013/18). The Law regulates protection, management, and special measures aimed at the preservation of natural and cultural-historical regions of Kotor, the boundaries of the protected sea-bay area, and land region of Cetinje [20]. Some provisions are indirectly related to ecosystem prevention and marine pollution. Also, pieces of other laws can rely on the topic of protection from pollution of the Boka Kotorska Bay (adopted from [20]): Law on Nature Protection ("Official Gazette of Montenegro", No. 54/16); Law on Environmental Protection ("Official Gazette of Montenegro", No. 52/16); Law on Coastal Zone ("Official Gazette of Montenegro", Nos.14/92 and 51/08); Law on Marine Fisheries and Mariculture ("Official Gazette of Montenegro", No. 56/09), etc. The National Plan for Emergent Reaction in the Event of Sea Pollution from Vessels from 2011 contains the principles, procedures, and other actions for prevention, mitigation, and minimization of consequences of sea pollution from ships [27]. The Plan is covering manuals for efficient reaction to maritime accidents of sea pollution from ships such as releasing harmful substances into the marine environment.

According to Nikčević [20], besides that Montenegro ratified the annexes of MARPOL, the first adopted national law that relies on the prevention of sea pollution from ships and protection and preservation of the marine environment is the Law on the Prevention of Sea Pollution from Vessels ("Official Gazette of Montenegro", Nos. 020/11, 026/11 and 027/14). Articles 35–37 of the Law regulate the release of harmful substances into the air. When it comes to air pollution prevention, Article 37 indicates that ships of a capacity of 400 gross tonnages or above must have an international certificate of air pollution prevention. Also, according to Regulation 13 of IMO, ships with marine diesel engines of over 130 kW output power have to dispose of an international certificate on the prevention of air pollution. Finally, a ship constructed after 1 January 2000, with a diesel engine power output of at least 130 kW must have technical instructions on engine characteristics, including fuel injection timing, and other engine operating instructions.

Law on air protection (“Official Gazette of Montenegro”, Nos. 025/10, 040/11 and 043/15) regulates the manner of air quality monitoring, protection measures, assessment, and improvement of air quality, as well as air quality planning and management. Article 8 of the Law defines pollutants and standards of air quality assessment, while Article 9 regulates air quality assessment and air quality management that are mandatory in all zones (zones represent air quality monitoring network stipulated by the Government) for:

- Sulfur dioxide (SO_2),
- Nitrogen dioxide (NO_2) and nitrogen oxides (NO_x),
- Particulate matters (PM_{10} and $PM_{2.5}$),
- Lead (Pb),
- Benzene (C_6H_6),
- Carbon monoxide (CO),
- Benzo(*a*)pyrene ($C_{20}H_{12}$),
- Ozone (O_3),
- Cadmium (Cd),
- Arsenic (As), and
- Nickel (Ni).

Article 10 of the Law describes the procedure for assessing air quality in zones. The Government prescribes the limit values for pollutants in liquid fuels of petroleum origin. The use of fuel onboard ships and by other vessels in ports, in territorial waters, and exclusive economic zones are defined by Article 30.

Considering the world trends in shipping, Montenegro set up the Regulation on limit values of pollutants in liquid fuels of petroleum origin (“Official Gazette of Montenegro”, No. 017/17) in 2017. The regulation prescribes the types of liquid fuels of petroleum origin, limit values for the content of pollutants, and the content of metal-based additives and other fuel characteristics. In terms of environmental protection, these limits must be met by the fuels currently on the market, use of fuel onboard ships in ports, territorial waters, and exclusive economic zones and zones of control of sulfur oxide emissions. It also defines a method of determining and monitoring fuel characteristics, methods for reducing emissions of pollutants into the air, and reporting on compliance with the limit values of pollutant content. The regulation is harmonized with the legal framework of the IMO.

Article 13 defines the use of fuel onboard ships and other vessels in the Montenegrin territorial waters and the exclusive economic zone by which the marine fuel is with the sulfur content equal or less than 3.50% m/m, except for marine diesel oil (MDO) and marine gas oil (MGO). The exception of paragraph 1 of the Article is firstly devoted to passenger ships on regular lines in the Montenegrin territorial waters and the exclusive economic zone which cannot use fuel with the sulfur limit of more than 1.50% m/m. The second exception is related to the berthed or anchored ships (hoteling regime) and the sulfur limit of used fuel for these operations cannot exceed 0.10% m/m. The third exception is for vessels that use closed methods for the reduction of emission pollution in the air and they can use fuel with more than 3.50% m/m of sulfur (excluding marine diesel and gas oils). It is also said that before entering the territorial waters of Montenegro, ships are obliged to respect this regulation for the sulfur content in the fuel and report it in the engine room logbook. Article 15 regulates the control of marine fuels, while Article 16 specifies the sampling of marine fuels. Finally, according to Article 19, the standards in SOx and PM from Table 2 for the sulfur content of 0.50% m/m on and after 1 January 2020 is active also for ships sailing in Montenegrin territorial waters and exclusive economic zone.

3 Bottom-Up Methodology: An Observation

Bottom-up approach in estimating emission from ships has been recognized as a very useful tool from the literature. It is also known as activity-based method that incorporates data on the ship movement and includes the values of engine power, emission factors for a specific activity, and an engine load factor (in %). Here we present a short overview and results of the bottom-up approach from the literature applied to passenger ships.

3.1 Results of the Bottom-Up Approach from Corbett and Farrell [3]

In the study, the integrated bottom-up methodology is used to calculate ship emissions per passenger at the BayLink ferry route and compared with the corresponding automobile route. The obtained results showed that a chosen ferry produced 0.42 tons of NOx per day.

3.2 Results of the Bottom-Up Approach from Tzannatos [28, 29]

Using port traffic data, there are two studies by Tzannatos [28, 29] who assessed the level of emissions from passenger ships. First, Tzannatos [28] studied the season effect on emission inventories at maneuvering and berthing ship-activity phases, and externalities for passenger ships in the case of Piraeus. Second, Tzannatos [29] described in detail the ship-activity based methodology for exhaust emission estimation from passenger ships (coastal and cruise ships) during berthing time in the same port. It included the definition of marine engine emission factors for NOx, SO_2, and PM, the actualities of sulfur content in fuel, types of generators, and values of their load factors. The special attention of the auxiliary engine performances was discussed in the paper. The recommendation of both studies for port authorities was to intensively control the produced emissions and the fulfillment of the 2005/33/EU Directive.

3.3 Specifics of the Bottom-Up Approach Described in Eyring et al. [7]

The elaboration of the uncertainty concept in the bottom-up approach is presented. The authors mentioned the results of the STEEM model developed by Wang et al. [30] as the first network based on traffic data and geographic information system (GIS). Other integrated approaches reported in [31, 32] are also reviewed.

3.4 Activity-Based Method from Nunes et al. [33]

This methodology is applied for evaluating ships emission of PM_{10}, $PM_{2.5}$, NOx, SO_2, CO, CO_2, N_2O CH_4, non-methane volatile organic compound (NMVOC), and HC in the case of four ports in Portugal for two-year time. It includes the definition of three operational modes, i.e., hoteling, maneuvering, and navigating for seven ship types, including passenger one. The results showed that the main air pollution sources are NOx and SO_2.

3.5 Activity-Based Emissions from Dragović et al. [18]

The methodology for calculating cruise ship emission during maneuvering and hoteling (at berth and at anchor) modes is proposed. It is based on the activities of cruise ships in ports of Dubrovnik and Kotor. The authors also emphasized on the uncertainty of the bottom-up approach in parameters such as the exact power and engine load factors during different cruise ship regimes and the values of emission factors necessary to estimate the emission.

3.6 Applied Methodology in Murena et al. [34]

The emission of NOx and SOx applying the bottom-up approach including hoteling, navigation in port during arrival and departure, and maneuvering phases is estimated in [34]. The case study included the cruise ship traffic in the Port of Naples for 2016. The implications to the urban area are modeled by using CALPUFF, a Gaussian puff model, and simulation.

4 Quantification of Ferry Emission in the Boka Kotorska Bay

4.1 Input Data

The actual passenger ferry transport in the Boka Kotorska Bay is characterized for a touristic purpose only, as described in [1]. There are various initiatives about the foundation of a regular passenger ferry liner service and some of them were the subject of feasibility study [35] and scientific investigation [1]. This service along various routes is active from March to October in a year. In the analysis of emission estimation of air polluters NOx, PM, SO_2, and CO, data were collected for 2018 of four ships that transported tourists at the four routes shown in Fig. 1 (routes are marked with white line).

The input data include tourists' transportation realized by four ships at four routes. The routes' characteristics are presented in Table 3.

The length of the route and trip duration are calculated for the round trip (including time for stops). The ferries transport tourists and make more than one trip per day during the summer season. The data on the maximal number of trips per day are provided in the fifth column of the table. The total tourists' traffic volume is also given. This transport was provided by four ferries with the basic data information given in Table 4. The total number of realized trips in 2018 is 455, 180, 236, and 200 by ferry J1, ferry J2, ferry J3, and ferry R1, respectively [36, 37]. Table 4 shows technical details such as a year of construction, total gross tonnages (GT), capacity, type of engines, and total installed power of main (ME) and auxiliary (AE) engines of ferries. The first three ferries are driven by main engines.

In the case of observed ferries, the policy for hiring them on a daily basis or per trip is dictated by the touristic agencies. They organize the transfer of tourists to different locations inside the bay. Some of them are offering refreshments and restaurant services.

4.2 Load and Emission Factors Determination

Analyzing the literature, there are several studies considering the specifics of harbor craft or recreational boats, including ferries/excursion boats relevant for this investigation. Applying the bottom-up approach, the definition of load factor values of passenger ferry engines was incorporated with the information received on the field, specific technical requirements, navigational performances in the Boka Kotorska Bay, and relevant experience of private operators [36, 37]. In the analysis, each ferry is passing through three phases: navigation, maneuvering, and hoteling regimes. The appropriate load factors per each ferry engine type and ship activity are introduced in Table 5.

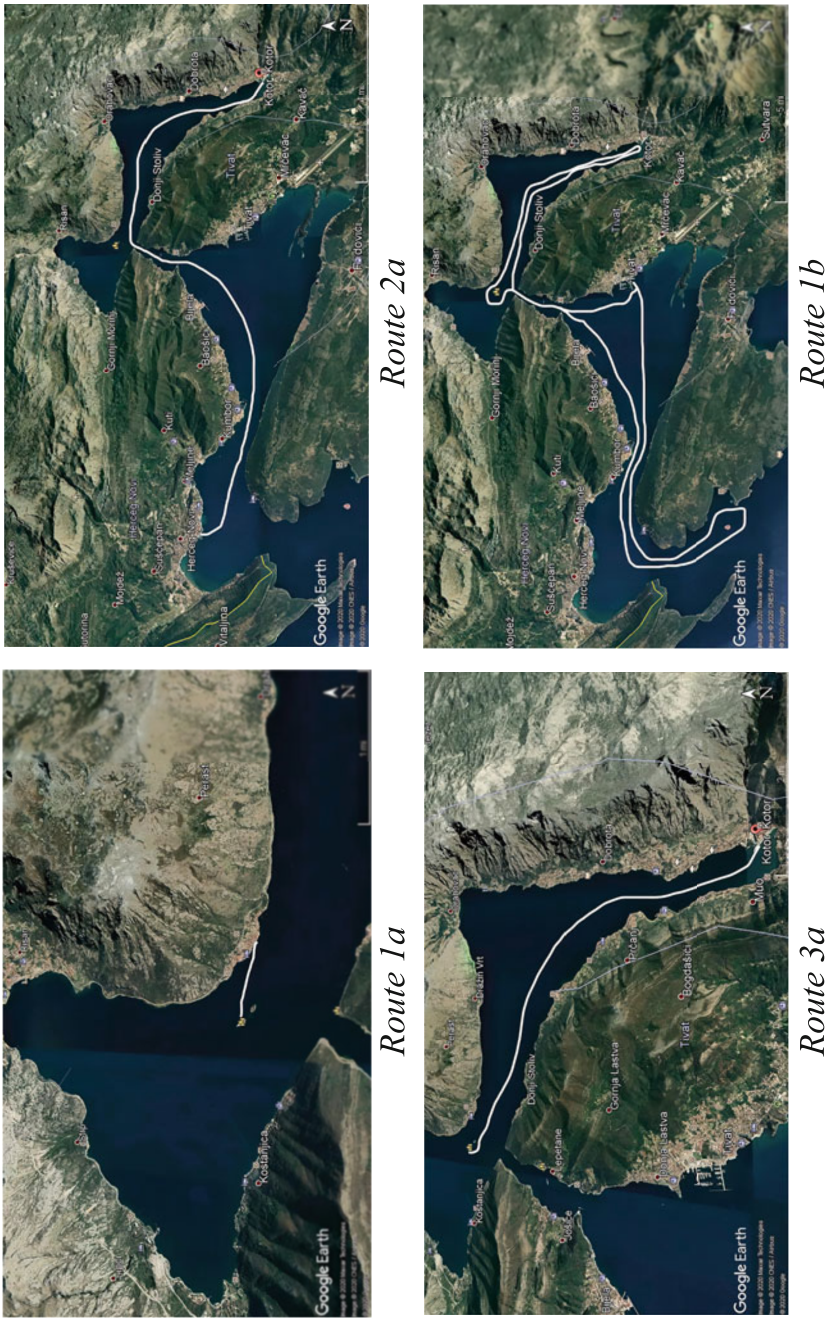

Fig. 1 Observed routes in Boka Kotorska Bay

Table 3 Basic routes characteristics [36, 37]

Route[a]	Distance (nm)	Approx. trip duration (h)	Engaged ferries	Max no. of trips/day[b]	Trips	Transported passengers	% of ferry transport capacity utilization
Route 1a (1 stop)	2	1.02	J1	J, D = 0; F, Ma, N = 1; Ap, My, Ju, Jl, Au, S, O = 2;	455	16,483	66
Route 2a (2 stops)	30	4.15 (0.75 h for stops)	J2	J, F, Ma, N, D = 0; Ap, My, Ju, Jl, Au, S, O = 1;	180	5,227	53
Route 3a (1 stop)	12	2.40	J3	J, F, D = 0; Ma, Ap, My, S, O, N = 1; Ju, Jl, Au = 2;	236	6,539	50
Route 1b (2 stops)	36	6 (2 h for stops)	R1	J, F, Ma, Ap, N, D = 0; My, Au, S, O = 2 Ju, Jl = 3;	200	30,685	38

[a]Note: Route 1a: Perast-Our Lady of the Rocks-Perast; Route 2a: Kotor-Herceg Novi-Kotor; Route 3a: Kotor-Our Lady of the Rocks-Kotor; Route 1b: All Bay tour
[b]Note: *J* January, *F* February, *Ma* March, *Ap* April, *My* May, *Ju* June, *Jl* July, *Au* August, *S* September, *O* October, *N* November, *D* December

Table 4 Basic ferries characteristics [36, 37]

Ferry	Year of construction	GT	Capacity	Average speed (kn)	Engine	ME power (kW)	AE power (kW)
J1	2006	8.89	55	9	Daf	150	n/a
J2	2010	8.89	55	10	Fiat	200	n/a
J3	2017	8.89	55	12	Iveco	300	n/a
R1	1989	126	400	9	Renault	410	160

Table 5 Engine load factors (%)

Ferry	Engine	Hoteling	Maneuvering	In navigation
J1	ME	25	25	80
	AE	n/a	n/a	n/a
J2	ME	25	25	80
	AE	n/a	n/a	n/a
J3	ME	25	25	80
	AE	n/a	n/a	n/a
R1	ME	30	30	80
	AE	40	60	40

Table 6 Emission factors (g kWh^{-1})

	NOx	PM	SO_2	CO
J1-J2/ME	12.71	0.22	0.76	1.10
J3/ME	7.92	0.22	0.76	1.10
R1/ME	13.18	0.22	0.76	1.10
R1/AE	12.05	0.22	0.78	1.10

The values are, in general, very similar to those used in the observed bottom-up literature in Sect. 3. The standard values for ME in navigation and maneuvering are almost identical to conventional researches in the field. The load factor for the hoteling mode is higher than usual and is adapted according to the received real-world input data due to the navigational conditions at berths in the bay. Unlike load factors defined in [38], the specifics for ferry R1 are related to the leisure services (including two stops of 2 h in total), the load factors of AE during all three phases are close to proposed in [39, 40] for passenger ships and Tzannatos [28] for the coastal passenger ships.

For determining the values of emission factors, we did an overview of the relevant publications and studies with the emphasis on the passenger ferry ships, coastal passenger vessels, harbor crafts, and recreational vessels. An interesting air pollutant emission inventory guidebook on international navigation, national navigation, and national fishing was prepared by the European Environmental Agency [41]. This study covers the performances starting from the recreational crafts to ocean-going cargo ships with details about their engines. The document includes the methods for emission calculation and other additional quantifications taking into account emissions from CO_2, methane (CH_4) and nitrous oxide (N_2O), carbon monoxide, non-methane volatile organic compounds (NMVOCs), sulfur dioxide, particulate matter, and oxides of nitrogen. Other studies and researches that were observed and whose data of the emission factors were taken into account are given in [3, 28, 38, 40, 42–45].

According to Moldanova et al. [46] for passenger ferries in the Mediterranean, the use of fuels with a sulfur content of around 2.7% is more present than with 1.5%. In the case of passenger ferries for touristic purposes operating in the territorial waters or exclusive economic zone in Montenegro, the sulfur content in the fuel is not greater than 0.1% m/m [36, 37]. The emission factors are interpolated and adopted from [45] and given in Table 6 for main and auxiliary engines.

The input data of previously mentioned researches were structured through the four criteria: ship-activity phase, type of engines (Medium Speed Diesel (MSD) engines, or High Speed Diesel (HSD) engines), fuel type, and the employability of main and auxiliary engines. Each emission factor was divided into four groups according to the number of air pollutants (NOx, PM, SO_2, and CO). For each group, the average value with a lower and upper bound of 95% confidence interval was calculated. The determined emission factors are applied for each of the ferry activities in the bay.

4.3 Emission Calculation Formulation

The ship-activity based methodology has been used for calculating the emission from ferries as described in [19, 28, 29]. Here we identify the three phases: maneuvering, hoteling, and navigation (the speed of the ferry is up to 12 knots). Most of the time, ferries are spending in the navigation regime with few stops. Input parameters are:

E_M – emission during maneuvering; (tons).

t_M – time spent in maneuvering; (h).

P_{ME} and P_{AE} – main and auxiliary engine power; (kW).

LF_{ME_M} and LF_{AE_M} – load factors of main and auxiliary engines in maneuvering; (kW).

EF_{ME_M} and EF_{AE_M} – emission factors of main and auxiliary engines; maneuvering; (g kWh^{-1}).

E_H – emission during hoteling; (tons).

t_H – time spent during hoteling; (h).

LF_{ME_H} and LF_{AE_H} – load factors of main and auxiliary engines during hoteling; (kW).

EF_{ME_H} and EF_{AE_H} – emission factors of main and auxiliary engines; hoteling; (g kWh^{-1}).

E_N – emission during navigation; (tons).

t_N – time spent in navigation; (h).

LF_{ME_N} and LF_{AE_N} – load factors of main and auxiliary engines in navigation; (kW).

EF_{ME_N} and EF_{AE_N} – emission factors of main and auxiliary engines; navigation; (g kWh^{-1}).

The total emission for each ferry call during maneuvering can be obtained by

$$E_M = \left[t_M\left(\left(P_{ME}\cdot LF_{ME_M}\cdot\sum EF_{ME_M}\right)+\left(P_{AE}\cdot LF_{AE_M}\cdot\sum EF_{AE_M}\right)\right)\right]\cdot 10^{-6} \tag{1}$$

For calculating emission of ferry call during hoteling, the following equation can be used

$$E_H = \left[t_H\left(\left(P_{ME}\cdot LF_{ME_H}\cdot\sum EF_{ME_H}\right)+\left(P_{AE}\cdot LF_{AE_H}\cdot\sum EF_{AE_H}\right)\right)\right]\cdot 10^{-6} \tag{2}$$

while the equation for calculating emission of ferry call during navigation is

$$E_N = \left[t_N\left(\left(P_{ME} \cdot LF_{ME_N} \cdot \sum EF_{ME_N}\right) + \left(P_{AE} \cdot LF_{AE_N} \cdot \sum EF_{AE_N}\right)\right)\right] \cdot 10^{-6} \quad (3)$$

The procedure of calculating emissions for each air polluter is the same and depends on the emission factors values. The total emission calculation in a year can be obtained by

$$E = E_M + E_H + E_N \quad (4)$$

5 Results

The total emission inventories for considered cases are presented in Fig. 2. Observing air pollutants, NOx produced 85.4% (7.017 tons) of total emission in 2018 (8.22 tons). SO_2 emitted 5.4% of total emission (0.447 tons), while PM and CO succeeded 1.6% (0.128 tons) and 7.6% (0.628 tons), respectively. NOx is the largest among all gaseous pollutants due to specificity of combustion process in diesel engines therefore having the largest emission factors. Emission of CO is significantly lower than NOx due to lean combustion process in diesel engines. Referring to SO_2 calculation, emission factor depends on the sulfur content in the fuel. The level of emitted PM is relatively low due to the usage of fuels of higher quality including low sulfur content up to 0.1% m/m.

The largest emission of NOx was reported by ferry R1 resulting in 4.569 tons, followed by ferry J2 (1.237 tons), ferry J3 (0.799 tons), and ferry J1 (0.412). In the

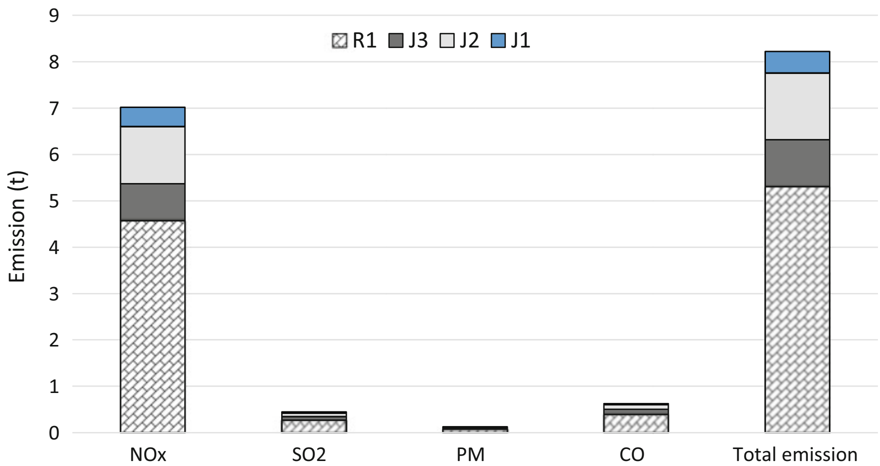

Fig. 2 Total emission in tons

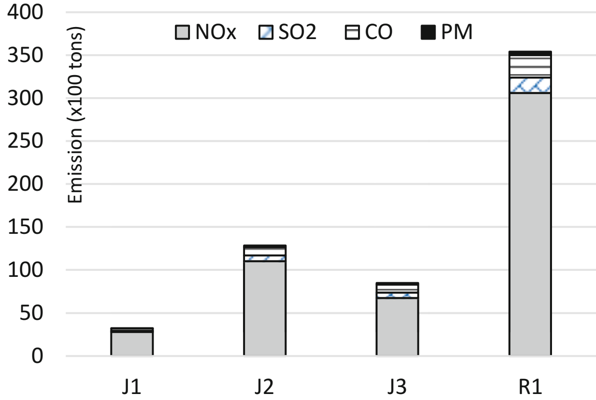

Fig. 3 Emission in navigation (x100 tons)

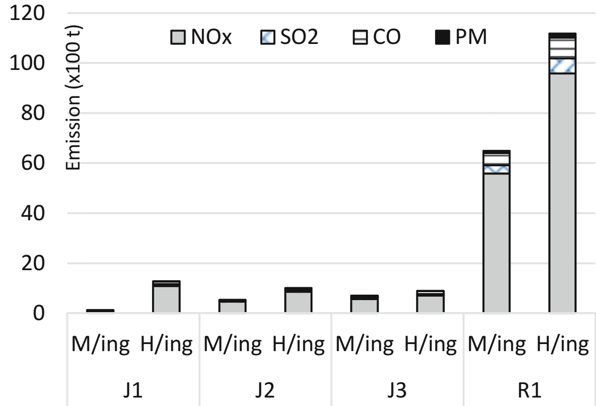

Fig. 4 Emission during maneuvering and hoteling (x100 tons)

case of SO_2 emission, the highest level of pollution was emitted again by ferry R1 (0.271 tons). Ferry J1 produced 0.025 tons of SO_2, ferry J2 emitted 0.074 tons, and 0.077 tons of SO_2 were produced by ferry J3, respectively. Regarding the same output of PM, the results are the following: ferry R1 emitted 0.078 tons and ranked first position; 0.022 tons, 0.021 tons, and 0.007 tons were produced by ferries J3, J2, and J1, respectively. Finally, CO emission of ferry R1 resulted in 0.389 tons, ferry J3 produced 0.111 tons, ferry J2 emitted 0.107 tons, and the lowest emission of CO was reached by ferry J1. These results are expected and in favor to ferry R1, due to the largest engine power onboard, gross tonnage, capacity for passenger transportation, and operation time in the longest route.

Analyzing ferries activities and achieved emission inventories, the results for each ferry are demonstrated in Figs. 3 and 4. There was an emission of 0.465 tons produced by ferry J1 which spent around 106 h in navigation, 32 h in maneuvering, and 133 h at the hoteling regime. During navigation, ferry J1 emitted 0.324 tons, 0.011 tons in maneuvering, and 0.13 tons at hoteling mode. Regarding ferry J2 results, the total level of produced emission was 1.44 tons. The ferry reached 1.29

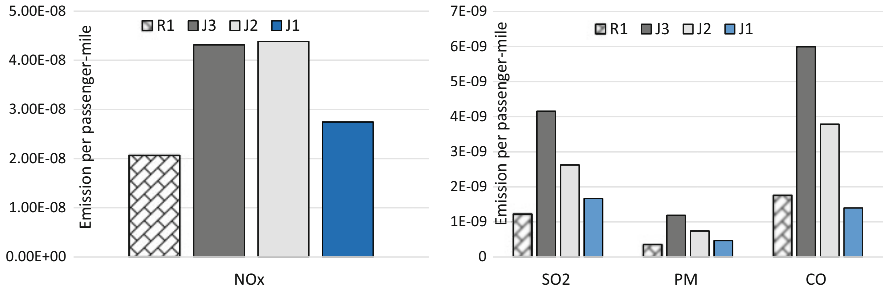

Fig. 5 Emission per passenger-mile in tons

tons of emission in navigation and spent more than 540 h. During the maneuvering phase of 72 h, the emission was 0.05 tons, while in the case of a hoteling regime (135 h), the level of emission was 0.1 tons. Ferry J3 spent almost 300 h in navigation, 80 h, and 100 h in maneuvering, and hoteling regimes, respectively. It is the biggest emission achieved during navigation – 0.85 tons of 1.01 tons as total pollution. During maneuvering and hoteling, the emissions were 0.07 tons, and 0.09 tons, respectively. The biggest emission of 5.31 tons was reported by ferry R1. It spent around 516 h in navigation, 172 h in maneuvering, and 344 h at the hoteling regime. During navigation, ferry R1 emitted 3.54 tons, in maneuvering reached 0.65 tons, and 1.12 tons at the hoteling phase.

The results of emission per passenger-mile are shown in Fig. 5. As it can be seen, the biggest emission of NOx per passenger-mile is produced by ferry J2 (4.38E-08 tons). A little less emission of NOx was produced by ferry J3 (4.31E-08), while ferry J1 and ferry R1 emitted 2.75E-08 and 2.07E-08 tons, respectively. The predominant emission per passenger-mile of other three pollutants was achieved by ferry J3, with amounts of 4.16E-09 tons of SO_2, 1.19E-09 tons of PM, and 5.99E-09 tons of CO, respectively. In the case of cumulative emission per passenger-mile, again ferry J3 achieved the biggest level of emission (5.45E-08 tons) as well, followed by ferry J2 (5.10E-08 tons), ferry J1 (3.10E-08 tons), and ferry R1 (2.40E-08 tons).

Ferry R1emitted the smallest amounts of NOx, SO2, and PM per passenger-mile although capacity utilization was far less than other ferries. It is expected that the emission of these pollutants per passenger-mile will be more favorable with the increase of its capacity utilization.

6 Conclusion

The analysis of air pollutant emission inventories from four passenger ferries in the Boka Kotorska Bay at the observed period of 1 year and for analyzed routes represents a first detailed study of the kind, knowing that Kotor and bay are under UNESCO heritage protection. The whole region is recognized by the high level of tourists' visits coming to a destination by cruise ships or by another landside transport mode. Besides the evident maritime activities in the bay, the domicile population is exposed to air pollution from ships, including passenger ferries that are transporting tourists from March to October each year in inner bay zones.

First, we started investigating the legislative framework at the international and national levels. The environmental concept is widely accepted, regulations are correctly ratified in Montenegro, and provisions of the laws are used in this chapter. Second, reviewing the approaches from the literature and having collected input data for the emission model in quantifying the emission inventories, the bottom-up approach has been selected as the appropriate one. We calculated the level of emission achieved by four air pollutants NOx, PM, SO_2, and CO during the ferries transportation at four routes in 2018. It is worth mentioning that we elaborated on one case of sulfur content in fuel having in mind the regulatory framework and situation in the field. The private operators are using fuel with no more than $S = 0.1\%$ m/m of sulfur, so we adopted the observations and maritime environment of this type of passenger transport from other studies in Europe and the US. The results showed that ferry R1, the largest of all ferries with respect to GT, transport capacity, engine power, and assigned to the longest route, emitted the largest amounts of NOx, SO_2, PM, and CO in total, as it would be expected as such. On the other side, it showed best emission performances when the emission of pollutants was brought down per passenger-mile. With its capacity optimization, emission of pollutants per passenger-mile could be more favorable.

Future researches can be directed to the optimization of the emission inventories along routes with the allocation strategy of ferries and fuel engine consumption (with a sulfur content of 0.001%). Also, the challenges in the new requirements for reducing ship emissions in the air available from January 1, 2020 can be very inspiring in the observation of regulatory requirements and technical solutions of ferries, especially in small regions such as Boka Kotorska Bay. Also, this and similar studies are emerging Montenegro to develop a concrete inspection policy in fuel and ship emission monitoring.

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Discourse Analysis of the Research Articles About Marine Environment Relating to the Adriatic Coast

Milena Dževerdanović-Pejović

Contents

Abstract Discourse analysis of the research articles about marine environment relating to the Adriatic coast reveals a variety of discursive features about marine environmental issues. There are many papers about marine biodiversity, uniqueness, and tourist attractiveness of the highly valued marine destinations along the Adriatic coast. The discourse analysis of the articles applied in this paper was aimed at establishing language peculiarities from surface to pragmatic level. Apart from the identification of the conventional structure of the research articles in this field, the paper also ran a qualitative analysis focused on the current questions about the Adriatic coast. In this paper, the research articles about the marine environment were used as a corpus for textual analysis. Based on theoretical knowledge of the critical discourse approach and genre analysis, the paper explored the academic research texts about the Adriatic coast. Employing Swales's moves model, the standardized surface structure of the research texts about the Adriatic coast was established. Description of data relied on the conceptual knowledge derived from the referent

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books about the marine environment domain. The results of the interdisciplinary approach in this paper outlined contemporary issues concerning the discourse community of the marine environment academics researching about the Adriatic coast.

Keywords Adriatic coast, Discourse analysis, Marine, Marine environment, Marine research texts, Maritime

1 Introduction

There are many definitions of genre in a linguistic sense regarding the standard linguistic features used by a specific discourse community. The notion of "family resemblance" [1] is used to point out to similarities in topics, form, and the content of genres. Linguist Swales [2] provided a fundamental notion in the studies of a discourse community. Swales put emphasis on the goals and objectives that the members of a specific speech community have in common. They are labelled discourse communities, and their members are connected with the same communicative purposes. Moreover, members of a particular discourse community apply specific discourse and communicative means in their language activities. Professional members, within their discourse fields, are familiar with genres they use in communication within their professional communities, by written or verbal media. In doing so, they use similar genres (notes, emails, reports, discussions, briefings, letters, articles).

Each specialized discourse community utilizes genres characterized by specific word forms, syntax, and morphological forms that might be incomprehensible to non-specialists. The most peculiar language signals of the subject experts' discourse are professional terms, phrases, and the rise of the new content-specific words.

According to Miller [3], genre studies are about relations established between patterns in texts and the social practices. More precisely, textual changes reflect changes in the world, and thus, genres are subject to changes. It is supposed that genres existing within the same discourse domain have drastically changed in form and structure because the social environment they reflect has also changed.

Given the social domain of this topic, the paper explores how linguistic changes mirror environmental changes in the Adriatic region. The pragmatic and social approach called for the knowledge of critical discourse studies. Van Dijk points to the interrelation between sociolinguistic factors and the way they manifest in a particular context in which language and discourse are employed [4]. Wodak also highlights the interdisciplinary view in exploring empirical data and a significant aspect of "the triangulatory" approach in the analysis of particular discourse event. These are historical, sociological, and psychological aspects that provide the grounds for the interdisciplinary approach [5].

Assuming that topics and structure of the research articles about the marine environment have substantially changed, the aspect worthy of analysis is how the rhetorics and discourse structure of these articles respond to external changes.

A growing number of stakeholders have become involved in marine environmental issues. These include environmental organizations, local communities, legal entities, researchers, and marine and maritime bodies [6]. As previously mentioned, the sociocognitive approach establishes the relationship between language and social environment: "When occurrences are interpreted as elements of dynamic and systemic developments, as anthropogenically caused or as posing management problems, the realm of environmental discourse is entered" [7].

Owing to its exquisite nature, diverse marine life, cultural and historical heritage, and the strategic position, the Adriatic Sea is seen as "an arena of high geostrategic importance in the changing geopolitical picture of Eurasia" [8]. Besides, the growth in commercial traffic and cruise ship calls to Mediterranean ports have drastically increased. All of this contributed to a considerable rise in the number of research articles, case studies, and projects related to the current issues concerning the environmental protection in the Adriatic coast.

Numerous research articles have shown a growing interest in the environment of the Adriatic Sea, but there have been a limited number of academic research papers regarding the academic discourse of this huge professional community.

The aim of the paper is to examine standardized organizational parts in the academic articles on the marine environment using a standard rhetorical move structure set by Bhatia [9, 10] and Swales [2]. Then, after the structural components of the papers were established, the focus was shifted towards general topics and emerging problems regarding marine life and marine species, biodiversity, marine pollution, and the role of legal and institutional organizations in the Adriatic region.

2 Methodology

Genre analysis of the marine research articles in this paper focused on the identification of distinctive discourse signals prevalent in academic writing about contemporary marine environmental issues. The written materials covered a broad range of topics regarding the aquatic species and marine life, marine pollution, maritime regulations, maritime policy, ship recycling, and marine spatial planning. In this paper, the research was "geographically" located on the Adriatic Sea region. The quantitative analysis of the academic research papers and the projects about the marine environment in the Adriatic coast was explicated by the subject-specific books published by Springer on marine environmental issues [6, 11–13].

A corpus of texts in English language comprised a total of 364 pages. In addition to 10 research articles [7, 8, 14–21] with 225 pages of text, published by the academics in referent journals, the corpus was complemented with 139 pages of texts from 2 case studies [22, 23] about the marine environmental issues in the region of the Adriatic. Firstly, the compiled texts were carefully read in order to obtain an

Table 1 Details of the corpus

Corpus description	Number of pages	Number of words
Research articles on the marine environment	225	35,105
Case study report about the Adriatic Sea	60	14,655
Blue growth trends in the Adriatic Sea	79	18,555
Total	364	68,315

Table 2 Moves in the academic articles about marine environment

Move 1	Background – setting the scene
Move 2	Indicating gaps and flows
Move 3	Presenting the research
Move 4	Presenting conclusions

overall comprehension of the dominant concepts of stakeholders in contemporary marine environment issues. Secondly, after gaining insight into the diversity of topics, the selection criteria in compiling the corpus were based on the four search words, *marine*, *maritime*, *environment*, and *the Adriatic*, as presented in Table 1.

Tables and graphs were removed from the corpus in order to retrieve precise quantitative data. For the sake of software scanning, the texts were converted to a textual file and processed in the textual analysis programme Textanz [24].

The mentioned programme used for the analysis of the texts in this paper enabled us to conduct a computerized method of the corpus processing. It facilitated the calculation of the frequency of the words, typical phrases, and context in which the searched word appeared.

3 Results and Discussions

The first part of the analysis explored a typical structure found in the academic articles about the marine environment in the Adriatic. The empirical analysis was based on the moves model set by Bhatia [9, 10] and Swales [2], who explored the academic research articles structure.

Based on the analysis of the academic articles making the corpus, a four-move model was established (Table 2).

3.1 Background: Setting the Scene

Move 1 – Setting the scene is a standardized part of the research articles. In our corpus, Move 1 is aimed at drawing author's attention to a specific problem. The idea that dominates Move 1 in our corpus is that the Mediterranean and the Adriatic present an area of a growing interest that should be in the focus of the academic research. Semantic choices confirming the uniqueness of the Adriatic coast are especially expressed by the words belonging to the semantic field of beauty, such as *distinct*, *precious*, *peculiar*, *desirable*, *specific*, *outstanding*, and *valuable*.

(1) "In recent times, many Marine Protected Areas throughout the Mediterranean area have been instituted for a very precise reason: to defend *beauty*" [14].

(2) "The Adriatic Sea, although a part of the wider Mediterranean region, has its own *specific* features and is considered a *distinct* marine sub-region. It is a narrow, semi-enclosed sea, formed as a gulf deeply incised into the European mainland" [8].

Background – Setting the scene is a standardized specialist's discourse strategy used to outline the uniqueness of the subject set forward by the conventional academic writing.

In addition to the presence of the adjectives indicating the exquisiteness of the Adriatic region, the marine environment stakeholders highlighted the decades-long clash between physical and human elements. The impact of the natural and human, that is, of exceptional synergy between the geographical and cultural components (example 3) prevails in Move 1. There is no doubt that the researchers in our academic texts agreed that numerous commercial human-initiated activities have placed the Adriatic among the most exploited and degraded regions, characterized as being "under siege" in modern times (example 4).

(3) "The Mediterranean Sea has a paramount role in both natural and human domains. In fact, it is both a hot spot of biodiversity and the cradle of western civilization, being a *crossroad* of three continents, having more than 380 million people living in the countries that form the basin, 146 million living directly on its shores" [14].

(4) "Because of intense pressure from multiple uses and stressors, the Mediterranean has been characterized as a sea "under siege" [23].

The idea of the overexploitation of the natural resources in the Adriatic made the standardized beginning of the articles about the Adriatic coast and was an introductory phase for the next Move 2 – Indicating gaps and flows.

3.2 *Indicating Gaps and Flows*

Move 2 – Indicating gaps and flows, as can be inferred from its name, is also an invariable component of the academic articles. This part is intended to introduce the main flaws of the previous research in the field and shortly present the author's intention in the paper [9]. In general, Move 2 – Indicating gaps presents the review of the previous literature on the subject. The communicative purpose of this move is to point out the lack of literature knowledge and insufficient research in the field and then to present the aim of the author's study.

The words that recurred throughout Move 2 were the phrases such as "gaps and flaws" and "weaknesses and stresses" (example 5). In 73 examples, the sentence highlighting flaws and gaps in the previous research was introduced by the contrastive connector *however* (examples 6, 7, 8) and with the phrases such as "lack of" (example 9). This, in most cases, underlined data insufficiency in exploring the particular subject.

(5) "The purpose of this study is to present in an efficient way possible positive and negative effects that maritime transport plays in the Adriatic Region. Likewise, this study aims at presenting the *weaknesses and strengths* of transport and will provide some ideas on where to constrain attention on enforcement of regional coordination and cooperation for the protection of the maritime environmental pollution in the Adriatic Sea" [8].

(6) "*However*, as explained above, the information contained in Fig. 3 should be carefully considered when dealing with a shallow, semi-enclosed, river dominated environment such as the Northern Adriatic basin. The mutual influence of lagoons and open seas in this coastal region is *not completely considered* in the modelling suite adopted, standing the relatively coarse numerical resolution" [17].

(7) "*However*, from national perspective these are mostly limited to the land-side of the coast and harbour areas" [12].

(8) "*However*, there is no homogenous framework concerning recreational fishing at the scale of the Mediterranean yet" [23].

(9) "*Finally*, the study showed that *lack of* biological and socio-economic data is an issue for many areas of the Adriatic, either because the areas are not covered by existing monitoring efforts or because national governments do not publically share all available datasets" [23].

3.3 Presenting the Research

Move 3 – Presenting the research is the longest and the most argumentative section of the academic articles. In this segment of our corpus, the academics wrote about the most critical aspects of the marine environmental issues regarding the Adriatic region. This move is, therefore, the body of the research papers and makes the core of the analysis. In this light, it demands a more detailed qualitative and quantitative examination.

Upon reading the texts making the corpus of our analysis, it was noted that the most frequent words were the adjectives *marine* that appeared 870 times and *maritime* that appeared 472 times.

The noun *environment* appeared 360 times and *environmental* 190 times. In order to get insight into the main contextual domains in the texts about the Adriatic region marine environment, the *Adriatic* was the fourth word searched for. It appeared 1,054 times in the text. Then, the analysis was focused on the characteristic discursive signals and the surrounding context in which the stated words typically occurred.

The authors of the analysed papers, whether "maritime-" or "marine-oriented", which will be elaborated in the following segment of the paper, had a common standpoint that the Adriatic region became commercialized, vulnerable, and exploited in terms of "marine life" and that it needed a "maritime" intervention.

In general, dominant concepts identified in our corpus refer to the geographic, cultural, aesthetic, and institutional problems. However, the general attitude found in the texts about the marine environment in the Adriatic is that in a geopolitical sense, it has been representing the area with the long and multicultural tradition, having in mind a variety of political conquerors who held dominance at sea.

The dynamic history of the Mediterranean resulted in close cultural and historical connections among the states belonging to the Adriatic area. Therefore, political and diplomatic managerial skills were needed to govern in such a complex environment. Each nation had a different management policy, meaning that the marine environment heavily relied on institutional decisions. Different nations and different policies had an impact on their manifold activities, and there was an unavoidable human impact on the marine environment [11].

Regarding this social or human factor involved in the marine environmental issues, the indicative discourse facts refer to the lack of legal unification among the coastal states of the Mediterranean. There is no harmony between political and legal regulations and establishments of a standardized framework [12]. The existence of research centres and marine centres in the Adriatic region, however, despite the historical turnovers and succession of the political masters at sea, resulted in a richness of data about water quality and marine life since the beginning of the last century [13].

3.4 Marine or Maritime?

In analysing the frequency of the terms *marine* and *maritime* in our corpus, the common terminological dilemma that maritime and marine professionals have been facing refers to the similar use of the two concepts. For example, in the Seafaring Dictionary [25], both terms are defined as “connected with” or “pertaining to the sea”, whereas the word “marine” also refers to the navy and trained soldiers or mariners. The more noticeable difference between the two concepts is given in the Oxford Advanced Learning dictionary [26], stating that the adjective *marine* means “connected with the sea and the creatures and plants that live there”, as in *marine biologists* and *marine life*. Likewise, the adjective “maritime” is defined as “connected with the sea or ships”, “near the sea”, as in *a maritime museum* or *maritime history*.

Therefore, it may be assumed that the adjective *maritime* is used in a broader and more commercialized context, indicating entities or activities based on shore. In contrast, *marine* refers to off-shore operations, sea, marine environment pollution, ocean-related issues, and underwater sea life. For instance, distinction in use between the two terms is evident in the example “maritime” in the word International Maritime Organization (the highest maritime authority dealing with seafaring and shipping) or the adjective “marine” in the Marine Environment Protection Committee (dealing with marine pollution) [27]. Additional examples illustrating the attributive use of “maritime” are the names of educational institutions as the World

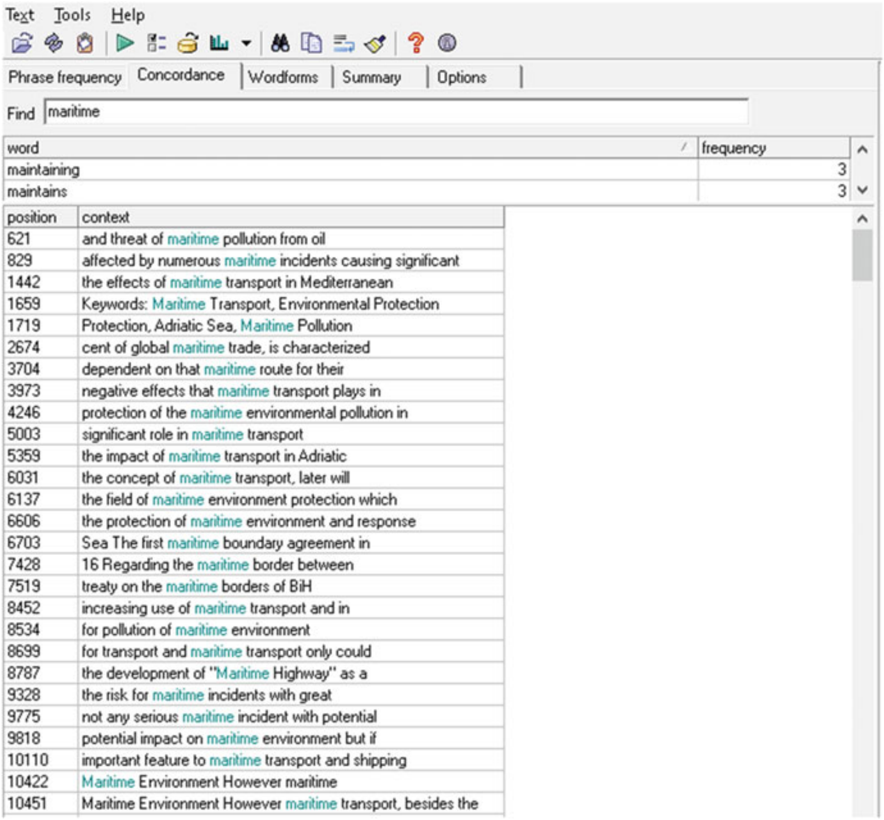

Fig. 1 Phrases with the word "maritime"

Maritime University, International Maritime Scientific Conference, Maritime Safety Committee, and Maritime Spatial Planning. In domain of legal issues, these are the phrases *maritime law*, *maritime jurisprudence*, and *maritime legislation*.

Concordance is a very analytical option that enables us to determine phrases that the central word forms or the typical surrounding in which it occurs (Fig. 1). The context in which the word appears is of valuable assistance in the research of the corpus of academic writing.

As said, the adjective "maritime" appeared 472 times in the text, and it formed 389 recurrent concordance lines. The ten most frequent are presented in Table 3.

There are other examples with "maritime": *maritime security* (18), *maritime management* and *maritime regulations* (10), *maritime boundaries* (11), *maritime sector* (10), and *maritime affairs* (10).

The most prominent concordance lines given in Table 3 infer that maritime surrounding is in the focus of the researchers' attention. The Adriatic region is seen as a sensitive *maritime environment*, described as a unique region. It stands on the crossroads of the important *maritime routes*. Currently, it records a significant

Table 3 Concordance lines with "maritime"

Phrase number	Concordance lines for *maritime* (more than 20 occurrences)	Number of occurrences
1	Maritime environment	45
2	Maritime transport	44
3	Maritime routes	43
4	Maritime pollution	40
5	Maritime incidents	33
6	Maritime planning	28
7	Maritime jurisdiction	22
8	Maritime domain	22
9	Maritime safety	21
10	Maritime borders	20

growth of *maritime transpor*t and an increased environmental threat to *maritime safety*. The Adriatic represents one of the most industrial regions that has been affected by many economic and environmental problems caused by marine pollution by noxious substances from the ships.

There is no doubt that the Adriatic coast is facing considerable ecological threats. In light of this, a general standpoint shared by the researchers in our corpus is about the evident lack of uniformed institutional and legal frameworks in the *maritime domain* and *maritime jurisdiction*. The researchers agree that significant improvement has been achieved by different umbrella acts such as the Integrated Maritime Policy or Maritime Spatial Planning acts regulating *maritime planning* and *maritime policy* [22].

(10) "Luckily until now there was not any serious *maritime incident* with potential impact on *maritime environment* but if it happens the separate operational response of regional countries to the incidents involving major spills it will take long time" [8].

(11) "Likewise, this study aims at presenting the weaknesses and strengths of transport and will provide some ideas on where to constrain attention on enforcement of regional coordination and cooperation for the protection of the *maritime environmental pollution* in the *Adriatic Sea*" [23].

Out of 870 occurrences, the word *marine* appeared in 587 concordance lines. The most common phrases are shown in Table 4.

As mentioned earlier in the paper, the main distinction between the terms "maritime" and "marine" is that the first refers to general issues in shipping mainly based on shore. In contrast, the latter term refers to *marine life*. Examples with fewer than 20 occurrences are *marine tourism* (16), *marine litter* (14), *marine debris* (10), *marine insurance* (10), and *marine habitats* (10).

The *marine environment* was the most frequently employed phrase of the researchers writing about the marine environment issues. It is the broadest or the most generic term used to denote various marine-related subjects, particularly the environmental and ecological issues dealing with *marine pollution*. Further, marine

Table 4 Concordance lines with "marine"

Phrase number	Concordance lines for *marine* (more than 20 occurrences)	Number of occurrences
1	Marine environment	121
2	Marine protection	88
3	Marine pollution	87
4	Marine life	60
5	Marine resources	42
6	Marine ecosystems	30
7	Marine waters	30
8	Marine biodiversity	27
9	Marine aquaculture	22
10	Marine populations	20

environment-related problems were in domain of *marine life* and *marine resources*, fish species, *marine animals*, seafloor protection, *marine habitats*, *marine aquaculture*, *marine biodiversity*, and *marine ecosystems*. The phrases covered by "marine life" are also *marine population*, *marine habitats*, and *marine species* (Fig. 2).

Therefore, having in mind distinction between the terms *marine* and *maritime*, the adjective "maritime" in the articles is taken as a broader term that implies sea or marine-related issues.

It is evident from Tables 3 and 4 (phrase number 1) that the researchers tend to use the phrases "maritime environment" and "marine environment" synonymously.

Nevertheless, the boundaries in the use of the two terms "maritime" and "marine" should not be set. To a large extent, the use of the two terms depends on the researcher's or specialist's point of view. The words "maritime" and "marine" are used in everyday discourse, and they are considered as "two sides of the same coin (or ship's hull)". What matters is which side of the hull, "marine" or "maritime", a specialist or researcher may choose [18]. The implication for such a linguistic choice is that the discourse of all parties involved in environmental issues could be analysed from the point of view of revealing the perceptions and attitudes of stakeholders engaged in the environmental issues [19].

3.5 Presenting Conclusions

The ideas presented in our research articles and projects about the marine environment in the Adriatic region were circled in the part Move 4 – Presenting conclusions. As expected, this part of the paper in academic writing is aimed at summarizing author's results elaborated throughout the preceding sections of the texts. Specifically, a discursive goal of this segment is to redefine the results, effectively and briefly, so that the author is not repetitive in this intention. As regards the pragmatic content of the conclusion in the articles about the marine environment in the

Fig. 2 Phrases with the word "marine"

Adriatic, the authors left space for further investigations in the field. The authors in this way implied that further investigations required a symbiosis, and the joint research of many stakeholders involved in marine and maritime domain (examples 12, 13, 14).

The use of hedging discourse, when the authors hesitate to give final assumption about the topic in question, is usually obtained in such a way that the authors offer several solutions about the topic in question. This discursive strategy is aimed at inferring possible activities and future investigations.

In our corpus, this was achieved by a notable use of modals, especially of the modal *should* which was found in 72 examples, whereas the modal *could* was found in 70 sentences. This meant that the authors left space for future investigation scenarios and projects (example 14).

Also, the use of modals *could* and *can* in our corpus imply that activities in the marine environment, particularly in marine biodiversity domain, require a lot of planning, modelling, observations, and predictions. In general, these researches bring interaction of many factors, along with data collection from the sites of exploration, sampling, simulations of real-world situations, and, finally, the analysis of the bioeconomic effects [12].

(12) "The unification of the regional law framework for response to maritime pollution and the drafting of common regulations is one of the most important steps *that should be taken*. This *would make possible* the ability of all regional countries to use the same laws and regulations for the common goal the protection of common Adriatic Sea from Pollution including the simplification of the cross boarding procedures and diplomatic clearances" [22].

(13) "The produced risk maps *can* be useful for the definition of adaptation plans aimed at reducing the risk in the considered region. In particular, in addition to the possible adaptation measures that were previously listed, some actions *could be taken* in order to improve the quality of marine coastal waters. In particular, the control of river discharges into the sea *could be imp*roved by reducing the discharge of nutrients and eutrophication-inducing substances through the construction of wastewater treatment plants" [17].

(14) "This framework for scenario evaluations *can be used* to identify efficient fishing spatial planning, which then serves as the starting point for stakeholder involvement in the design, advisory, and decision process" [22].

The conclusion reached is that there are many stakeholders involved in the marine environment-related topics in the Adriatic region. Still, a need to join managing institutions with a scientific community in marine and fisheries protection is of vital importance. These attitudes are triggered by the fact that marine environmental issues have become, more than ever, dependent on the integration of the involved stakeholders (examples 15, 16) and the need for "regional coordination and cooperation" [8]. It can be assumed that the Adriatic region legal policy is rather uneven and as such poses a problem in laying down uniformed standards in international shipping. This is, to a great extent, the consequence of the existing differences in national and regional regulations. Therefore, the accent in the analysed papers is placed on the common goals and efforts of the countries belonging to the Adriatic coastline (example 16).

(15) "The cooperation among MPA managers, through the formation of an extensive network, and *the collaboration* with the scientific community to solve both specific and general problems regarding marine protection, are the key to taking proper advantage of this unique occasion to protect the sea" [14].

(16) "We are far from having the silver bullet able to solve all issues and bring the Mediterranean close to the 2020 target, but surely there is a very evident need for a *common effort* from all the parties involved. Regionalization has been put forward as one of the focal points of the new CFP" [15].

The Adriatic region has become a subject of the intensive research due to vulnerability and the rise of impacts that have accelerated the loss of marine habitats, negative impacts on the water quality, biodiversity, and aquaculture. After reading the conclusions of the analysed texts, it was assumed that from a standpoint held by either the academic researchers or project designers, the region of Adriatic needs a much more inclusive research and the promotion of national and regional cooperation towards "social, economic and environmental sustainability of the region" [27]. Specialists in this field insist that the laboratory-focused activities should be expanded to cover external factors and include as many institutional stakeholders as possible. Besides, the practical activities and on-scene work have to be coordinated, and there should be an increased awareness about the importance of the prevention of pollution and preservation of the underwater life [28].

Using the first pronoun *we* in writing, the researchers left space for further on-scene investigations relating to the marine pollution exponents (example 17). In addition, apart from the mentioned first-person pronoun (we), the linguistic markers of the impersonal writing are *believe*, *think*, and *find*.

(17) "*We think* that additional initiatives for increasing awareness are necessary, together with the prevention of sea pollution and regional approaches, to deal with the problem of marine litter" [20].

There is no doubt that the above assumptions confirm the previously mentioned interrelation between geographic reality and governmental roles. This calls for the integration between marine and maritime environment stakeholders and "complex regional responses to the uses of the sea" [21].

4 Conclusion

The approach taken in this paper has combined the knowledge of discourse analysis in the research articles about the marine environment in the Adriatic. The analysis has shown that there is a consistent interrelation between marine and maritime aspects. For this reason, the two terms were first explained from the language standpoint. Then, the view of the stakeholders in the field was presented.

From the methodological point of view, the paper was focused on the quantitative and qualitative aspect of analysis. The presentation of the typical organizational structure of the marine environment articles was based on the moves models. It was established that the subject specialists in the marine environment field complied with the conventional text organization used in the academic writing. Also, the specificity of the topics and problems involved in preserving the marine environment in the Adriatic was revealed using the quantitative tools that helped to calculate the frequency of the searched terms (*marine*, *maritime*, *environment*, *Adriatic*). Central values and concepts were then supported by the literature knowledge derived from the books on marine environment in the Adriatic.

It was undoubtedly established that the discursive analysis of the marine research articles and projects on the Adriatic region brought similar conclusions. There is a common standpoint that the Adriatic region presents a unique destination characterized by specific geographic position and rich cultural and historical heritage.

Also, important findings of this paper are that the region of Adriatic has a recognizable synchronic and diachronic identity and that there is a reciprocal relationship between human and natural factors. Marine resources have become overexploited owing to the rise of sea traffic and the cruising industry. There is a need to shift the focus from in-laboratory marine research to social and economic impacts as well. Also, there is a rising need for unification of the maritime spatial planning, state regulations, and clearance procedures connecting the Adriatic states.

As stated at the beginning of this article, discourse is a reflection of social and cultural relations and reveals the implications of interdisciplinary subject fields. In that light, the research in this paper has revealed that marine environment in the Adriatic coast possesses valuable and specific natural resources that have come into scientific focus owing to the external factors threatening to ruin its historic status.

In this sense, this paper could be a base for further elaboration of discourse-based research, having in mind the rising number of stakeholders interested in marine environmental subjects. Discourse-oriented research might help to establish communicative practices of numerous marine environment participants – in terms of how discourse displays their attitudes on contemporary issues (marine biologists, marine researchers, local communities, marine institutes, and research centres).

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Coastal Towns and Settlements of the Montenegrin Coast

Svetislav G. Popović

Contents

Abstract Certain typological urban and architectural complexes of coastal towns and settlements have been elaborated through this paper, which are characteristics as topics in the given cases and do not depend on regional individualities. The diversity and stylistic specifics of the coastal towns are a reflection of civilisational migrations through time and space. The examples of the coastal towns and settlements provide appropriate guidelines for the sustainability of traditional and original architecture. The morphological phenomena of construction in the spirit of originality are observed through the two examples of the houses of the Bay of Kotor and the Paštrovići.

Keywords Adriatic Sea, Categorisation, Montenegro, Settlement, Typological coastal town

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1 Introduction

The territory of Montenegro consists of the following three areas, which are recognisable by their natural and cultural features:

- I Coast (Southern Region) (Fig. 1)
- II Karst Area with the Zeta and Bjelopavlići Plain (Central Region)

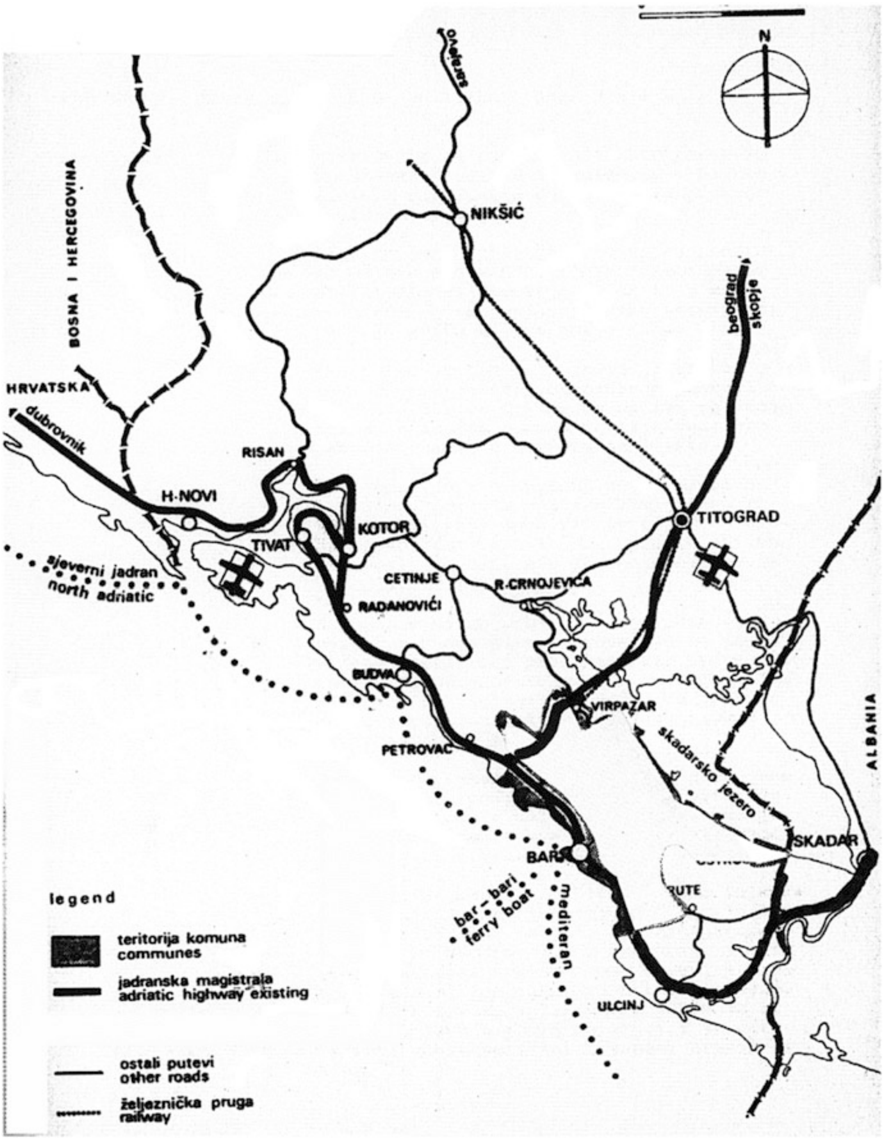

Fig. 1 Map of the Adriatic Sea with the coastal towns [1]

- III Area of High Mountains and River Valleys (Northern Region)

Six municipalities belong to the Montenegrin Coast: Herceg Novi, Kotor, Tivat, Budva, Bar and Ulcinj and they constitute the backbone for the development of the Coastal Region and Montenegro as a whole. According to the 2011 Monstat Census, 149,705 inhabitants lived in this area, which is 23.9% of the total population of Montenegro.

The towns and settlements in the Coastal Region offer a picture of preserved and protected urban complexes, and therefore it is necessary to insist on urban organisation of space around the existing nucleus, as well as integrating the coastal towns with the hinterland.

The natural conditions are subject to change and are endangered by development itself, and this requires strict control of land use and protection of all potentials.

2 Coastal Region

The Coastal Region is a part of the territory of Montenegro that is located in the south-western part of the country, at the geographical coordinates of 42°09′59″ North latitude and 19°00′12″ East longitude. It stretches from the entrance to the Bay of Kotor (Cape Oštro), to the estuary of the Bojana River into the Adriatic Sea in the total length of 316 km (of which the coast makes 249.1 km). Towards the hinterland, the Coastal Region forms a narrow coastal belt, only 2–3 km wide, limited by the longitudinal mountainous and steep limestone rim of the mounts of Orjen, Lovćen, Sutorman and Rumija, which rises 900–1,000 m above the sea level.

The area of the Coastal region is 2,440 km^2, which is 17.7% of the territory of Montenegro. The final point of the Coastal Region in the south is located on Ada – Sveti Nikola, not far from the Albanian border, and the final point in the north is near Crkvice in the area of Krivošije, north from the Bay of Risan. The westernmost point is located in the rural area of the village of Sutorina, west of Herceg Novi, and to the east on the Bojana River east of Šasko Lake [2].

The Coastal Region lies between the state of Croatia, with which it shares the state border in the length of 18 km, and Bosnia and Herzegovina to the west and Albania to the southeast. It borders Italy across the Adriatic Sea in its widest part (about 200 km). The inland waters belong to Montenegro, the territorial sea that stretches 12 nautical miles (22,224 m) from the inland waters line (connecting the final points of the capes along the coast), and on the outer side of that line is the free sea.

The Montenegrin Coast is located in the south-eastern part of the Adriatic Basin, which forms the dividing line between the Eastern and Western Mediterranean. This position places the Coastal Region within the Adriatic and Mediterranean macro-region. The distance from Bar to the Strait of Otranto, which separates the Mediterranean from the Adriatic Sea, is 180 km, thus provides it a position that allows direct maritime connection with all Mediterranean and world countries. The openness of the waterway to the Mediterranean and further on makes the Coastal Region a potential transit region for the wider hinterland of the Central Balkans, Central and Eastern Europe.

However, the mountain massif in the immediate hinterland of the Coastal Region represents a barrier that makes this region relatively isolated from the continent.

2.1 Regional and Landscape Characteristics

When talking about the regional and landscape characteristics of the area (Fig. 2), the joint potential of the entire Coastal Region consists of the following:

- Morphologically attractive terrain,
- Hard leaved evergreen bushy Mediterranean vegetation that is the most widespread on the coastal slopes facing the sea. The degraded macchia ecosystems are followed by pseudo macchia that practically stretches from the seashore to the heights of 300–400 m,
- Richness of the regional elements of high landscape values and degree of preservation,
- Natural heritage sites and areas,
- Cultural heritage sites and areas,
- Natural rarities (specific plant communities and distinctive specimens and groups of flora, including rare, very old, endemic and endangered plant species),
- Green eco-corridors that connect the urban greenery with the natural landscape, i.e. the green areas of the hinterland,
- Shore and landscape along the coast (lungo mare),
- Urban units and strings of small settlements along the coast with urban greenery, old parks, squares, gardens, etc. [4].

Several different types of landscape character can be noticed in the Coastal Region, from the cultural landscape of settlements (of a compact and broken type), over agricultural landscapes (settlements with traditional agriculture in the fields, settlements with traditional agriculture on terraces), to the landscape types that have natural and semi-natural landscape features (karst slopes on massive limestone, wooded hills on flysch and diluvium, hilly terrains on layered and softer limestone with sparse vegetation, as well as limestone terrains with typical Mediterranean vegetation and flooded and coastal alluvial plains).

Apart from the mentioned types, what makes the Coastal Region recognisable are the characteristic landscape elements and landscape patterns/benchmarks where, by the sea, low and steep rocky shores and reefs, islands and beaches certainly dominate. Certain regularity has been observed, settlements with traditional terraces occur mainly on gentle slopes on flysch terrains and deluvium, and to a certain extent they are followed by settlements with traditional agriculture in the fields. To a lesser extent, settlements with agriculture on terraces are present on layered and flat limestone terrains and these are mainly olive groves. A specific type of agriculture

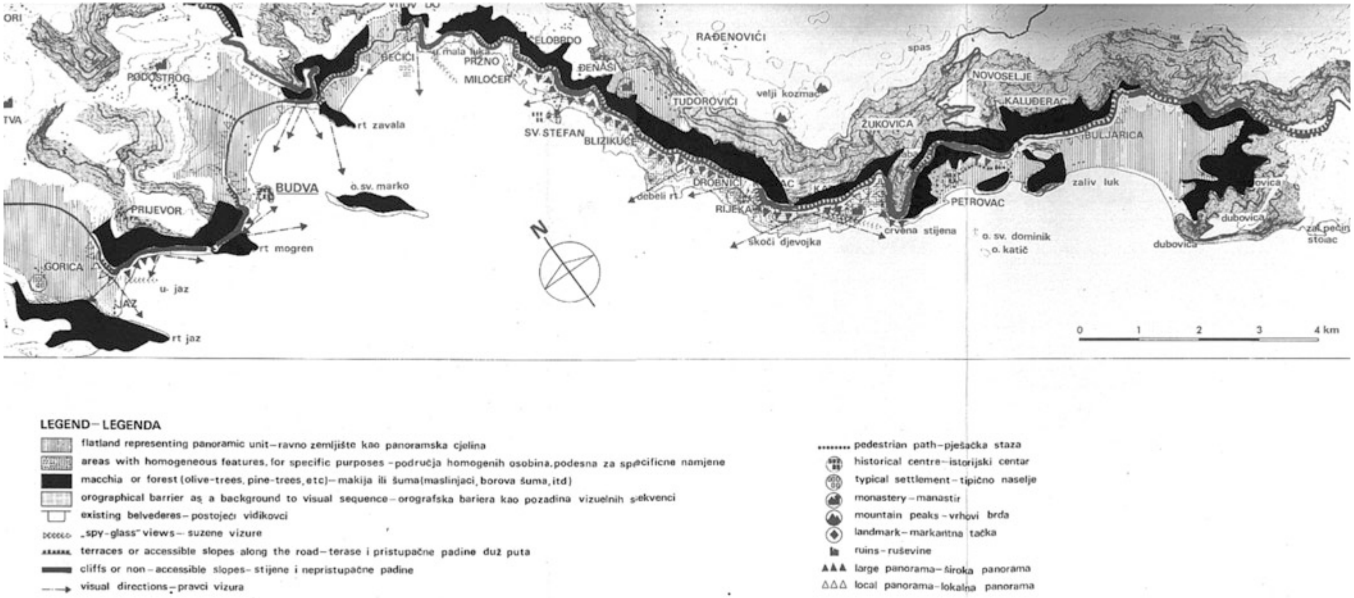

Fig. 2 Landscape analysis – scenery values in the Budva region [3]

with fields has been recognised on fluvial glacial deposits and moraines in the area above Herceg Novi in the zone of pure karst.

In the zone of 1,000 m from the shore, a more detailed categorisation has been made and the following landscape character types have been singled out: green and free areas in settlements (parks, squares, tree lines and remnants of forests and natural vegetation in settlements), larger tourist complexes, sports and recreational areas, cultural heritage – old town centres, churches, monasteries, fortresses, Lungo mare – developed coastal promenade and an airport. In this way, the structures in space that stand out for their uniqueness and significance are recognised. Therefore, within the built structures, smaller or larger park areas, squares, sports terrains, larger tourist complexes and the like are the bearers of the identity and recognisability of the settlement itself and thus have a greater value.

2.2 Sea Aquatorium

The aquatorium of the Adriatic Sea opposite the Montenegrin Coast, which is about 200 km wide, is part of the Southern Adriatic Basin in which the greatest depths of the Adriatic (1,340 m) have been measured. It differs from the other parts of the Adriatic Sea by the largest water mass (26,000 km^3 of the sea, out of 32,000 km^3) and by stronger direct exchange of water with the Mediterranean Sea. This inter-basin exchange, which is carried out through the submarine (Otranto) entrance, which is 741 m deep, has a great impact on the open and coastal waters of the Southern Adriatic, including the waters along the Montenegrin Coast.

The Bokokotorski Bay (Fig. 3), composed of the outer (Herceg Novi), middle (Tivat) and inner (Risan-Kotor) part, is the most indented part of the shore of the Montenegrin Coast.

The average depth of the entire Bay is 27.6 m, and the average depths in the individual bays range from 27.0 m in Kotor, 25.7 m in Risan, 25.5 m in Tivat, to 31.0 m in the Bay of Herceg Novi. The maximum depth in the Bay of Kotor is 52.0 m, in Risan 36.0 m, in Tivat 47.0 m and in Herceg Novi 60.0 m.

Two steps are distinguished in the relief of the seabed of the Bay: the shore and the continental shelf. Given the structure and vertical spreading of the coastal part of the mainland, in most parts of the Bay there are no beaches, but the rocky slopes of the steep sides descend from the very surface of the sea to the very bottom.

The sea aquatorium from the Bokokotorski Bay to the estuary of the Bojana River leans on the shore of Coastal Region, which is mostly rocky and with well-formed cliffs, while in the far south-eastern part is low, sandy, partly of a lagoon-like type and is more strongly influenced by freshwater from the mainland (Fig. 4). The shelf area (continental floor, up to a depth of 200 m) at Cape Oštro is at 9.5 NM from the shore and at the estuary of the Bojana River at 34 NM. The total shelf area is 3,300 km^2. From the shelf boundary, the seabed descends towards the South Adriatic Basin, where the greatest depths of the Adriatic have been measured (Fig. 5).

Fig. 3 Morphology of the Bokokotorski Bay – 3D view (https://maps-for-free.com/#close)

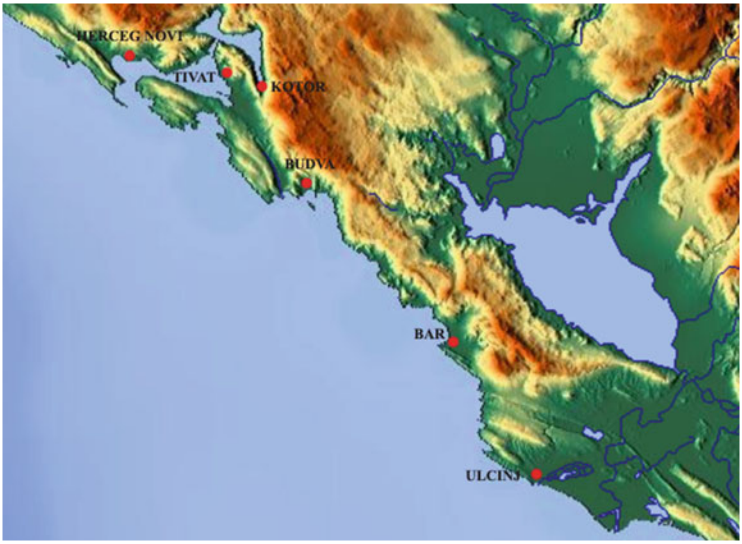

Fig. 4 Morphology of the Montenegrin Coast – 3D view (https://maps-for-free.com/#close)

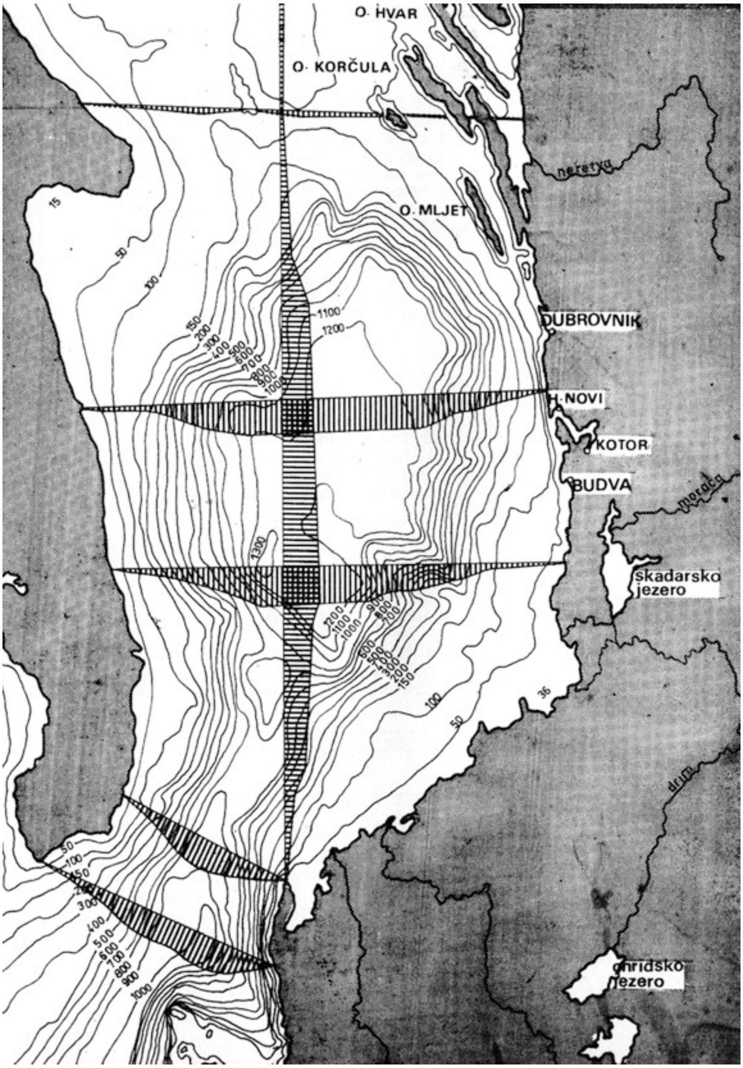

Fig. 5 Morphology of the Adriatic Sea [5]

There is no closer data on the relief of the seabed along this part of the coast, except for part of the aquatorium that gravitates towards the shores of the municipality of Ulcinj (based on research carried out by the Institute of Marine Biology – Kotor), where the shore and shelf, i.e. the littoral ring (up to 200 m in depth) and the initial part of the bathyal system are clearly developed. The shore is a narrow belt of the seabed, which lays between high and low waters and thus has an amphibious character, because during high tide it is covered by the sea, and during low tide it remains above the sea level. This zone is highly exposed to the mechanical action of seawater and is characterised by frequent and periodic changes in the physical and chemical conditions of the environment. The beaches of Ulcinj are typical representatives of a developed shore. The shelf or littoral system is a part of the seabed, which continues on the shore, usually with a slight fall, and extends into the aquatorium in front of Ulcinj to a depth of about 200 m. In the physical structure of the seabed there are three main and well-developed types – rocky, sandy and muddy bottom – whose particles are of terrigenous (terrestrial) and pelagic marine origin.

3 Montenegrin Coastal Towns

The Montenegrin coastal towns were created in direct interplay with the environment, such as:

1. Interplay with the coastal towns along the entire Adriatic Coast,
2. Interplay with the towns and settlements of the continuous part of Montenegro,
3. Interplay with the at that time already routed network of roads along which trade caravans travelled,
4. And most importantly, by adapting the choice of locations for the coastal towns and settlements of Montenegro to the morphological conditions that the coast provided,
5. In the end, the role of the (so-called) micro-location had a decisive influence, as the main attractive force by which the towns and settlements of Montenegro were located [6].

In the area of Montenegro, the most important construction structures are located at the Montenegrin Coast.

According to the period of origin, the medieval towns in Montenegro are divided as follows:

– The towns that were created before the migration of the people and then in the Middle Ages they were expanded and significantly repaired and represent medieval structures.
– The towns that have not been fundamentally changed and also represent medieval structures.
– The second division is division by purpose and character, i.e. by internal facilities, and is as follows:
– Large towns of the Montenegrin Coast that unite a large number of inhabitants and protect them with their ramparts and walls from the external enemy.
– Towns that have a military character and represent small fortifications with military units and more often they have the residence of one feudal lord.
– Towns, i.e. established units that have a church character and these are mostly fortified monastery complexes [7].

3.1 Typologies of Coastal Towns and Settlements of Montenegro

Typology based on the character, degree and type of urbanity can be classified in the Basic level, Secondary level and Tertiary level of categorisation. The Basic Level consists of: coastal towns, coastal urban settlements, coastal villages and coastal habitats and dwellings. The Secondary Level of categorisation can be made according to the type of "fortification" of the settlement structure, which is reflected in the type and form of fortification of the core, whereas the following types are recognised: fully and completely fortified towns and settlements, partially fortified towns and settlements, non-fortified towns and settlements and specific forms of settlements (free towns). The Tertiary Level of categorisation of the coastal towns and settlements of Montenegro can be made according to their position in relation to the sea, namely: island towns and settlements, peninsular towns and settlements, coastal towns and settlements close to the sea, coastal towns and settlements with different distances from the sea, hinterland towns and settlements in the coastal hills.

Finally, we should also mention the other possibilities of categorisation of types of coastal towns and settlements of Montenegro, such as types of coastal settlements and towns of Montenegro according to the height position at which the coastal towns and settlements are located (in a valley, on a plateau, on a hill, etc.), according to their main activity such as trade, military, administrative, agricultural and according to the specific role they have, such as monastic coastal towns and settlements, church settlement structures, as well as according to their position in relation to the sea (protruding towards the sea, indented in relation to the sea) [8].

3.2 The Location of Coastal Towns and Settlements of Montenegro

The location of the coastal towns and settlements of Montenegro is the result of the contextual environment of the towns and settlements, i.e. the territory immediately around them and the morphological conditions.

3.2.1 Ulcinj

The old town of Ulcinj (Fig. 6) is located on a peninsula so that with its position it "controls" and observes access from the sea. Moulding of the town is completely consistent with the physical morphology of nature. In the background is a hilly morphology, while between the settlement and the town there is a flat part. The town is located on a large and not very hard compact cliff by the sea. The upper surface of the cliff on which the town lies is inclined towards the sea, so that the lowest parts of the walls and one tower are located almost on the shore [10].

a) b)

Fig. 6 (**a**) Aero photo of the urban space of Ulcinj [9]; (**b**) Vision of Ulcinj (photo montage by Krekic)

a) b)

Fig. 7 (**a**) Aero photo of the urban space of New Bar [11]; (**b**) Urban space of New Bar (photo by Bakovic)

3.2.2 Bar

The Old Town of Bar (Fig. 7) was developed in a triangular area that is protected from the east and south sides by vertical cliffs and defensive walls. At the far northern part there was a mighty fortress, known as Tatarovica, located on a high plateau in the hills above the sea, form which at the same time one could observe and control both the open sea and even more the surrounding territory. The town expanded with the change of rule, and during the Venetians the street network is irregular, although some regularity can be sensed in the oldest south-eastern part. The Old Town of Bar, as an important urban entity of the medieval town type in Montenegro, is located about 3.5 km northeast of New Bar [12].

3.2.3 Budva

Positioning of the town of Budva (Fig. 8) is based on the selection of a key point from which complete "control" of sea access is possible considering the entire Bay of Budva, Bečići and Rafailovići. The town itself protrudes towards the sea in the form of a natural or artificial peninsula, as if it lies with its entire town structure "on the sea".

3.2.4 Tivat

Tivat is a settlement that in contemporary conditions has grown by its size into one of the most important centres of the Montenegrin Coast, especially since the airport was built (Fig. 9). Tivat itself began to develop as a town only at the end of the nineteenth century, when the naval port of Arsenal was founded. At the time when Tivat and other coastal settlements were formed, it was located along by the shore and the first streets that were created ran parallel to the shore in length and acquired the character of the main streets. Secondary streets were formed perpendicularly to the sea and connected to the "main" longitudinal streets. At a later stage, the town also began to expand in depth, towards the surrounding hills, so that these streets were connected to the previous longitudinal ones, adapting to the natural morphology of the hills. Along the typical streets, both towards the sea and towards the hills, the houses lined up in the form of "clusters" and thus formed an urban matrix.

3.2.5 Kotor

Kotor (Fig. 10) is the largest medieval town in Montenegro. The position of Kotor at the very end of the bay is remarkable for a port sheltered from all strong winds,

Fig. 8 (**a**) Aero photo of the urban space of Budva [13]; (**b**) The ambience of the urban space Budva (photo by Krekic)

Fig. 9 The ambience of the urban space of Tivat, Porto Montenegro (photo by Krekic)

Fig. 10 (**a**) The ambience of the urban space of Kotor; (**b**) Segment of the street in Kotor (photo by Ilijanic)

therefore this, with rich freshwater sources and smaller arable land nearby, was probably one of the most important reasons for formation of the first settlement. The example of Kotor best shows how all possible natural conditions for setting up of a town and its defence have been used to the maximum. Apart from its position by the sea, its lower part is the area between two rivers, the Škurda River from the south and the Gurdić Spring from the north, while the upper part of the fortification is at the top of the inaccessible cliff of the hill Sv. Ivan (260 masl), which is separated from the Lovćen massif by a deep fault. Kotor was divided into upper and lower Kotor. The Castle of Sv. Ivan is called Gornji Kotor (Upper Kotor), and the lower one is the current inhabited complex within the walls. The lower part of the town was located along the almost vertical cliffs of the hill and around the Cathedral of St. Tripuna [14].

3.2.6 Herceg Novi

Herceg Novi (Fig. 11) is the centre of the municipality of the same name, which stretches from the border crossing Debeli Brijeg to the narrowest part of the Bokokotorski Bay (Veriga Strait – 300 m wide). Around the town are Mount Orjen, the hills Dobroštica and Radoštak and the Luštica Peninsula with the highest peak Obosnik. The base of the Old Town has the shape of an irregular triangle. From the northern corner of the Kanli Tower, two town walls extend: one to the Forte Mare Fortress, along a route that deviates slightly from the north–south direction and the other one towards the southeast, with several polygonal towers. On this basis, another smaller triangle was added on the east side. The distance between the outer corners of Kanli Tower and Forte Mare is 360 m, and along the second rampart is also 360 m, while between these two directions by the sea the distance is 180 m. The smaller triangle to the east has sides of 180 m and 170 m and a base of 100 m. The inner area of the Old Town is divided by a transverse wall. The remains of the middle town perimeter on the south side, with a defensive watchtower, represent the final southern perimeter of the earlier phase of the town's development. By adding the southern perimeter of the town on the shore in the sixteenth and seventeenth centuries, the old southern rampart remains in the town's tissue [15].

3.3 Coastal Settlements of Montenegro

The coastal settlements to which the larger urban settlements of Risan, Perast, Petrovac, etc. and the smaller settlements of Gornji Stoliv, Dobrota, Krašići, Brca, Sutomore, etc. certainly belong occupy their position according to the following priority characteristics: they are located by the sea (if possible by the seashore), they are formed along the "slope" which falls slightly towards the sea, they occur in the form of "terraced" structures along the slope and parallel to the sea and fully follow the terrain morphology.

Fig. 11 (**a**) Forte Mare Fortres; (**b**) The ambience of the urban space of Herceg Novi (photo by Ilijanic)

The basic and initial characteristic of the coastal villages is their connection to all the advantages of the sea, as well as to their accessible continental part – the hills. The main reasons for such a balanced relation towards the sea and the hills are of an existential character, which means that they wanted to "draw" all the advantages offered by the sea (such as the possibility of fishing) and all the resources offered by the hills (such as agriculture and livestock breeding). In that sense, in relation to the position towards the sea (and the hills), there are three categories of coastal villages. Fishermen's villages that were located "right" by the sea, along the coast, including the littoral and part of the land of the hills in the village hinterland. Rural coastal "agricultural habitats and farms" that were created "close enough to the sea" to be able to easily reach its resources and located "far enough" in the "centre" of the territory that they could cultivate. In that sense, it can be said that they developed "in depth" in relation to the coast. "Mountain villages" are villages that originate in the "hill" zone, directed primarily towards agricultural farming and "close" enough to be able to reach the seashores on foot "during the day". They are usually located on hilly plateaus or in valleys [16].

3.4 Common Typological Characteristics of Houses at the Coast

The general type of a house within the frame of the Montenegrin Coast is a storey house (ground floor, first floor and attic) with stone walls and an oblique double sloped roof, covered by hogs-back tile "ćeramida". The house often appears as a part of the residenti alline, where the segments of the line keep the same construction line and basic elements of the constructing language (Figs. 12, 13 and 14). The ground

Fig. 12 Coastal settlement Gornji Stoliv (picture by Petrovic)

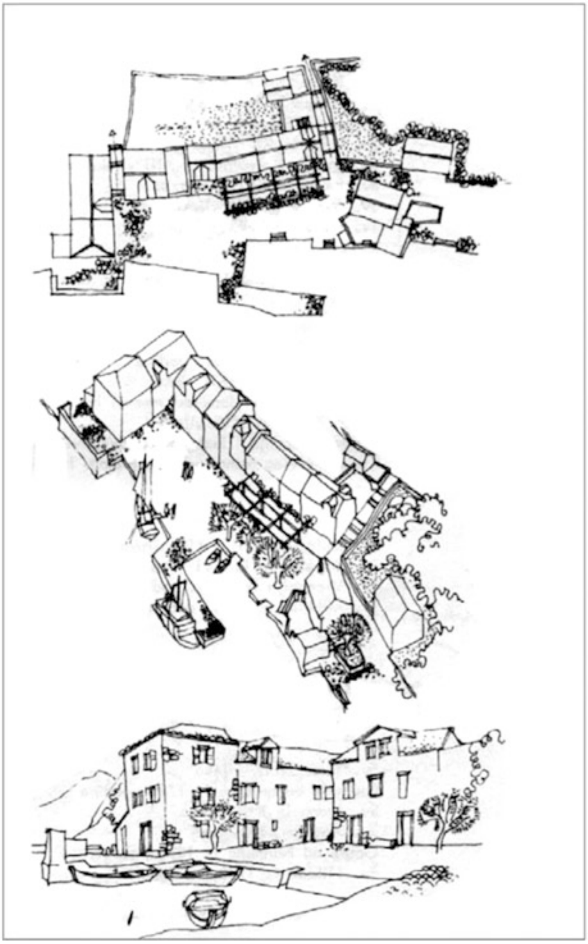

Fig. 13 Typical organisation of settlements on the coast in Orahovac (picture by Petrovic)

floor has the function of a cellar storey (cellar). The first floor has a residential function (rooms), and in the attic there is a kitchen, because a chimney was not used. The development variety is transfer of the kitchen in the garden as an overbuilt facility. The entrance is through the terrace – fenced terrace in the level of the ground floor or terrace “na volat” in the level of the first floor with outside stairs.

A house of the Bay of Kotor – particular typological distinctiveness of the houses in the Bay of Kotor represents the roof dormers “vidjelice”. Usually, small double sloped roofs above “vidjelice” sometimes become a special transversally placed roof, whose ridge is higher than the main ridge of the house. As a functional distinctiveness the use of space under the archon on which the terrace is placed as a tank for collecting and keeping rainwater (“bistijerna”) is distinguished.

Paštrovska house – the main element of distinctiveness of architecture of the Paštrovska house is a single sloped roof. The reasons for forming and keeping such a

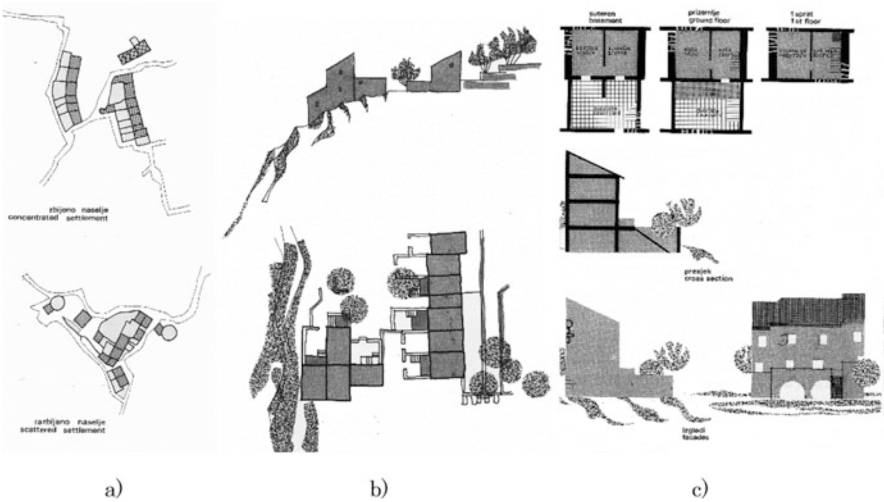

Fig. 14 (**a**) Types of settlement, (**b**) structure of the rural old settlement of Srzentić Krš, (**c**) typical Paštrovska house [17]

roof form are connected with allied functional reasons and the local terrain morphology. A single sloped roof, which is approximately parallel to the slope inclination, is characteristic for the houses placed along the contour lines, which creates an obstacle for damaging the back wall of the house by rainwater flow. Double sloped roofs are connected with locating the house vertically on the contour lines. In line with the construction response to the local relief conditions, elongated double sloped roofs appear – on lined houses with a joint ridge and double sloped roofs with a saw-tooth (shed roof) silhouette – on lined houses connected among each by the longer base sides [18].

4 Conclusion

The presented typology of the coastal towns and settlements of the Montenegrin Coast can serve as an example for spatial planning and for forming the conditions for construction and reconstruction in the subject area. Traditional experience warns us that we need to adhere to the typological elements that are present in the urban and architectural composing of space that is best seen in the rows, groups or clusters of houses that are incorporated into the existing morphology of the terrain, with which they form an integral whole.

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Tourism in Budva, Bar, and Ulcinj Area of Montenegrin Coast

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Contents

Abstract Budva, Bar, and Ulcinj Riviera have great potential for tourism development thanks to rich cultural heritage and natural attractions. Significant improvements in tourism development were made during the second half of the twentieth century. This development was briefly halted by a devastating earthquake in 1979, which was followed by reconstruction and further development. During the last decade of the last century, due to conflicts in the former Yugoslavia, tourism began to stagnate.

According to the Master Plan for the Development of Tourism of Montenegro by 2020, all three municipalities observed had great potential for the development of sustainable tourism. However, the plan has not been implemented to a significant extent, and sustainable development has been affected by numerous issues, which have been present over the past two decades.

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The current situation in tourism is characterized by a summer season of only 3 months, inadequate accommodation structure, underdeveloped transport accessibility, dependence on two outbound markets, overbuilding of rental apartments, grey economy…

Inadequate tourism development management has resulted in the devastation of space, decreasing quality in tourist offer, mass tourism development focused in particular on outbound low-income markets, and lower occupancy rates.

The potential for further development is seen in taking appropriate actions and addressing these issues, focusing on the principles of sustainable development and developing of tourism aspects that are equivalent to it. The valorization of cultural heritage, the conservation of nature, and the development of tourism in rural areas provide a chance to improve the tourism offer and further development sustainable in the long term.

Keywords Bar, Budva, Coastal zone, Development potential, Montenegro, The Adriatic Sea, Tourism, Ulcinj

1 Introduction

Tourism development is determined, above all, by natural and geographic characteristics, as well as cultural heritage, along with the appropriate development and engagement of human factors. From a geographical perspective, the most important is the concentration of natural resources and the diversity of offers in a small geographical area. Coastal tourism is a form of tourism, based on which Montenegro designed its offer, for the most part, in previous decades. The basic assumption that coastal tourism is based on is the use of the resources of the sea, which consist of: beaches, sea aquatorium, submarine area, marinas, ports, and docks. While the emphasis in the tourist offer was placed on bathing tourism, coastal tourism comprises several segments, at different developmental and valorization levels in Montenegro, which are: nautical tourism, sports at sea, cultural tourism offers, and various events.

The potential for tourism development in the area of Budva, Bar, and Ulcinj Riviera is large. This area is characterized by beautiful beaches, the proximity of the sea and the hinterland, rich cultural heritage. However, the resources available are not adequately utilized. Although rich in natural and cultural values, providing an extraordinary basis for sustainable tourism development, this area has faced numerous challenges in recent decades.

2 Natural Attractions of Budva, Bar, and Ulcinj Riviera

The Municipality of Budva covers the central part of Montenegro's coast, covering an area of 122 km^2. To the north-west, it borders the Municipality of with Kotor, to the north and northeast the Municipality of Cetinje, and to the south-east the Municipality of Bar. The southern land part of the municipality is the coast with the Island of Sveti Nikola (Saint Nicholas). The Municipality of Budva is known for its Riviera, which, by the total value of tourist and recreational features, is one of the most beautiful beach zones in the Mediterranean. Climate conditions make this area the most attractive area for bathing tourism on the entire European coast of the Mediterranean. The annual mean air temperature is 17°C, and there are up to 270 sunny days in the year. The calm sea with an average annual water temperature of 18.5°C, azure-blue and clear waters is what attracts tourists. The Municipality of Budva has 17 highest-category sandy beaches. They are its extraordinary value. The average beach strip width is 25 m and the total area is approximately 290,000 m^2. Of Montenegro's total coastline length, the Municipality of Budva has almost one-quarter, i.e. 24.6% of its tourist active coast, although it accounts for only 13.7% of its total length. The high natural value of tourism resources is complemented by Mediterranean vegetation and rich fauna. Olive trees, grapevine, fig-trees, orange trees, tangerine, lemon, etc. grow in Budva, and the area is rich also in exotic plants such as palm trees, eucalyptus, oleander, etc., Fig. 1.

The area of the Municipality of Bar is located in the south of Montenegro, between the Adriatic Sea and the Skadar Lake, bordering the municipalities of Budva, Cetinje, and Ulcinj. The land area of Bar of 506 km^2 is located at 4 m above sea level, together with the water surface of the Skadar Lake of 370 km^2, of which 222 km^2 is located on the territory of Montenegro, it covers an area of 634 km^2 in total. In the coastal zone, the main natural receptive factors are beaches – 15 of them. When it comes to natural conditions, the hydro-geographic potential has the greatest importance for the development of this area, Fig. 2. The Adriatic Sea is of particular importance due to the conditions for the development of tourism, transport, trade, and fishing. Also, the importance of the Skadar Lake is multi-

Fig. 1 Budva (Photo by Dragana Zećević)

Fig. 2 Bar (Photo by Emil Kukalj)

faceted – it is the largest freshwater source. Relief forms divided the region of the Municipality of Bar into the Adriatic, lake, and mountain belts. The Adriatic belt is characterized by a mild climate. The Adriatic thermal influences penetrate the area along the Bojana River so the coastal part of the Skadar Lake and Crmničko Field also has a mild climate. The reefs of mountain ranges of the Sutorman, the Rumija, and the Lisinj have the characteristics of the Alpine-Mediterranean climate. They serve as a rampart that protects against the ingress of cold and dry northern and northeastern winds into the coastal belt. The effects of the Mediterranean climate can be seen and followed also by the cultivation of olives, the best indicator of this climate in the Adriatic. The climate of the area of Bar is characterized by long and dry summers and mild and rainy winters due to the thermal influence of the Adriatic Sea. The high average temperature in Bar (9.1°C) indicates that there is actually no proper winter. There are very few days with the temperature below zero. Spring starts early, summers are very warm with an average temperature of 22.6°C, while autumn is mostly long and pleasant. On average, the number of sunshine days in Bar is 208 days per annum, placing it among the sunniest cities in Europe. One of the characteristics of the climate in Bar are the winds [1].

It can be said that *the geographical position of Ulcinj* is very favourable, since it is situated directly on the Adriatic Sea and not far from the Otranto Door. Historically, Ulcinj's geographical position played an important role in the development of Ulcinj as a city with a rich historical heritage. The construction and operation of the railway Belgrade-Bar influenced the geographical location, especially the transport position of Ulcinj. The Bojana River forms the border to the east in the length of

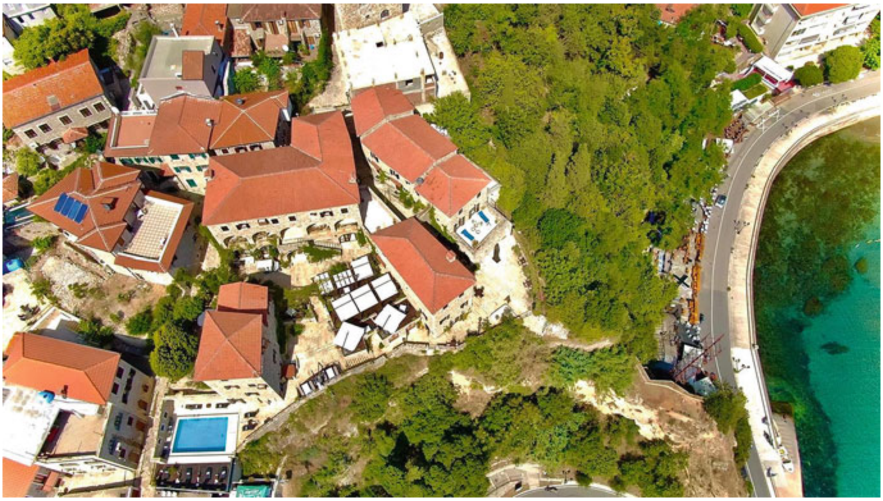

Fig. 3 Ulcinj (photo by Dženita Bakić)

30 km, which is at the same time the state border with Albania. In the vicinity of the village of Štodra, it extends over the land and bends northeast towards the Rumija Massif, which acts as a northern border of Ulcinj and a shared borderline between municipalities of Ulcinj and Bar in the length of 18 km. The Adriatic Sea forms the southern border, from the Bojana River mouth and 30 km upstream. The Municipality of Ulcinj covers an area of 255 km^2, Fig. 3.

3 Cultural Heritage of Budva, Bar, and Ulcinj Riviera

The first record of Budva (Butua) dates back to the fifth century BC. Originally, it belonged to the state of Illyria. The wave of Greek colonization affected also this settlement, which used to be a Greek emporium from sixth to fourth century BC. From the middle of the second century BC, it was a Roman oppidum with a municipal system. Before World War II, the necropolis of Budva was discovered by accident, confirming that it was under the influence of Illyrian, Hellenistic, and Roman culture. It is also evidence that Budva was an advanced ancient city. The Old Town was built on a rocky peninsula more than 2,500 years ago. Despite the continuous destructions that were followed by rebuilding, the Old Budva was preserved as a unique architectural and urban entity. As a unique monument of culture, the Town, as a whole, was placed under the protection of the law. There are several monuments of sacral architecture in the Town. These are the remains of the architecture of the Christian basilica from the end of the fifth century AD, the cathedral church of St John origins of which date back to the seventh century, the Church of Santa Maria in Punta from the year 840, St Sabas of Jerusalem from the

Fig. 4 Budva – Old Town (Photo by Dragana Zečević)

twelfth century, the remains of the church Santa Maria de Castello in the Citadel dating back to the fourteenth century the church of the Holy Trinity of 1804 [2]. There are several monasteries in the Municipality of Budva that were founded in the Middle Ages. The state they are in today are entities most of which were built relatively recently, mostly in the nineteenth century. Significant changes occurred after major disturbances, fires, earthquakes, or Turkish invasions. No less did the monasteries' appearance change in times of more perceptible prosperity of the population, Fig. 4. The monasteries were rebuilt and expanded by the money of many *ktetors*. Podlastva Monastery, Podostrog Monastery, Duljevo Monastery, Praskvica Monastery, Reževići Monastery are some of the monasteries in the Municipality of Budva. Not far from Budva, about 9 km away, is Sveti Stefan (Saint Stephen) a modern and attractive town-hotel. This typical island settlement, established in the fifteenth century, surrounded by high stone walls, was a cultural and commercial-transport centre of the Paštrovići region. Between 1954 and 1957, the settlement was adapted and transformed into a unique hospitality-tourist facility. Its outward appearance was preserved in entirety, while its interior was designed in the most modern way.

The Town of Bar, like other coastal towns, has a long and interesting history. However, Bar is distinctive by the fact that Bar was not built right above the sea, but on higher grounds, 5 km from the coast. Also, the first historical records date back only to the ninth century, while the history of our other coastal towns dates back to ancient times. It is known that in the Middle Ages, Bar had the role of an important religious and political centre. Although Slavicisation started early, it is not clear when the city got into the hands of Doclean rulers for the first time, although it can be assumed that it was the ninth century.

The oldest literary work of all South Slavs, the chronicle of the oldest Slavic state of Duklja (Doclea), was made in Bar, some eight centuries ago. It is the Chronicle of the Priest of Doclea. Bar has a significant cultural heritage, Fig. 5a, b. The most important cultural monument is the Old Town in the Old Bar, Fig. 5c. It is the point

Fig. 5 Bar – Cultural heritage (Photo by Emil Kukalj)

of convergence of different civilizations. In its long history, starting from the sixth century (in historical records, the town was first mentioned in the tenth century as Antibaris – opposite to Bari (Italy)), the city was under the influence of Rome, Byzantine, Doclea – Zeta and the headquarters of the Archdiocese of Bar, the Ottoman Empire, the Venetian culture, and then returned back first to the Kingdom of Montenegro and then the Republic, i.e. the modern state of Montenegro. There are historical and religious monuments of all these civilizations, such as mosques, churches, houses, of ancient, Christian and Turkish architectural styles, *kaldrma* (cobblestone) streets, famous Old Bar marketplace... Most of the cultural activities are related to the Cultural Centre. It includes the Culture House, the National Library and the reading room, the Heritage Museum, the Art Gallery and the Old Town of Bar. There are 32 registered and categorized immovable cultural monuments in the area of the Municipality of Bar [2].

The area of Bar and Ulcinj in its turbulent historical development has passed through the Illyrian, Roman, Byzantine, and Doclean-Zeta periods, and the periods of the Nemanjić, the Balšić. Serbian Despotate, Venetian, and Turkish periods, liberation and annexation to the Kingdom of Montenegro, and the state of Montenegro, in the modern period. Among the oldest historical monuments in Ulcinj, visited most frequently by tourists, are: ancient history-Illyrian ceramics, a pedestal of an ancient tombstone with Greek inscriptions dedicated to the goddess Artemis, the citadel, the Tower of the Balšić, the Renaissance church-mosque. The facilities on the town walls and the citadel originate from the Venetian period. Monuments with Latin and Arab inscriptions, columns, and other objects were preserved from cathedrals and medieval churches from the eighth to sixteenth century [3]. Legend has it that in the Middle Ages, the Old Town of Svač, 25 km northeast of Ulcinj on a hill near the Šasko Lake, had as many churches as days in a year. From 2012 to date, continuous archaeological and conservation research and conservation measures have been implemented to revive a part of this myth. In Ulcinj, 15 entities have the status of cultural resources: The Old Town of Ulcinj, the Bećir Bey's House with the interior woodwork, St Nicholas Church under Bijela Gora, church-mosque, main mosque called Namazdjah, Pasha's Mosque, Pasha's house with woodwork ceiling, the Clock Tower, the Cathedral Church St Nicholas, the woodwork ceiling in the family house of late Đuro Đurišić, the medieval town of Svač, Kruče, the home of the hero of the revolution Nikola Đ. Đakonović, the commemorative plaque to the fallen fighters in the liberation of Ulcinj, the commemorative plaque to seven fallen fighters of the People's Liberation War in Yugoslavia.

4 Early Tourism Development in the Area of Budva, Bar, and Ulcinj Riviera

The modern tourism epoch *in Budva Riviera* began in 1960, when the luxury town-hotel Sveti Stefan was opened, which soon became one of the most famous and prestigious hotels worldwide. In addition to this world-famous hotel, old hotels Mogren and Avala (built in 1939) were refurbished. In the period of 1960–1987, tourism turnover generated in the receptive capacities on the territory of the Municipality of Budva increased more than nine times. A strong boost to the expansion of tourism development from the 1960s to the 1990s, along with extensive investment in tourism and utility and transport infrastructure, was provided by the Spatial Plan South Adriatic. According to this regional planning document, the General Urban Plan of Budva was adopted. This general plan gave Budva the role of an exclusive high-category tourism centre. The period from 1960 to 1990 is characterized by the implementation of three grandiose projects in the area of the Municipality of Budva. The first of them is the elite Hotel Sveti Stefan, which received the world's greatest tourism awards for the supreme quality of its services and unique environment,

Fig. 6 Sveti Stefan (Photo by Jelena Rađenović)

Fig. 6. Another significant project in that period was the authentic reconstruction and revitalization of the Old Town of Budva. It is one of the greatest and most successful reconstruction undertakings in the entire Mediterranean, implemented in the 1980s. The construction of the modern and attractive tourist village Slovenska Plaža was the third major undertaking. In the period from 1960 to 1990, tourism in Budva was recording a relatively stable and dynamic growth and development rate [4].

The beginning of the tourism industry on *the territory of the Municipality of Bar* dates back to the eighteenth century. The mild Mediterranean climate, the healing powers of seawater and sandy beaches, an exceptional architectural – ambient entity of this area, offered holidays to the first organized tourist groups in 1890, from the present-day Czech Republic and Slovakia. In the early twentieth century, the first tourist facility in Bar, the Hotel Marina, was built for the needs of the Italian Navy. It was a three-floor building with 60 different rooms and was in operation until 1947. In the 1930s, the hotels Dekleva and Jugoslavija were built. While the Hotel Jugoslavija had two rooms only, the Hotel Dekleva had 20 rooms with a sea view, a hall, a restaurant, a big garden, and a terrace. In the early 1950s, the accommodation facilities included the Hotel Rumija, Hotel Sozina, as well as several camp sites in Sutomore and Žukotrlica, which were particularly attractive to the younger population. With the construction of the railway Bar – Podgorica in 1957, the development of weekend tourism began – that is, construction of weekend homes. During that period, the first socially owned tourist resort of the Trade Union of Montenegro was built. In the decades to come, some of the hotels were expanded (Agava in 1966, 13 July in 1966, Korali in 1969, Nikšić in 1970, Inex in 1971), so the total number of bed places in hotels in 1983 was 5,333.

The early days of tourism in *Ulcinj* date back to the period before World War II, namely the construction of the hotel of Zeta Banovina, the former Hotel Jadran and hotel of the Yugoslav Trade Union, former Hotel Galeb (thoroughly reconstructed from the foundations up after the 1979 earthquake and demolished in the privatization process in the early twenty-first century), initially built between 1933 and 1937, with a total of about 260 bed places. Although transport connections were bad, Ulcinj was at that time visited by wealthy Yugoslav citizens and tourists from

Europe, especially from Czechoslovakia. In 1938, 732 tourists were registered in Ulcinj, with 9,714 overnight stays. More intensive post-war construction of tourist facilities can be divided into two stages: The phase of construction of the tourist village Mediteran with 480 bed places and the extension of the Hotel Galeb with about 160 bed places, which was completed in 1962–1964. The second major construction phase was in 1967–1973, when a resort of hotels and restaurants on Velika Plaža was built with the capacity over 2,000 bed places in hotels and resorts, then the Hotel Albatros, the resort Globus, etc. In 1966, central heating was introduced for the first time into Montenegrin facilities, Hotel Galeb, for the purpose of the development of winter tourism. In 1967, Hotel Lido with 430 bed places was opened; Hotel Bellevue with a capacity of 574 bed places was built in 1968; new 150-bed Hotel Albatros was built in 1969; in 1971, Category A Hotel Olympic with a capacity of 240 bed places was built on Velika Plaža with central heating and a swimming pool [5].

5 Tourism Development in the Area of Budva, Bar, and Ulcinj Riviera in the Second Half of the Twentieth Century

Intensive tourism development in the second half of the twentieth century transformed *Budva* from a very passive and economically disadvantaged environment into one of the most developed municipalities not only in Montenegro but also in Yugoslavia. In this period, the Municipality of Budva achieved a lot in terms of development. In the second half of the twentieth century, the tourism and hospitality industry was the main economic activity on the territory of the Municipality of Budva. In terms of development, the tourism and hospitality industry in Budva can be generally divided into four distinct periods: the period from liberation to 1962, period 1963 to 1978, the period from 1979 to 1990, and the period 1991 to 2000. The period from 1945-1958 is characterized by rather limited accommodation capacities, inadequate transport connections, relatively modest tourism turnover with less than 100,000 visitors a year. The next four-year period significantly exceeded the previous period, primarily as a result of the implementation of economic policy measures by countries that stimulated tourism development. The new, more comfortable Hotel Mogren with 78 beds was built in 1959 at the site of former small hotels Mogren and Budva, which were in poor condition. The Hotel Sveti Stefan with 226 bed places received its first visitors in 1960, and later this unique town-hotel brought fame and recognition to the tourism of Budva and Montenegro. Significant accommodation capacities were built at this time. In 1963, half a million overnight stays of domestic and foreign tourists were achieved. The period from 1963 to 1973 was a period of intensive investment in tourism. In this period, numerous hotels were opened in the area of Budva Riviera: Hotel Avala (1963) with 284 bed places, hotel complex on Slovenska Plaža with a total of 1,654 bed places, hotel complex on the Bečići beach with 2,380 bed places, Hotel Maestral in Pržno with 294 bed places, hotels in Petrovac with 888 bed places, and Hotel As in Perazić Do with 419 bed places. The period from 1974 to 1978 is characterized by investment standstill but also the founding of hotel and tourism company Montenegroturist Budva, combining the tourism offer of 15 OOURs (OOUR, short for the Basic Organization of Associated Labour, a form of business organization in former Yugoslavia) formed from former hotel companies from Ulcinj, Bar, Petrovac, Sveti Stefan, Budva, Tivat, and Kotor. The year 1978 was a record year, with the accommodation capacity in the Budva Riviera reaching 36,152 bed places with 2,745,139 overnight stays. This intense development was halted by a devastating earthquake that razed to the ground numerous hospitality and accommodation facilities, as well as cultural and historical monuments. The remarkable results of the restoration works and revival of the hotel and tourist industry were achieved as soon as in 1983. At the Slovenska Plaža site, where five hotels used to be, the first phase of a tourist resort of 2,413 bed places was opened in 1984. In 1984, the Budva Riviera disposed of 37,000 bed places, which is somewhat more than it had before the earthquake. The last decade of the twentieth century of tourism in Budva and Montenegro was characterized by numerous retrograde processes, both in terms of tourist offer and in terms of tourist demand. Conflicts in former Yugoslavia caused a decline in the complex tourism product and a sudden downturn in tourism turnover. During the observed period, foreign visitors, in all accommodation types, made negligible 887,691 overnight stays in Budva Riviera. The accommodation capacities ranged from 25,000 to 32,000 bed places. In this 10-year period, very little was done when it comes to the organization, the ownership and control transformation of the tourism industry in Budva. Having regard to all the negative trends, it can be concluded that the last decade of the twentieth century was marked by devolution, rather than the expected progress.

In order to make an overview of the main characteristics of tourism development *in the Municipality of Bar* in the second half of the twentieth century, we can distinguish between three distinct periods when it comes to tourism turnover in the Municipality of Bar. The first period is from 1962 to 1979, characterized by a trend of increasing number in visitors and their overnight stays. This trend shows that in 1962, the number of tourists was 7,865, the number of overnight stays 72,106, and in 1978, 153,794 tourists and 1,468,525 overnight stays. The end of that period is 1979, when the result of the catastrophic earthquake caused a halt in an upward trend when it comes to the numbers of domestic tourists by about 77% compared to 1978 and foreign tourists by 85% compared to 1978. The second period from 1980 to 1989 can be characterized as the most successful in both the number of tourists and the number of overnight stays, for both domestic and foreign tourists. The record year was 1989, when the highest tourism turnover was recorded with 185,272 tourists and 1,648,067 overnight stays. The third period begins after 1989 as the year by which the tourism turnover had an upward trend, which was followed by a drastic decline due to the political and economic situation when negative trends took prevailed in the tourism turnover. This was particularly reflected in the decline in the number of foreign tourists. The major decline took place in 1993 when only 618 foreign guests with 2,102 overnight stays were registered on the territory of the Municipality of Bar. The largest number of foreign guests was registered in 1986, with 32,324 foreign visitors, and the largest number of domestic guests in 1989-161,960. In the early 1950s, the accommodation facilities included Hotel Rumija, Hotel Sozina, as well as several camp sites in Sutomore and Žukotrlica, which were particularly attractive to the younger population. With the construction of the railway Bar – Podgorica in 1957, the development of weekend tourism began, that is, the construction of weekend homes. The first socially owned tourist resort, the vacation facility of the Trade Union of Montenegro was built. It replaced the Hotel Južno More, which had been built in 1963 at the same site. In the ensuing decades, the number of hotels in Bar Riviera was growing, so the total number of bed places in the hotels in 1983 was 5,333. In addition to the basic accommodation facilities, numerous children and labourers' vacation facilities and camp sites were developed in this period. Private accommodation in the accommodation capacity structure was growing by 1990, and from that year onwards, the number of registered bed places in this sector was in decline [6].

In the second half of the 1930s, construction of hotel facilities began *in Ulcinj*. In 1936, the construction of the so-called Banovina Hotel began. Although it was completed in terms of construction in 1939, due to the lack of funds for furnishing it was opened as late as in 1946, and it was expanded in 1949, under the name of Hotel Jadran. The Hotel of the Confederation of Cooperatives of State Employees of Belgrade was opened in 1939. In World War II, it was demolished, later on renovated and it operated until 1954 as a resort Ivan Milutinović and later called the Hotel Galeb. After the 1979 earthquake, it was reconstructed and expanded, so it disposed of significantly larger accommodation capacities. The Hotel Republika was completed in 1947, but it collapsed in the 1979 earthquake. It was not reconstructed, nor was Hotel Jadran. From 1952 to 1956, the introduction of a new economic system created favourable conditions for hospitality companies that were granted various incentives and support by the community. In the new planning period, from 1956 to 1965, significant attention was paid to domestic tourism by providing subsidies to initiative tourism organizations. In 1964, the construction of the tourist resort Mediteran was completed, while the construction of the Hotel Lido on Velika Plaža began. The Bellevue Hotel, with 574 bed places was built in 1968 and 1970 the annexe to the Hotel Albatros with 192 bed places was built. The 240-bed Hotel Olympic was built in 1971 [7].

Table 1 Tourism turnover in the period 1965–1994 is shown below [7]. The decline in the number of tourists following the catastrophic earthquake in 1979. A major decline was observed again since 1991 as a result of conflicts in the former Yugoslavia.

Table 1 Tourism turnover in Ulcinj 1965–1994

Year	Number of tourists (in thousands)	Domestic	Foreign
1965	72.4	61.8	10.6
1970	80.9	60.2	20.7
1975	98.6	66.1	32.5
1978	144.9	96.7	48.2
1981	110	74.4	35.6
1989	122.8	74.5	48.3
1990	120.1	69.6	50.4
1991	36	32.9	3
1992	38.1	37.8	0.3
1993	50.4	50.3	0.1
1994	53.3	53.2	0.1

Source: According to [7]

6 The Future of Tourism in the Area of Budva, Bar, and Ulcinj Riviera

6.1 Characteristics of Current Tourism in the Area of Budva, Bar, and Ulcinj Riviera

Tourism is Montenegro's main economic industry. However, the development of tourism, particularly of currently leading tourism centres on the coast, is not sufficiently aligned with the principles of sustainable development. The following are among the main issues:

- uncontrolled construction of housing units and apartments,
- grey market,
- unfavourable accommodation infrastructure,
- underdeveloped transport infrastructure,
- lack of parking space,
- the overload of tourism centres during the summer season,
- underdeveloped ancillary facilities,
- lack of workforce,
- excessive dependence on a few low-budget and short-season outbound markets.

The uncontrolled construction of residential units and rental apartments, which have been going on in coastal cities for the past three decades, has a major impact on the development of the grey market and the unfair competition. This further affected the overload of tourist centres during the summer months: heavy traffic jams, lack of parking space, overcrowded beaches, etc. Thus, the quality of the offer has significantly decreased, attracting tourists with lower purchasing power and higher seasonal concentration, mainly from the region and Russia. Such developments are consistent with mass tourism development, which is not sustainable in the long term.

Ancillary facilities and attractions that would attract tourists in the low season are either non-existent or underdeveloped. Apart from the uncontrolled construction of housing facilities, the construction of hotel facilities is also not consistent with sustainable development and recommendations from the Master Plan for Tourism Development by 2020. Most of them are high-category hotels, condo-hotels, etc. that do not match the global structure of the tourist demand. The Master Plan envisions the construction of hotels most of which would be 3-star and 4-star hotels (about 80%). In recent years, condo-hotels are frequently constructed in Budva in high-rise buildings in attractive coastline sites, so the Mediterranean landscape and hinterland of these construction mastodons are permanently destroyed. One of the major problems is the large fluctuations in the workforce, a factor contributed by low wages, seasonal work, etc. Inadequate or under-motivated workforce further affects the quality of the offer and management of hotels and other hospitality facilities.

Table 2 and Fig. 7 present the relationship between basic and accommodation capacities in the areas of Budva, Bar, and Ulcinj, with the data for the basic accommodation capacities for 2018, while the data for the complementary capacities were recorded last in 2014 [8]. Due to the uncontrolled construction, the number of

Table 2 The accommodation capacity structure in the area of Budva, Bar, and Ulcinj Riviera (2018)

	Number of accommodation units		Number of bed places	
	Basic	Complementary	Basic	Complementary
Budva	7,277	40,996	17,636	41,129
Bar	2,285	952	5,606	13,525
Ulcinj	1,935	10,008	5,012	22,308

Source: Monstat [8]

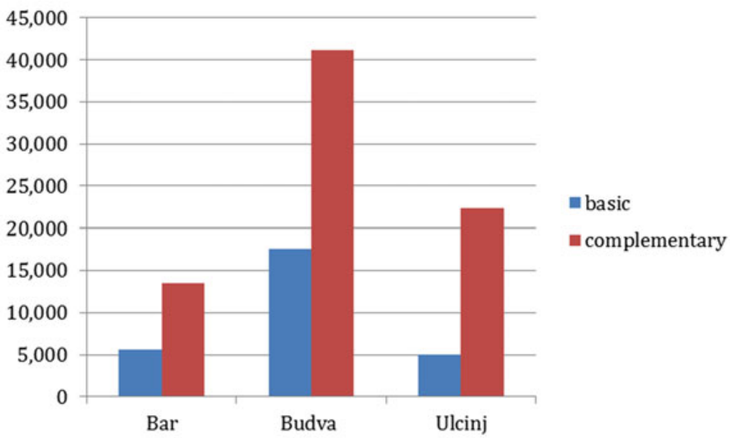

Fig. 7 The accommodation capacity structure in the area of Budva, Bar, and Ulcinj Riviera (2018) [8]

Table 3 Apartments based on the intended use (2011)

	Apartments total	Residential only	Seasonal use and similar
Bar	33,371	13,638	19,733
Budva	23,805	6,401	17,404
Ulcinj	15,763	5,279	10,484

Source: MONSTAT [9]

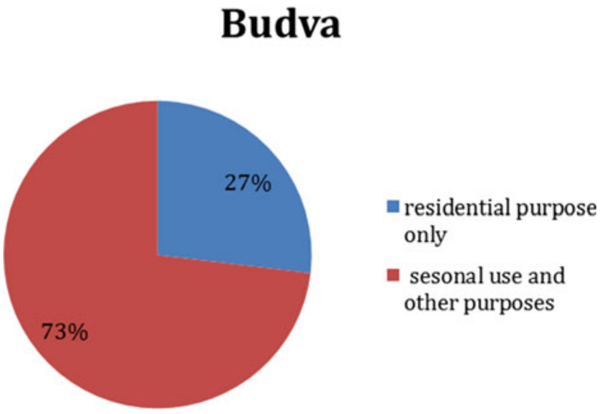

Fig. 8 The intended use of the apartments in Budva (2011) [9]

accommodation units and the number of bed places in the complementary accommodation capacity is currently higher than the one shown. Even from the structure shown it can be concluded that the accommodation capacity structure is unfavourable, and that the offer is based in most cases on the complementary accommodation capacity, which is not consistent with sustainable tourism development.

The unfavourable accommodation capacity structure can be further observed based on the use of apartments. Table 3 shows the number of apartments per municipality and their intended purpose, according to the most recent Census in 2011 [9].

Figure 8 shows the ratio of apartments intended for residential purposes only and apartments for seasonal use and other purposes in Budva, according to the Census 2011 [9]. Over 70% of the apartments were intended for seasonal use or other purposes. The number of apartments in the Municipality of Budva increased dramatically after the census, and for the most part, their intended purpose is seasonal use.

Figure 9 shows the ratio of apartments intended for residential purposes only and apartments for seasonal use and other purposes in Bar, according to the Census 2011 [9]. Almost 60% of the apartments were intended for seasonal use or other purposes.

Figure 10 shows the ratio of apartments intended for residential purposes only and apartments for seasonal use and other purposes in Ulcinj, according to the Census 2011 [9]. Somewhat less than 70% of the apartments were intended for seasonal use or other purposes.

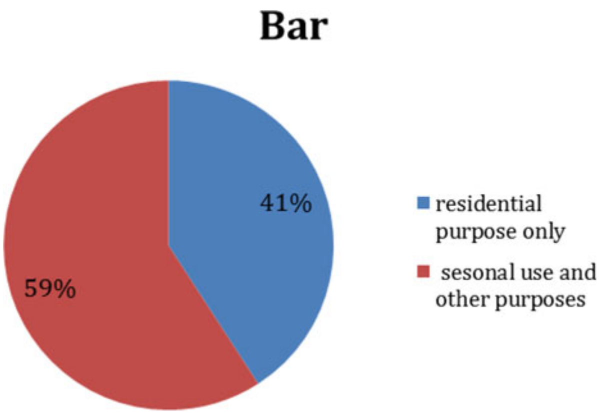

Fig. 9 The intended use of the apartments in Bar (2011) [9]

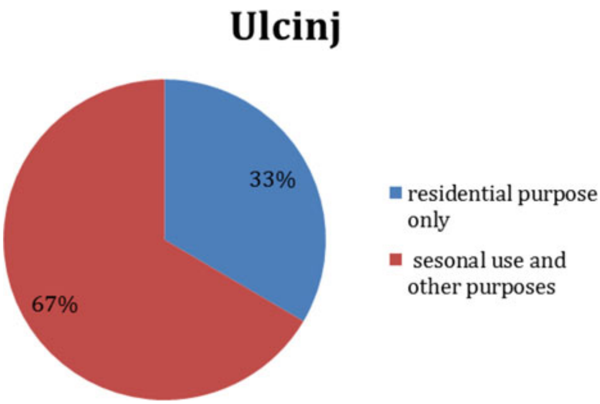

Fig. 10 The intended use of the apartments in Ulcinj (2011) [9]

Budva, Bar, and Ulcinj Riviera used to have significant potential for tourism development. A part of natural and cultural resources has been destroyed. However, based on those that are preserved still and based on the glory days, these destinations still attract a large number of tourists. Table 4 provides an overview of the number of arrivals and overnight stays for both domestic and foreign tourists in 2019 [10].

Figures 11 and 12 show the share in arrivals and overnight stays, compared to the total number of arrivals and overnight stays in the Budva, Bar, and Ulcinj Riviera [10]. Budva stands out with more than 70% of arrivals and overnight stays among the three municipalities observed.

Seasonality is shown in Figs. 13, 14, and 15 [10]. Seasonality is evident in all three municipalities, Budva, Bar, Ulcinj. The largest number of tourists is recorded during the summer months.

Table 5 and Fig. 16 provide an overview of the arrivals and overnight stays in the individual accommodation [10]. The data presented is incomplete, since a large number of accommodation facilities do not register tourists. The number of tourists

Table 4 Arrivals and overnight stays in the collective accommodation (2019)

	Arrivals			Overnight stays		
	Foreign	Domestic	Total	Foreign	Domestic	Total
January						
Budva	6,389	1,163	7,552	12,544	2,981	15,525
Bar	362	399	761	768	1,218	1,986
Ulcinj	–	28	28	–	60	60
February 2019						
Budva	12,108	1,268	13,376	17,853	2,624	20,477
Bar	572	316	888	1,860	694	2,554
Ulcinj	3	–	3	9	–	9
March 2019						
Budva	20,789	1,737	22,526	29,695	2,822	32,517
Bar	651	387	1,038	1,356	552	1,908
Ulcinj	93	33	126	95	65	160
April 2019						
Budva	39,895	3,154	43,049	97,803	7,515	105,318
Bar	2,359	373	2,732	7,105	734	7,839
Ulcinj	2,928	34	2,962	5,996	59	6,055
May 2019						
Budva	51,160	7,143	58,303	199,862	23,029	222,891
Bar	3,605	712	4,317	14,127	2,247	16,374
Ulcinj	3,602	118	3,720	14,089	354	14,443
June 2019						
Budva	61,726	5,294	67,020	307,305	16,908	324,213
Bar	8,639	2,029	10,668	46,072	7,196	53,268
Ulcinj	12,217	959	13,176	61,773	2,869	64,642
July 2019						
Budva	64,327	3,969	68,296	392,555	22,125	414,680
Bar	15,920	1,503	17,423	99,089	8,159	107,248
Ulcinj	19,721	1,192	20,913	110,818	5,752	116,570
August 2019						
Budva	80,223	4,572	84,795	451,673	26,361	478,034
Bar	17,410	2,059	19,469	103,252	10,773	114,025
Ulcinj	23,214	1,249	24,463	123,157	6,181	129,338
September 2019						
Budva	62,660	3,105	65,765	322,970	8,158	331,128
Bar	9,197	1,186	10,383	48,582	4,158	52,740
Ulcinj	11,259	621	11,880	58,093	2,189	60,282
October 2019						
Budva	44,464	2,514	46,978	127,968	6,076	134,044
Bar	2,339	326	2,665	9,036	854	9,890
Ulcinj	2,472	306	2,778	10,290	893	11,183
November 2019						

(continued)

Table 4 (continued)

	Arrivals			Overnight stays		
	Foreign	Domestic	Total	Foreign	Domestic	Total
Budva	19,983	1,153	21,136	33,165	2,074	35,239
Bar	786	304	1,090	1,624	631	2,255
Ulcinj	518	166	684	3,604	594	4,198
December 2019						
Budva	12,520	2,324	14,844	22,214	3,872	26,086
Bar	569	298	867	1,210	486	1,696
Ulcinj	5	64	69	7	91	98
Total Budva 2019	476,244	37,396	513,640	2,015,607	124,545	2,140,152
Total Bar 2019	62,409	9,892	72,301	334,081	37,702	371,783
Total Ulcinj 2019	76,032	4,770	80,802	387,931	19,107	407,038

Source: MONSTAT [10]

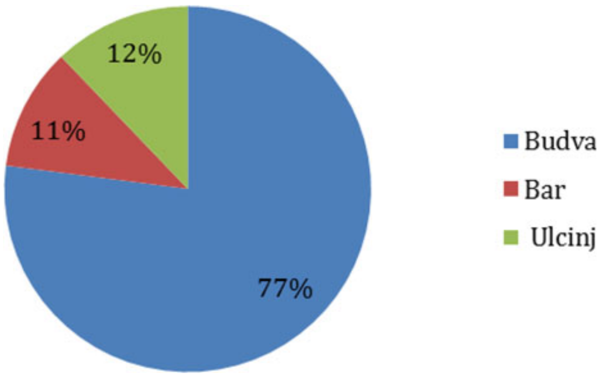

Fig. 11 Arrivals in collective accommodation in 2019 [10]

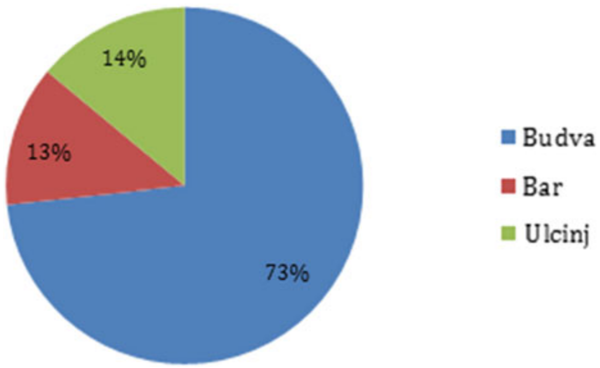

Fig. 12 Overnight stays in collective accommodation in 2019 [10]

in individual accommodation would be significantly higher if the grey market data were to be counted.

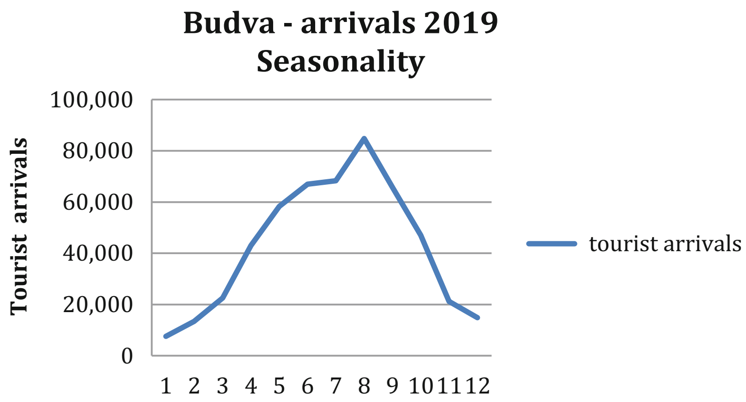

Fig. 13 Seasonality – Budva [10]

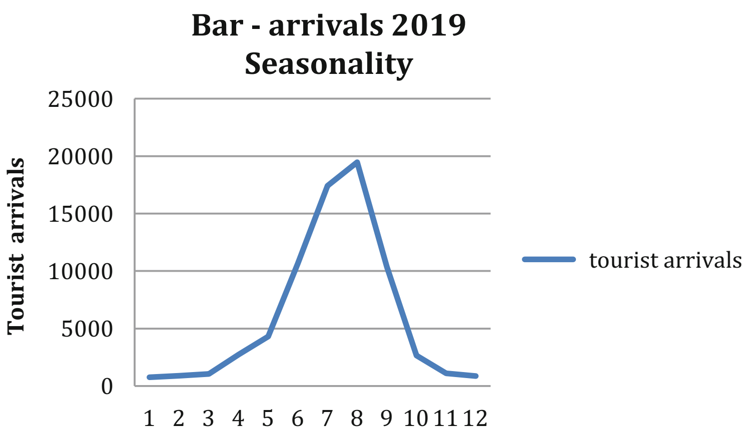

Fig. 14 Seasonality – Bar [10]

Figure 17 provides an overview of the share of revenues by sectors generated in the total revenues in Budva in 2018 [11]. Tourism revenue, that is, revenue from accommodation and food services, amount to 29.67%, i.e. direct revenues from tourism account for most of the total revenue in Budva. A similar situation was registered in 2017, as shown in Fig. 18 [11].

Figure 19 provides an overview of the share of revenues by sectors generated in the total revenues in Bar in 2018 [11]. Revenues from the provision of accommodation and food services amount to 7% of total revenue, while the highest share of 40% is generated in the trade sector. Similar results were recorded during 2017, as shown in Fig. 20 [11].

As shown in Fig. 21, on the territory of Ulcinj in 2018, 17% of total revenue is generated from the provision of accommodation and food services, while the highest

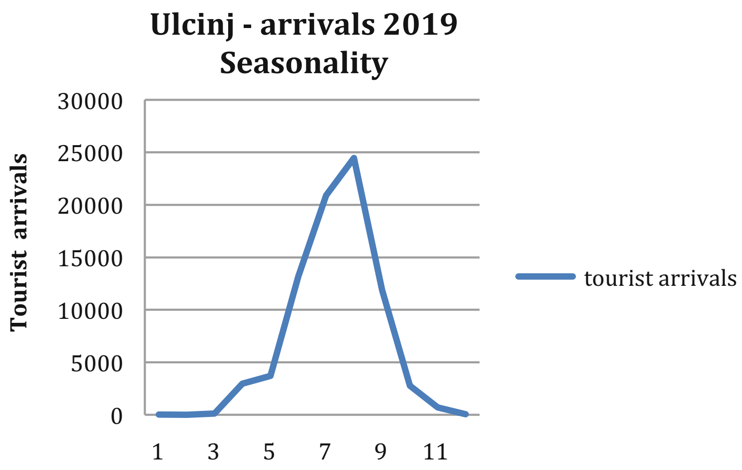

Fig. 15 Seasonality – Ulcinj [10]

Table 5 Arrivals and overnight stays in individual accommodation in 2019

	Arrivals			Overnight stays		
	Foreign	Domestic	Total	Foreign	Domestic	Total
Budva	401,668	3,355	405,023	2,440,958	12,071	2,453,029
Bar	138,218	270	138,488	1,636,741	1,939	1,638,680
Ulcinj	342,780	2,226	345,006	1,736,105	13,304	1,749,409

Source: MONSTAT [10]

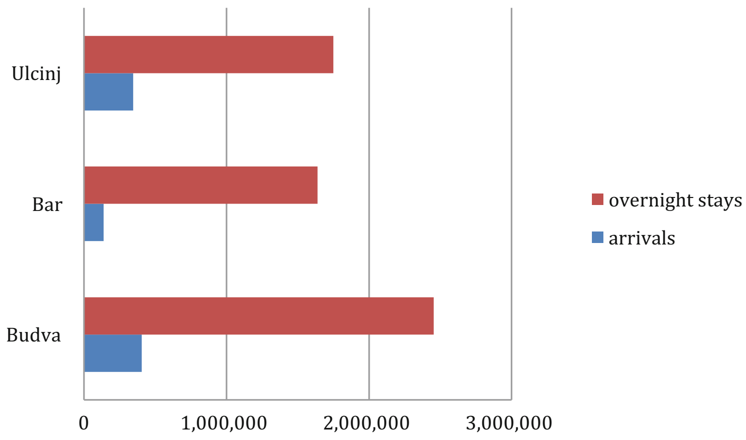

Fig. 16 Arrivals and overnight stays in individual accommodation in 2019 [10]

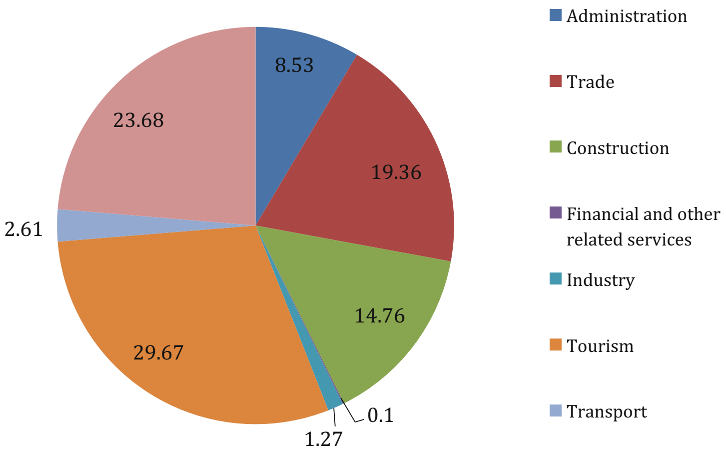

Fig. 17 Share, by sectors, in total revenues on the territory of Budva in 2018 [11]

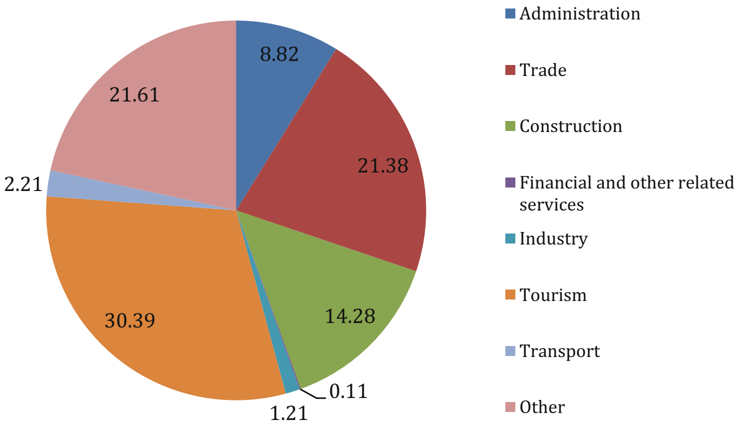

Fig. 18 Share, by sectors, in total revenues on the territory of Budva in 2017 [11]

share is generated in the trade sector [11]. Similar results were recorded also for the last year, as shown in Fig. 22 [11].

An overview of the economic indicators of the tourism sector, namely the sector of accommodation and food and beverages, for all three municipalities observed, is shown in Table 6 [11]. The share of operating expenses in total revenue is 89% or more. Gross operating profit is 11% for Budva, 3% for Bar, and 6% for Ulcinj. Budva and Ulcinj make a net profit with a 1% share in total revenue, while Bar makes a net loss. These figures show an adverse economic situation in the tourism sector in all three municipalities observed as a result of the structural disproportions in Montenegrin tourism described above (unfavourable structure of tourism offer,

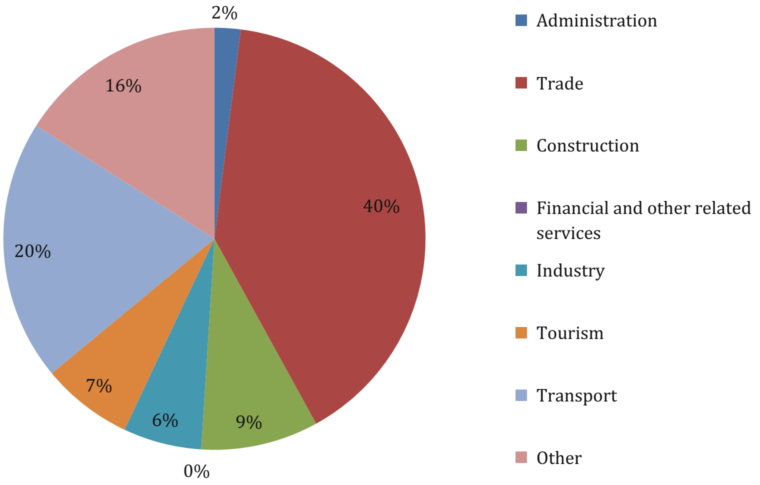

Fig. 19 Share, by sectors, in total revenues on the territory of Bar in 2018 [11]

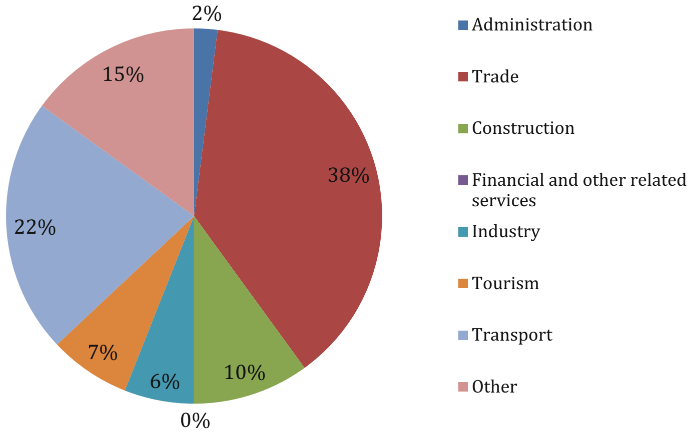

Fig. 20 Share, by sectors, in total revenues on the territory of Bar in 2017 [11]

unfavourable structure of tourism demand, underdevelopment of ancillary services and alternative tourism forms, highly seasonal character of tourism. . .).

6.2 Tourism Development Prospects in the Area of Budva, Bar, and Ulcinj Riviera

According to the Master Plan for Tourism Development by 2020 [12], in the area of Budva and Bar Riviera, the development of beach tourism should be given a priority.

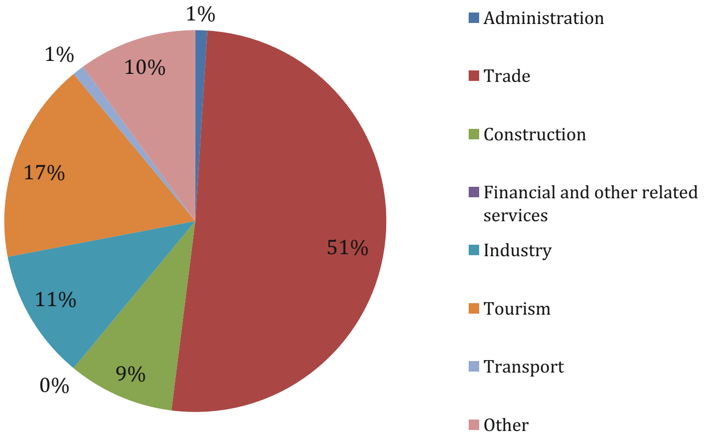

Fig. 21 Share, by sectors, in total revenues on the territory of Ulcinj in 2018 [11]

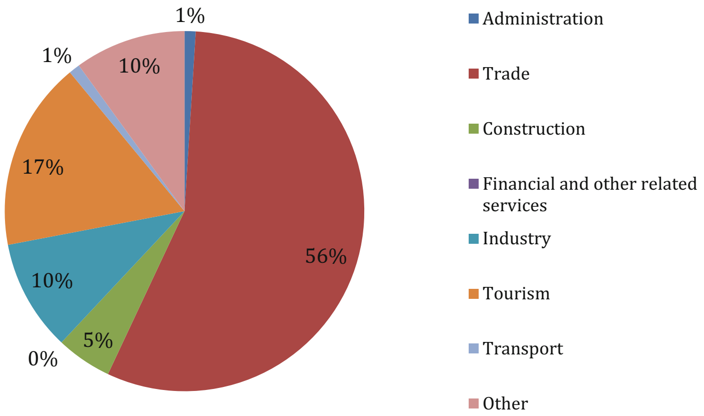

Fig. 22 Share, by sectors, in total revenues on the territory of Ulcinj in 2017 [11]

Table 6 An overview of economic indicators of the tourism sector (accommodation and F & B) per municipality, for Budva, Bar, and Ulcinj in 2018

Ordinal number	Elements	Budva		Bar		Ulcinj	
		Amount	%	Amount	%	Amount	%
1	Revenues	168,278,099	100%	25,888,389	100%	19,506,457	100%
2	Operating expenses	149,719,931	89%	24,993,964	97%	18,352,970	94%
3	Gross operating profit	18,558,168	11%	894,425	3%	1,153,487	6%
3	Net profit/loss	1,018,998	1%	−5,932,194	−23%	122,368	1%

Source: Central Bank of Montenegro [11]

The advantages of these destinations are the nature of the coastal area and the mountains, magnificent and partially as yet unbuilt bays (Jaz, Buljarica), the Old Town of Budva and the Old Bar, several monasteries, Sveti Stefan. A vision of the development of the two Rivieras is the development of a destination that would be open throughout the year with the Mediterranean spirit on the sub-tropical coast. To this end, it is necessary to increase the quality of accommodation, refurbish places, plan active centres, build infrastructure for leisure activities, connect the seaside to the continental part of Montenegro. The development of beach tourism and nature tourism is planned for Ulcinj Riviera. The development vision for Ulcinj is to make it an exceptional, professionally designed destination of international tourism throughout the year with modern accommodation facilities for different target groups [13].

In order to improve the quality of the offer, current deficiencies need to be addressed to the extent possible. Further development should be aligned with well-designed development strategies at the local level and measures should be defined for their implementation. The offer in complementary accommodation capacity, currently in the grey zone (major or prevailing secondary housing units), should be grouped in the form of diffuse and integral hotels and further construction should be placed under control. In order to extend the tourist season, cultural and historical monuments need to be valorized and additional entertainment and recreational facilities developed. This development would result in the redistribution of tourists from the high season, which would reduce the overload. Also, transport accessibility needs to be improved, and in particular to provide additional parking spaces and invest more effort in the promotion of other forms of transport, to the destination and within. The extension of the tourist season would also allow for longer-term employment, possibly throughout the year, which would contribute to a better quality workforce and thus to a better quality of the service provided.

The chance for a radical extension of the tourist season is given by the rural tourism resources in all three municipalities: Budva (the area Maine, Pobori and Grbalj, Paštrovići, in particular, Paštrovska Gora and revitalization of villages in the hinterland), Bar (villages under the Rumija Mt., Crmnica in the area towards Ulcinj), and Ulcinj (Ulcinjsko Field, Zoganj, Briska Gora, the Šasko Lake and rural structures in that area). An adequate rural offer (rural accommodation, hiking, biking, wine roads, etc.) would attract tourist arrivals in early preseason and late postseason, even during the winter. The valorization of this offer has the highest chance in Europe's main outbound markets (Germany, the United Kingdom, France, the Scandinavian countries, Austria, Italy).

7 Conclusion

Tourism is Montenegro's main economic industry. Therefore, particular attention needs to be paid to its development. Coastal tourism is a form of tourism, based on which Montenegro designed most of its offer in past decades. The area of Budva, Bar, and Ulcinj Riviera has great potential for development, both due to cultural and natural resources. However, the resources available are not adequately utilized. These areas have a long tradition of tourism development, with occasional upward and downward trends. The last three decades have been characterized by not sufficiently sustainable tourism development, continuous spatial devastation, extremely pronounced seasonality, as well as the lack of an up-to-date and holistic tourism information system.

A more detailed analysis of available data suggests that tourism development in Montenegro is not adequately managed. The increasing number of tourist arrivals and overnight stays (compared to the previous crisis years from 1991 onwards) creates an appearance of record growth rates, and if qualitative operation standards (occupancy rates, market structure, profit rates. . .) from the period before the 1990s are far from being met – not to mention the current economic standards of tourism in the Mediterranean, which is the proper standard and benchmark for Montenegro's tourism. In reality, the main tourist centres on Montenegro's coast are overbooked during the summer months, when the beaches, the city centres are overloaded, along with the lack of parking space and traffic congestion. Also, a significant number of overnights are made in accommodation capacities that belong to the grey economy. Economic indicators show that the situation in the tourism sector is significantly below the desirable and achievable economic, social, and environmental sustainability standards. Inadequate housing structure, with a significant share of residential and rental apartments, especially in the grey zone, are among the main problems. This results in unfair competition and non-standardized offers.

Remediation of the consequences of space devastation and ecological protection of the sea and the coast is a key challenge in further tourism development. The subject of special ecological protection should be locations such as Valdanos near Ulcinj, Buljarica, the Island "St. Nikola" in Budva. River and canal beds in the hinterland of sandy beaches should be rehabilitated, which bring excess atmospheric water and aggregates for the production of sand in the sea, which revitalizes the beaches. This unit is accompanied by solid waste, such as plastic, metal, wood, car tires, garbage, construction waste, which should be solved by cleaning and controlling the disposal of solid waste. Possible oil spills from vessels and wells must be prevented by the strictest measures to limit and control maritime traffic and oil exploration. Further rehabilitation measures include cleaning the sandy and recreational part of the beaches from any facilities, as well as stopping residential and tourist construction in the immediate vicinity of the Sea coast. An integral solution to the problem of wastewater is crucial for the prevention of pollution of the sea and the surrounding area, as is the case with the Port Milena canal in Ulcinj, or with the Buljarica field, especially in its wetland part. The protection of indigenous flora and fauna along all three rivieras is key to the development of sustainable tourism.

These issues are realistically solvable by implementation of the following measures: halting further residential and housing construction in tourist zones that results in the devastation of the area; integrating a part of individual accommodation capacities (in particular in the area of secondary housing) into diffuse and integral hotels; developing rural, cultural, creative and other forms of tourism that would result in the extension of the tourist season and the redistribution of tourists;

developing plans for further tourism development with strong control measures for their implementation. Taking adequate measures would result in better quality of the tourism offer; it would attract tourists from the higher income outbound markets extend the tourist season and reduce the load on destinations that is above their actual capacity. These measures are in the spirit of the recommendations of tourism science and profession for the development of tourism in the post-pandemic times ahead.

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Landscaped Green Areas of the Coast of Montenegro

Željka Ćurović, Tamara Marović, Milić Ćurović, and Svetislav G. Popović

Contents

Abstract This chapter analyzes the basic characteristics of landscaped green areas of hotels, public green areas, and former military complexes on the Montenegrin coast. For the purposes of this paper, green areas at nine different locations were analyzed, as well as data on all public green areas in the municipality of Kotor. Data at all locations were collected using the same methodology. The great diversity of dendroflora is evident in almost all analyzed locations. The absence of adequate care measures in one period led to a partial degradation of the quality of greenery and an increase in the share of invasive and less decorative species.

The paper points out the importance of greenery for the life of the inhabitants of this part of the Mediterranean, as well as the impact of landscaped green areas on the overall impression of the space.

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Keywords Coast, Decorative species, Landscaped green areas, Montenegro

1 Introduction

The importance of landscaped green areas of the Montenegrin coast can be seen from different aspects. Greenery is a significant element in the design of urban units that gives additional value to settlements. In addition to their ecological function, landscaped green areas of coastal settlements have a social and aesthetic function as well. Green areas intended for public use are of general importance to the population, so it is important to ensure their accessibility to each individual in order to provide a variety of physical, psychological, and social benefits to residents [1].

There are many studies which have shown that green urban areas during summer days have temperatures up to 2.5–3°C lower than urban areas, and the temperature reductions could be observed up to 50 m from the parks' edges [2–4]. Other positive environmental properties of green areas in settlements such as acoustic factors, visual aspects, etc. should also be taken into account [5]. Public green areas are contributing to physical and mental well-being of people who are living in urban areas. The calculated carbon saving for just four parks in Rome corresponding to 3.6% of the total greenhouse gas emissions of that city for 2010 resulted in an annual economic value of 23,537$/ha [6].

The green fund of inhabited parts of the Montenegrin coast is mostly present in the form of public green areas (parks, squares, and tree lines) and is supplemented by the remains of block greenery, greenery around the headquarters of public institutions, business facilities, hotels, and private gardens. The rich exotic flora of the settlement, well adapted to the given environmental conditions, aesthetically enriches the landscape of the coast. Due to their importance, these spaces form part of the identity of the space in which they are located and are arranged, as a rule, to satisfy high aesthetic values.

Accelerated and partially unplanned urban development in developing countries in the last 20 years has resulted in a decrease in green areas and an increase in degraded and landscape-impoverished areas [7]. In the coming period, special attention should be paid to this segment. Through the reconstruction and extension of the system of landscaped green areas, the planned system of urban greenery should satisfy aesthetic, ecological, and social aspects, and follow the matrix of cultural landscape as historical heritage with emphasis on implementing the principles of horizontal and vertical connection of green areas.

In order to fully understand the basic characteristics of landscaped green areas of the Montenegrin coast, this chapter describes selected green areas of several types of hotel complexes, as well as green public areas of Kotor, a large city park in Tivat and the former military facility in Kumbor – Herceg Novi (Fig. 1).

The aim of this chapter is to observe the state of dendroflora richness and the state of landscaped green areas of the Montenegrin coast. This was done by analyzing the data from green fund studies that have been done in the last 10 years at several

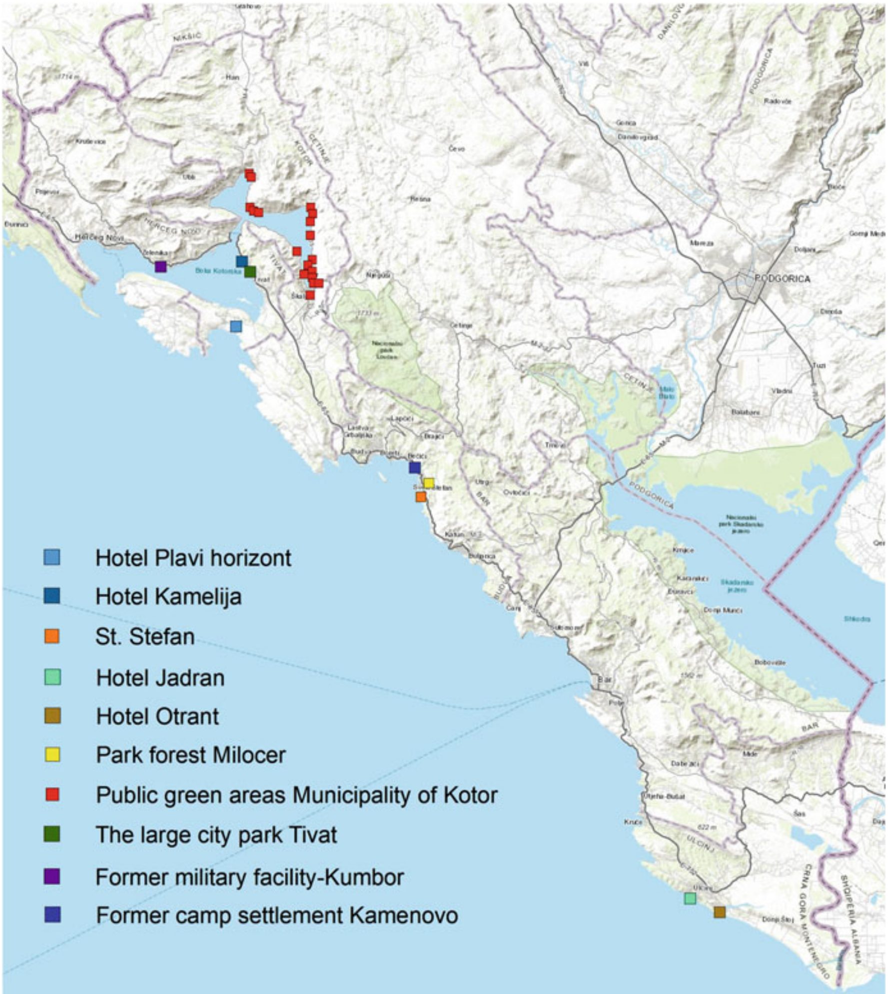

Fig. 1 Location of researched sites

locations. So far, this topic has rarely been covered, and in more segments, incompletely, without a uniform methodology. This is the first time that data collected by a unique methodology for such coverage have been processed and compared, which adds to the significance of this chapter.

2 Material and Methods

Basic data on landscaped green areas of the Montenegrin coast were determined for the purpose of making green fund studies at certain locations in the period from 2009 to 2019 [8–17]. These studies were done for the area around hotels, campsites, former military facilities, and public green areas (parks, squares, greenery along roads, etc.). The task of these studies was to determine position and evaluate the existing trees of the dendrological fund so that during the reconstruction and revitalization of these green areas these data could serve as a good starting point for future landscape architecture project.

The method of data collection consisted of accurate positioning of trees in the geodetic division, species determination, and measurement of dimensions and evaluation of general characteristics of the tree.

Determination of dimensions included measurements of: chest diameter, total tree height, tree height without branches, and crown width.

Evaluating the characteristics of each individual tree consisted of assessing decorativeness, vitality, estimating age, and expected duration.

Based on certain dimensions and condition assessment, all trees are classified into categories:

- A: high quality trees (for preservation);
- B: trees of limited quality (preservation with care measures);
- C: low quality trees (transplanting with significant care measures);
- R: low quality trees (for removal).

The studies also contained data on landscape characteristics, potential vegetation, pedology and climate, as well as field photographs.

3 Results

3.1 Hotels

Analyzing the tourist facilities on the Montenegrin coast in political, social, economic, and cultural environment, especially those built until the late 1970s and early 1980s, it can be concluded that they are generators of social development and one of the key segments of social identity – reflecting modernity, freedom, and innovation, while respecting local tradition. Tourism takes on a role in achieving ideological goals, so it is clear that the development of tourism and architecture are intertwined in this context – the development strategies of the state and political orientations (in this case through tourism) influenced the development of architecture, as architecture influenced social and cultural emancipation within the state.

Evaluating the tourist facilities on the Montenegrin coast according to the architectural conception of the objects, the volumes created in the space and the

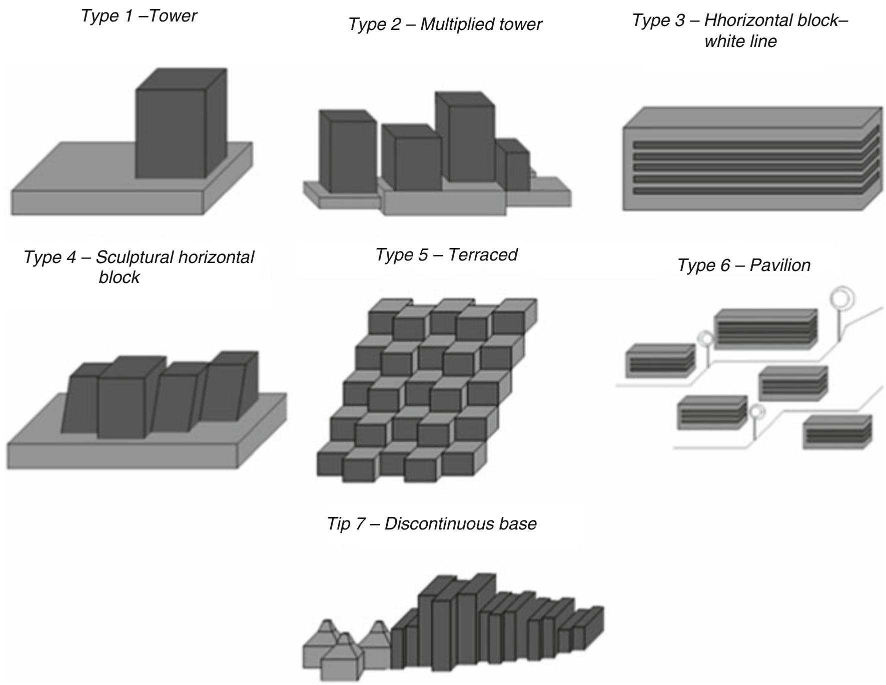

Fig. 2 Types of hotels according to the architectural conception of the objects (designed by: T. Marovic)

projection of the built structures on the field – a typology of tourist facilities was formed (Fig. 2) [18].

Objects have been identified as ones that stand out with their volume in relation to the landscape in regular cubic masses – both in a strict form (tower) and in a discontinuous one, forming masses reminiscent of a city silhouette (multiplied tower); then buildings of smaller floors with a characteristic horizontal white line, i.e. prominent horizontal structural elements (horizontal block/white line); modified sculptural block in relation to all planes of the object (sculptural horizontal block); compact structure that adapts to the terrain and becomes an integral part of the landscape (terrace type); free structures in the space that form a tourist settlement (pavilion type); and buildings that are irregular in shape at the base, of various volumes and materialization of the facades (discontinuous base).

The terraced, pavilion and discontinuous base types have the greatest interaction with the environment and the synergy of the building and nature has been achieved. Furthermore, the elements of comfort are another quality of these concepts, considering that the orientation is mostly adequate and spaces are created for users to provide the connection with nature.

In the terraced type, the building adapts to the terrain, and greenery permeates through the building so that the complex becomes an integral part of the landscape.

The pavilion type is a special type of urban scheme created with the possibility of forming large green oases with various facilities for hotel users. Forms are usually simple and properly oriented, creating a micro climate and identity. In the case of buildings with a discontinuous base, many smaller areas create space "pockets" suitable for adequate ground floor arrangement, leaving space for rest and recreation.

In this chapter, the green areas of several hotel complexes that were created in the second half of the twentieth century are analyzed. In the last 10 years, a large number of hotel complexes from that period have entered the process of reconstruction. In contrast to the buildings that have fallen into disrepair over time, imposing specimens of pines, cypresses, olives, palm trees, etc. have been recorded at these locations. In order to preserve the authenticity and spirit of the place, the reconstruction of these areas was preceded by analyses of the existing green areas with the aim of fitting all vital and decorative trees into future architectural and landscaping designs.

3.1.1 Green Fund of the Hotel "Kamelija": Park Ivović in Donja Lastva – Tivat

Landscaped green area of the hotel complex "Kamelija" better known as Ivović Park in Donja Lastva is located between the main road and the coast. It covers an area of 1.44 ha [16]. In this area there are green areas built as an integral part of the former Zmajević complex. Today, the area is characterized by features typical of tourist areas in the sixties of the twentieth century, so there are 12 buildings surrounded by greenery, sports, and recreational terrain and parking.

Vegetation of the annex of the hotel "Kamelija" – Park Ivović was created by the joint action of man and nature during the decades of use of this space, at first for the purpose of arranging the property of the noble family Zmajević and later for tourist purposes. Together with facilities it became a whole in a horticultural and ambient sense.

In the park there are old pine trees (*Pinus pinea* L.), Himalayan cedar (*Cedrus deodara* G.Don), Holm oak (*Quercus ilex* L.), Japanese cheesewood (*Pittosporum tobira* WTAiton), and other species typical of coastal parks. The presence of trees camphor (*Cinnamomum camphora* J. Presl.) suggests that the vegetation was also composed of exotic species (Fig. 3). Rectangular concrete surfaces for mini golf were subsequently placed in the park, which are inappropriate for this type of park and its original stylistic characteristics. The remaining greenery is located on free areas between tourist accommodation, sports field, and parking lot, with a significant share in the structure of vegetation made up of acacia specimens (*Robinia pseudoacacia* L.).

The dendroflora of this green area consists of 35 species and varieties, represented by a total of 271 specimens [16]. They are dominated by deciduous species, which are represented by 28 species and 240 specimens, which makes up 88.56% of the total dendroflora of the area. Conifers are represented by only seven species and varieties and 31 specimens (11.44%).

Fig. 3 Camphor with old pines and cypress tree (Photo by M. Curovic)

Table 1 List of the most common species of trees and shrubs – Hotel Kamelija

Species	Quantity	Percentage share (%)
Robinia pseudoacacia L.	74	27.31
Nerium oleander L	27	9.96
Pittosporum tobira W. T. Aiton	26	9.59
Laurus nobilis L.	22	8.12
Tilia argentea DC.	22	8.12
Phoenix canariensis Chabaud.	14	5.17
Ligustrum lucidum W. T. Aiton	8	2.95
Cedrus deodara (Roxb.) G.Don	7	2.58
Citrus x aurantium L.	6	2.21
Pinus halepensis Miller	6	2.21
Pinus pinea L.	6	2.21
Quercus ilex L.	6	2.21
Cupressus sempervirens L	5	1.85

The most common species in the total dendroflora of the area are acacia (*Robinia pseudoacacia* L. oleander (*Nerium oleander* L.), pittosporum (*Pittosporum tobira* WTAiton), laurel (*Laurus nobilis* L.), and silver-leaved linden (*Tilia argentea* DC.) (Table 1). These floristic elements are an indicator of the deterioration of the original structure of the dendroflora of this area. With a smaller number of specimens, there are species of ornamental trees and shrubs that belong to the original vegetation created by the planned raising of the green area during the establishment of the park and later the area around the facilities for tourists and sports fields. These include: *Pinus pinea* L., *Cedrus deodara* G.Don., *Cupressus sempervirens* L., *Quercus ilex*

L., *Pittosporum tobira* WTAiton, *Euonymus japonicus* Thunb., *Cinnamomum camphora* J.Presl., *Ligustrum lucidum* WT Aiton., and other species, which are mainly represented with a small number of individuals.

Of particular botanical value is the camphor (*Cinnamomum camphora* J.Presl), a species that is rarely found in the horticulture of this area.

The general condition in which the vegetation is located indicates the degradation processes caused by the long-term absence of cultivation. Due to irregular care, the physiological and decorative characteristics of the vegetation are disturbed, and the trees are mostly in a neglected state.

3.1.2 Green Fund of the Hotel "Plavi horizont," Luštica

Plavi Horizonti is a former hotel located in the bay of Pržno on the Luštica Peninsula. It covers the area from the beach to the vast hinterland with olive groves, groups of cypresses and Aleppo pine [9] with dense maquis which are important for erosion-protective function, conservation of the biodiversity of the area and are giving a distinctive character to the Mediterranean landscape [19]. From the beach to the hotel "Plavi horizont" there is a landscaped green belt with dominant old canary palm trees (*Phoenix canariensis*).

The hotel complex was built in the early seventies of the last century. It includes a hotel, a car camp, sports and recreational grounds, an access road, and park areas. The accompanying hotel structures are harmoniously blended and incorporated into the area so that the olive grove complex (Fig. 4) is preserved as well as the valuable pine trees and their groups.

Fig. 4 Olive grove complex hotel "Plavi horizont" (Photo by Z. Curovic)

Table 2 List of the most common tree species – Hotel Plavi horizont

Species	Quantity	Percentage share (%)
Pinus halepensis	687	35.47
Olea europaea	423	21.84
Cupressus sempervirens	255	13.16
Arbutus unedo	123	6.35
Phillyrea media	76	3.92
Quercus ilex	54	2.79
Prunus sp.	53	2.74
Fraxinus sp.	46	2.37
Robinia pseudoacacia	31	1.60
Ficus carica	19	0.98

Paired green areas, in addition to the introduced species traditionally used in the coast (*Cupressus sp., Phoenix canariensis, Chamaerops humilis, Washingtonia sp, Nerium oleander, Cedrus sp., Prunus laurocerasus, Eucalyptus sp.*, etc.), also contain numerous individuals of indigenous plant species (*Quercus ilex, Phillyrea media, Erica arborea, Quercus pubescens, Arbutus unedo, Punica granatum, Ficus carica*). Given the inadequate maintenance of green areas in recent decades, the decline of some trees and the development of invasive weed plant species (*Robinia pseudoaccacia*) is evident (Table 2).

The dendroflora of the investigated area consists of 45 species and varieties, represented by a total of 1937 specimens [9].

3.1.3 Green Fund of the Hotel Complex "Otrant," Ulcinj

The representatives of the dendroflora in the area surrounding the hotel "Otrant" in Ulcinj are dominated by centuries-old Aleppo pine trees (*Pinus halepensis*). This species is represented by 214 trees or 96.4% of the total fund of tree species [14]. Regarding the current physiological condition and aesthetic characteristics of the trees, it can be said that the current condition is the result of insufficient, unprofessional, and untimely care in the last few decades. The consequence of the absence of care measures is not only the presence of mechanical and phytopathological damage, but also the presence of physiological weakening and drying of trees.

Apart from the Aleppo pine, there are only *Robinia pseudoacacia* – acacia and *Cedrus deodara* – Himalayan cedars in the area around this hotel complex. The dendroflora of the investigated area consists of three species, represented by a total of 222 specimens.

Table 3 List of tree and shrub species – Hotel Jadran

Species	Quantity	Percentage share (%)
Cupressus sempervirens	71	52.20
Pinus halepensis	44	32.35
Olea europaea	5	3.67
Pinus pinea	4	2.94
Ligustrum japonica	3	2.20
Paulownia tomentosa	3	2.20
Quercus ilex	1	0.74
Phoenix canariensis	1	0.74
Nerium oleander	1	0.74
Laurus nobilis	1	0.74
Cercis siliquastrum	1	0.74
Ceratonia siliqua	1	0.74

3.1.4 Green Fund of the Hotel "Jadran," Ulcinj

Until the catastrophic earthquake on 15/04/1979, the Hotel Jadran, located on the Ratislava Peninsula, where King Nikola built a residence and a summer house, was one of the symbols of Ulcinj. The "Adriatic" was a lavish building erected on a cape above the city beach, as a continuation of the architectural coastline that begins with the Old Town.

The narrow rocky belt along the coast was spared from construction due to inaccessibility, so that the solitary pine trees and stands of wild plants remained intact and represent the connection of Ulcinj with Velika plaža and its hinterland in terms of vegetation.

Of the representatives of the dendroflora, 12 species have been recorded [10]. Dominant species are centuries-old trees of Aleppo pine (*Pinus halepensis*) and pine (*Pinus pinea*). Slightly younger trees of Aleppo pine, cypress (*Cupressus sempervirens*), olive (*Olea europaea*), and one specimen of palm (*Phoenix canariensis*) were also recorded on the central plateau (Table 3). The consequences of the influence of external factors on the growth and development of the flora at this location are noticeable on the trees. This especially refers to the influence of wind, salt, and insolation. A large number of crooked Aleppo pine and pine trees have been recorded. This, in addition to reduced decorativeness, also reduced the lifespan of these trees and increased the possibility of windbreaks.

3.1.5 Green Fund of Sveti Stefan

Landscaping of Sveti Stefan was done in several phases. In addition to older specimens (cypress, Aleppo pine, phoenix palms) and wild flora (fig, pomegranate), there are also floral elements of later stages of landscaping (pittosporum, laurel, oleander, Japanese spindle, cycads, magnolias, etc.). In addition to these species of evergreen deciduous trees, several holm oak trees have been recorded – coastal oak

Table 4 List of tree species – Sveti Stefan

Species	Quantity	Percentage share (%)
Laurus nobilis	27	24.8
Cupressus sempervirens	26	23.9
Pinus halepensis	13	11.9
Phoenix canariensis	12	11.0
Tamarix tetrandra	5	4.6
Albizia julibrissin	4	3.7
Ficus carica	4	3.7
Quercus ilex	4	3.7
Broussonetia papyrifera	3	2.8
Magnolia grandiflora	3	2.8
Chamaecyparis lawsoniana	2	1.8
Morus alba	1	0.9
Ceratonia siliqua	1	0.9
Fraxinus ornus	1	0.9
Ligustrum japonica	1	0.9
Paulownia tomentosa	1	0.9
Thuja orientalis	1	0.9

(*Quercus ilex*), carob tree (*Ceratonia siliqua*), and a couple of magnolia trees (*Magnolia grandiflora*) in one place.

Of the shrub species, the most common are *Nerium oleander* (37% of all shrub species), followed by *Pittosporum tobira* (36%), *Punica granatum* (16%), *Euonymus japonica* (5%), and other species. Among the floral elements that gave a special stamp to the appearance of Sveti Stefan are creepers, among which the most common are ivy (*Hedera helix*) and wisteria (*Wisteria sinensis*).

There is a rather small presence of perennials: santolina, rosemary, lavender, cineraria, roses, and annual ornamental plants were not even planted in the time before the renovation. At that time, almost all arrangements lost their decorativeness, the concept was disturbed, and a part of the floral elements lost its vitality. During the recording of the current situation in the field, 33 different dendrological species were recorded [8].

The most common trees (Table 4) are laurel (*Laurus nobilis*), cypress (*Cupressus sempervirens*), and Aleppo pine (*Pinus halepensis*). These species, along with the canary palm (Fig. 5), at that time, gave the basic contours of the landscape of Sveti Stefan.

3.1.6 Green Fund of the Former Camp-Settlement "Kamenovo": Budva

On the green area where the camp settlement "Kamenovo" used to be, the most cypress trees Cupressus sempervirens L., medunca – Quercus pubescens Wild and

Fig. 5 Old Canary palm in hotel complex “St. Stefan” (Photo by Z. Curovic)

Table 5 List of the most common species of trees and shrubs – Kamenovo

Species	Quantity	Percentage share (%)
Cupressus sempervirens	272	36.22
Quercus pubescens	95	12.62
Olea europaea	79	10.52
Phoenix canariensis	45	5.99
Tilia grandiflora	41	5.46
Cedrus deodara	31	4.13
Pittosporum tobira	27	3.60
Cupressus arizonica	24	3.20
Ficus carica	20	2.66
Pinus halepensis	15	2.00
Laurus nobilis	14	1.86
Robinia pseudoacacia	9	1.20
Morus sp.	8	1.07

Olea europaea olives were recorded (Table 5). Of the shrub species, the most common are oleander, laurel, and pitospor.

The areas between the old, abandoned, and demolished buildings, and buildings that are in operation along the coast and the promenade are completely abandoned, over grown with creepers and weeds. Parts of these areas are completely overgrown, with visible dried, fallen trees, intertwined with wild bushes. Medunca trees show weaker vitality than would be expected from this species in this development phase, with numerous mechanical damage and trunks surrounded by densely intertwined ivy (*Hedera helix* L.). The areas along the coast are in a slightly better condition, thanks to the active use of space during summer months. Cypresses, Canary palm (*Phoenix canariensis* Chabaud.), Cedars (Cedrus deodara Laws.), and specimens of Aleppo pine (*Pinus halepensis*) are found in these areas. The general impression is that this is a very neglected green area on which the minimum care measures have been missing for a long time.

Dendroflora consists of 34 species and varieties, represented by a total of 750 specimens [11].

3.2 *Public Green Areas*

Public green areas, with their free accessibility for all residents, fulfill the most important social functions. This group of green areas consists of the following categories: parks, squares, greenery along the roads, landscaped shores, and forest parks.

Each of these categories is characterized by a specific functional and urban purpose. Green areas intended for public use are formed within public areas where general interests are satisfied, i.e. specific contents of importance for settlements are developed.

Parks and squares are public areas that, as an integral element of the environment, are of special value for settlements, especially when they contain spatial, content, and design benchmarks that give a special character to the space and thus define the landscape of the settlement [20].

Street greenery – green areas along roads are formed in order to separate pedestrian flows and peripheral facilities from road traffic and create more favorable sanitary-hygienic and microclimatic conditions of urban space. This greenery has primarily a protective character, but its special significance is also in connecting all categories of greenery into a single system.

3.2.1 Public Green Areas of the Municipality of Kotor

The inventory of public green areas of the municipality of Kotor was made in 2019 with a detailed survey and assessment of the situation at 22 locations [17].

In the area of public green areas of the coastal part of the municipality of Kotor, 111 different species (1946) were determined, of which the most represented are: *Phoenix canariensis* (Fig. 6), *Pittosporum tobira*, *Magnolia grandiflora*, *Cupressus sempervirens*, *Pinus halepensis*, *Laurus nobilis*, *Quercus ilex*, etc. (Table 6). Of the shrub species, the most common is *Nerium oleander*.

Fig. 6 Old canary palm in public areas in front of Old City of Kotor (Photo by M. Curovic)

Table 6 List of the most common species of trees in public green areas of the municipality of Kotor

Species	Quantity	Percentage share (%)
Phoenix canariensis Chabaud.	216	11.10
Trachycarpus fortunei H. Wendl.	140	7.19
Pittosporum tobira W. T. Aiton	94	4.83
Cupressus sempervirens L. var. Stricta	69	3.55
Magnolia grandiflora L.	67	3.44
Ligustrum lucidum W. T. Aiton	64	3.29
Cupressus sempervirens L. var. Robusta	63	3.24
Pinus halepensis Miller	58	2.98
Cupressus sempervirens L. var. Horizontalis	45	2.31
Tilia sp. L.	44	2.26
Laurus nobilis L	43	2.21
Quercus ilex L.	43	2.21
Chamaerops humilis L.	36	1.85
Prunus laurocerasus L.	34	1.75
Robinia pseudoacacia L.	33	1.70

The large number of species and varieties in a relatively small area speaks of the importance of arranging green areas over a longer period of time. The need to enrich life with a narrow space at the foot of steep cliffs, to calm the view from the gray cliffs of the angry karst in the tameness of cultivated greenery is certainly not recent.

Maintaining the green fund and its enrichment over time was a kind of indicator of progress and connection with the world. Hence the tradition of sailors from Boka to bring and cultivate plants from afar and thus make their place richer. Thus, over time, different floral elements were introduced. Stories about who and when brought a certain plant species to the Boka area would be told for generations, so the very desire to leave something to live and remind after a short lifespan created a kind of green endowment in this area.

Of the recorded floral elements, the largest number are species to which climatic conditions correspond. However, due to environmental factors and species biology, some representatives of the flora do not find their optimum for growth and development in the given locations. These are mainly continental species which, due to the specific climatic conditions, do not have the decorative properties of the continental part. These species therefore do not use the space in the right way and their replacement should be considered.

Of the invasive species *Robinia pseudoacacia* and *Ailanthus altissima* are the most numerous [21]. Their number should be controlled and prevented from spreading, and specimens that are self-growing and do not correspond to the places where they are located should be replaced with species that will enrich the space in a better way.

Floral elements are mainly widespread, which, given the habitat, is expected in this area. However, the lack of timely care measures in the long run also affected the condition of these representatives of tree species fund.

During the earlier period, the lack of care measures contributed to the reduction of the visual experience as well as to the reduction of the vitality of the existing vegetation. Mechanical damage is noticeable on the trunks of a large number of trees. Trees with dry and damaged branches can additionally be a potential hotbed of phytopathological and entomological attacks.

The proximity of the road additionally affects the greater vulnerability of vegetation and causes a shorter lifespan, so intensive care of these green areas is necessary.

All this has reduced the decorativeness of both individual trees and the entire greenery. From this we should single out a number of decoratively valuable trees that give recognizable contours to this space.

3.2.2 The Large City Park: Tivat

The large city park Tivat is one of the oldest planned parks in Montenegro, whose basic floristic, architectural, and stylistic features are still well preserved. Large City Park is one of the oldest parks in Montenegro. It was founded in 1892 by Admiral of the Austro-Hungarian Navy Freiherr Von Sterneck, and the construction was led by the commanders of the ships Hnatek, Padevit, Ziegler, Denning, Heinrich, and C. Lanjuz, as well as manager Nedwich, as evidenced by the inscription on the memorial plaque in the central part of the park. The boundaries of the park were corrected during 2007–2008 through cooperation between the Municipality of Tivat

Table 7 List of the most common species of trees and shrubs – Large City Park in Tivat

Species	Quantity	Percentage share (%)
Pinus halepensis Miller	209	18.85
Robinia pseudoacacia L.	138	12.44
Laurus nobilis L.	120	10.82
Cupressus sempervirens var. Horiz. L.	86	7.75
Pinus pinea L.	75	6.76
Viburnum tinus L.	63	5.68
Pinus pinaster Aiton	32	2.89
Eucalyptus globulus Labill.	29	2.61
Quercus petraea Liebl.	26	2.34
Cupressus sempervirens L. var. pyramidalis	27	2.43
Ligustrum lucidum W.T.Aiton	21	1.89
Platanus x acerifolia Willd.	18	1.62
Chamaerops excelsa Thunb.	18	1.62
Nerium oleander	17	1.53
Melia azedarach	14	1.26
Celtis australis L.	12	1.08
Cedrus deodara G.Don	12	1.08
Quercus pubescens Willd.	11	0.99

and the Institute for Nature Protection. This area has been under protection since 1968, and its management is taken care of by the Protection Committee under the auspices of the Municipality of Tivat.

In addition to indigenous species of trees and shrubs, there are numerous Mediterranean species and exotics with specific phytogeographical, taxonomic, and ecological characteristics. The richness of plant species was acquired by the park by the custom that every sailor tied to Tivat, on his return from his travels, would bring a tree to be planted in this area. Thus, the park, in its heyday, was an exhibition of numerous exotic plant species. Although devastated and greatly impoverished, this park still represents a unique plant whole. Numerous trees of Aleppo and coastal pine, eucalyptus, large-flowered and lily-of-the-valley magnolia, cypress, cedar, etc. still testify to its former splendor, and a very old wisteria that climbed up a pine tree (Table 7). Two Chilean fir trees (*Araucaria bidwillii*), which are often said to be unique in Europe, also provide park specialty.

The survey from 2013 recorded 97 species of trees and shrubs [13]. The representatives of the dendroflora are dominated by centuries-old trees of Aleppo pine (*Pinus halepensis*), pine (*Pinus pinea*) (Fig. 7), and cypress (*Cupressus sempervirens*).

In addition to these species, there are eucalyptus (*Eucalyptus globulus* Labill.), Coastal pine (*Pinus pinaster* Aiton), pedunculate oak (*Quercus petraea* Liebl.), Laurel (*Laurus Nobilis* L.), but an increasing number of invasive species such as acacia (*Robinia pseudoacacia* L.). Of the shrub species the most common are *Viburnum tinus* and *Nerium oleander*.

Fig. 7 Pinus pinea in the Large City Park – Tivat (Photo by M. Curovic)

3.2.3 Park-Forest: Miločer

Miločer Park-Forest is located on the stretch between Pržno Bay and Sveti Stefan. The dendroflora of the investigated area consists of 42 species, represented by a total of 812 specimens [15].

A large part of this area is under olive trees with a characteristic terraced terrain. The belt along the road is dominated by Aleppo pine and cypress. The area where the hotel building "Kraljicina plaza" is located with a small parking lot, driveways, terraces, etc. The green areas next to the hotel are planned, and elements of exotic plant species can be seen: *Phoenix canariensis, Magnolia grandiflora, Taxus baccata, Pittosporum tobira*, but also *Platanus acerifolia*. The unarranged parts are dominated by *Carpinus orientalis, Morus sp*. and acacia *Robinia pseudoacacia* (Table 8).

3.3 Former Military Facilities

3.3.1 Kumbor

The location is located 6 km east of Herceg Novi, is a coastal belt of the northern part of the Kumbor Strait. Until about 20 years ago, this location was intended for use by the Army. During the period of using this location, special attention was paid to

Table 8 List of the most common tree species and varieties – Miločer Forest Park

Species	Quantity	Percentage share (%)
Olea europaea	252	31.03
Cupressus sempervirens horizontalis	85	10.47
Pinus halepensis	75	9.24
Carpinus orientalis	72	8.87
Cupressus sempervirens pyramidalis	69	8.50
Quercus pubescens	50	6.16
Laurus nobilis	47	5.79
Platanus acerifolia	22	2.71
Cupressus sempervirens	12	1.48
Robinia pseudoacacia	12	1.48
Ficus carica	11	1.35
Morus sp.	10	1.23

Fig. 8 Old cypress trees with California fan palms (Photo by Z. Curovic)

landscaping, which resulted in a rich dendrological basis that gave special value to this area.

During a survey in 2013 [12], in an area of a total of 241,695 m^2, which once housed a military complex with a barracks, a former command building, a military ambulance, a dock, warehouses, a stadium, a church, etc., neglected green areas were found with groups of outstanding specimens of old cypresses (*Cupressus semp. Pyramidalis*) (Figure 8), palms (*Washingtonia filifera* H.Wendl. and *Phoenix*

Table 9 List of the most common tree species – Kumbor

Species	Quantity	Percentage share (%)
Pinus halepensis Mill.	316	21.70
Cupressus semp. horizontalis	274	18.82
Cupressus semp. pyramidalis	241	16.55
Phoenix canariensis Chabaud	110	7.55
Eucalyptus globulus Labill.	89	6.11
Washingtonia filifera H. Wendl.	60	4.12
Robinia pseudoacacia L.	38	2.61
*Melia azedarach*L.	32	2.20
Ligustrum japonicum Thunb	29	1.99
Cupressus arizonica Greene	24	1.65
Platanus orientalis L.	18	1.24
Morus alba L.	17	1.17
Pinus nigra Arn.	16	1.10
Pinus pinea L.	15	1.03
Laurus nobilis L.	14	0.96
Citrus sp.	12	0.82
Olea europaea L.	11	0.76
Quercus ilex L.	10	0.69

canariensis Chabaud), Stone pine (*Pinus pinea* L.) and eucalyptus (*Eucalyptus globul*. Labill.) as well as individual valuable specimens of veterans of Aleppo pine (*Pinus halepensis* Mill.) and plane trees (*Platanus orientalis* L.) (Table 9).

The dendroflora of the investigated area consists of 52 species, represented by a total of 1,456 specimens [12].

4 Conclusion

The presented data on landscaped green areas of the Montenegrin coast showed the following:

– A large number of species are present on public green areas in relation to hotel complexes.
– 111 species have been recorded on the public green areas of the municipality of Kotor, and 97 species in the Great Park in Tivat. At the location of the former military complex Kumbor, 52 species were recorded, while 42 species were registered in the park-forest Miločer, which surrounds the former hotel Kraljičina plaza.
– When it comes to greenery within hotel complexes, the number of registered species ranges from a minimum of three within the Otrant hotel, over 12 different species within the hotel complex Jadran, 33 on Sveti Stefan, and 45 within the hotel complex Plavi horizonti.

- The following species have a large presence on almost all landscaped green areas of the Montenegrin coast: *Pinus halepensis, Cupressus sempervirens, Olea europaea, Laurus nobilis*, while on the public areas of the municipality of Kotor the largest representation is the Canary palm *Phoenix canariensis* Chabaud.
- The Canary palm, together with the pine *Pinus pinea* and cypress, also had high marks for decorativeness in the mentioned studies. Unfortunately, with the appearance of the red palm weevil (*Rhynchophorus ferrugineus* Olivier), the number of canary palm specimens has been significantly reduced in the last few years.
- The most common shrub species are: *Nerium oleander, Pittosporum tobira, Viburnum tinus, Punica granatum, Euonymus japonica.*
- As a consequence of the absence of care measures during the nineties of the last century, and even later, there was a degradation of landscaped green areas. This is the reason for the significant presence of invasive species, especially *Robinia pseudoacacia*, which is the most common species in the green belt around the Kamelija Hotel, while it is the second most numerous species in the Great City Park in Tivat.

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Quantification and Classification of Beach Litter in Montenegro (South-East Adriatic Sea)

Milica Mandić, Slađana Gvozdenović, Ines Peraš, Aleksandra Ivanović, and Nemanja Malovrazić

Contents

Abstract Marine pollution affects the changes in the physical and chemical characteristics of the sea and the ocean, biological communities, and the overall health of the marine ecosystem. Measures to control pollution, prevention, and improvement of conditions are essential to preserve the state of the sea and they represent one of the greatest challenges of the Integrated Coastal Zone Management (ICZM). This paper presents results of the monitoring activities of two beaches on Montenegrin coast conducted during three seasons (autumn 2018, winter 2018, and spring 2019). Obtained results indicate a fairly high level of beaches pollution by solid waste during all investigated seasons. Average abundance of marine litter was estimated to be 0.35 items/m^2 and 0.85 items/m^2 on Jaz and Blatna beach, respectively.

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According to Clean Coastal Index (CCI) Jaz beach belongs to moderately clean beaches (average CCI = 7), while Blatna beach belongs to dirty beaches (average CCI = 17.14). The largest percentage share of marine litter belongs to artificial polymer materials (APM) on both beaches with cumulative percentage of 90.6% and 79.11% of total litter on Jaz and Blatna beach, respectively. Comparative data with similar research in the Adriatic-Ionian region suggest there is a growing trend of the amount of marine litter on beaches.

Keywords Clean coastal index, Marine litter, Marine pollution, Montenegro, South Adriatic

1 Introduction

Marine litter is one of the most widespread problems facing all countries in the world. Beaches, coastal ecosystems, and river basins, which are the basis of tourism development in Montenegro, are negatively impacted by litter, and it is extremely important to reduce the amount and negative impact of marine litter through a collaborative, state, and inter-institutional approach that relies on the strengths and resources of local communities, organizations, and state institutions.

Marine litter (any manufactured or processed solid material discarded in the marine and coastal environment) poses a major threat to marine ecosystems in the Mediterranean Sea due to its environmental, economic, safety, health, and cultural impacts.

In some Mediterranean countries, marine litter problem is reaching a state of emergency. The amount of litter on the beaches is constantly increasing, along with the increase in the amount of marine litter on the seabed and floating litter [1–3]. Marine litter that reaches the beaches and the sea is transported via rivers dumped directly as a result of various activities occurring on land, litter coming from ships, while part of the litter reaching the sea through the illegal management of urban waste.

In some areas of the Adriatic Sea and the Mediterranean, the situation is deteriorating by the circulation of sea waters that result in accumulation of litter in coastal areas or beaches, while in some cases origin of litter could be from nearby countries. In general, sea bed litter tends to become trapped in areas of low circulation where sediments are accumulating [4–6].

The regional approach to problem solving is a step towards success, especially given the fact that marine litter goes beyond national borders. The Adriatic Sea is a semi-enclosed basin with poor seawater circulations and long water retention, making it vulnerable and very sensitive to persistent pollution, especially when it comes to plastic waste. Practices to date have shown that the most effective system is system of interventions and organized intensive marine litter monitoring programs

[7–11] which include also volunteer work, or more coordinated and widespread waste collection programs (especially including the fisheries sector).

The management of marine litter should include the collection, sorting, transport, storage, and disposal, that is, a set of all activities and measures prescribed usually by the Law on Waste Management. Waste management depends on many factors, but above all on the existence of legal regulations and good organization, inter-institutional cooperation and good information of all participants in the process.

In order to achieve a good environmental status of the marine ecosystem, Montenegro, together with other European Union countries, has committed itself to implementing the Marine Strategy Framework Directive (MSFD) (EU 2008/56/EC). The MSFD is an environmental pillar of European maritime policy designed to establish a framework for the sustainable use of European marine waters. The MSFD aims to achieve Good Environmental Status (GES) of EU marine waters by 2020. For those countries that have not defined criteria and standards for achieving good environmental status by 2020, they must do so during the initial environmental assessment; identify objectives, monitoring programs, and proposed measures for each area defined through MSFD. In order to assist Member States in interpreting the meaning of GES in practice, the Directive sets out 11 qualitative descriptors in Annex I of the MSFD describing what the environment will look like when a GES is achieved. Among the above descriptors, descriptor 10 refers to the problem of marine litter. MSFD requires EU member states to ensure that “the properties and quantities of marine litter do not harm the coastal and marine environment.” In order to contribute to the assessment of the coastal marine ecosystem state when it comes to marine litter pollution, this paper will present the results of monitoring of marine litter on beaches on the Montenegrin coast, which was conducted within the UNEP project “Adopt a beach.”

2 Material and Methods

Methodology used in this survey is in line with “Guidelines for the Implementation of the Adopt-a-Beach Measures in the Mediterranean” in accordance with Article 10 of the Regional Plan on Marine Litter Management in the Mediterranean.

A sampling unit is defined as a fixed section of a beach covering the whole area from the strandline to the back of the beach. One section of 100 m at each beach was monitored. The same sites were monitored during all surveys. In order to identify the start and end points of each sampling unit permanent reference points are used and coordinates obtained by GPS.

It is recommended that the “Adopt-a-Beach” measures should be conducted in the selected beaches at least two times a year in spring and autumn and ideally four times in: Spring, Summer, Autumn, and Winter.

The survey periods below are monitored:

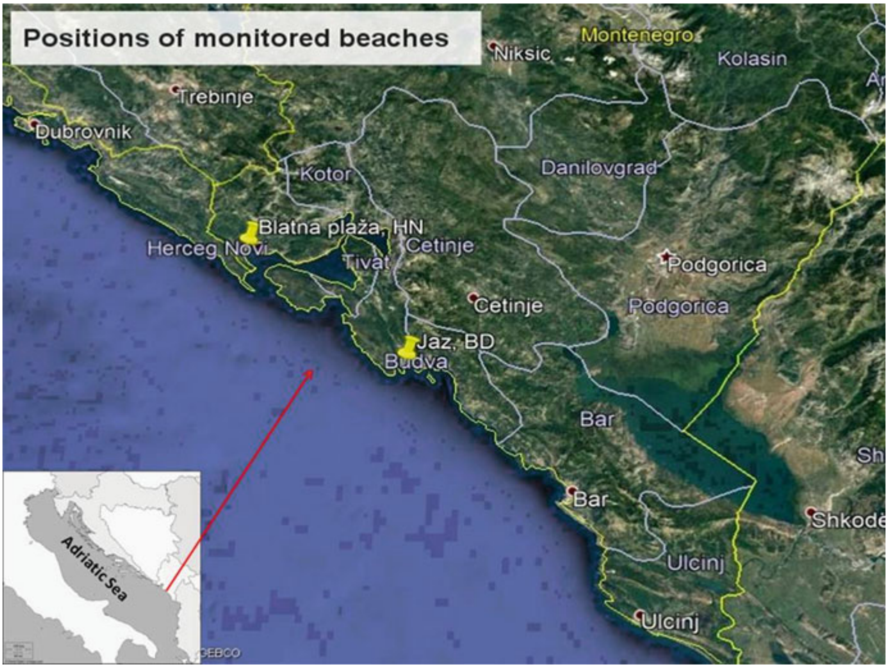

Fig. 1 Study area – positions of monitored beaches (yellow marks) (Source: Google earth)

- Winter: mid-December
- Spring: May
- Autumn: mid-October

The summer period has been excluded from the monitoring proposal due to the very high number of tourists, the fact that the beaches are cleaned during the season (from May to October), and the assumption that the data collected during the summer will not be adequate and will not show the right state of marine litter. Namely, all beach renters are obliged to clean the beaches all year round, especially from May to October. Beaches that are not leased are cleaned on a regular basis by the Public Enterprise for Coastal Zone Management of Montenegro in cooperation with coastal utility companies.

Two beaches were selected in order to monitor abundance, type, and distribution of marine litter (Fig. 1). First beach – Jaz (Svetionik beach) belongs to the municipality of Budva, it is situated in the vicinity of River Jaška and it is under the influence of open sea. The total length of the beach is about 1,300 m, with a slope about 5%. The whole length of the beach is actually an active zone that is used during the touristic season (May–October) both for swimming and recreation, and partly for the needs of restaurants, coffee bars, and accommodation for tourists. Dominant substrate is stones, while about 20% of substrate is sand.

Table 1 Coordinates and estimated area of transects

Beach	Code	Starting coordinates	Ending coordinates	Estimated area
Jaz beach	JBD	42° 16′ 46.35″ N 18° 47′ 58.89″ E	42° 10′ 49.48″ N 18° 48′ 00.37″ E	4,000 m^2
Blatna beach	BHN	42° 27′ 10.68″ N 18° 30′ 22.28″ E	42° 27′ 08.08″ N 18° 30′ 19.72″ E	1,500 m^2

Second beach – Blatna beach belongs to the municipality of Herceg Novi, it is situated in the area of semi-enclosed Boka Kotorska Bay, in the vicinity of River Sutorina. The total length of the beach is about 800 m, with a slope about 5%. The whole length of the beach is actually an active zone that is used during the touristic season (May–October) for swimming, sunbathing, and recreation, and partly for the needs of restaurants, coffee bars, and accommodation for tourists. Dominant substrate is sand, while about 30% is covered by stones.

On both beaches collection of litter was done on 100 m long transect, while width of the transect starts from shore line up to hinterland of the beach. Methodology of sampling and categorization of marine litter was based on the MEDPOL protocol (MEDPOL Marine Litter Beach Form). Sampling of litter was realized during three seasons – autumn 2018, winter 2018, and spring 2019.

The macro-litter density was calculated as follows: $CM = n/(w \times l)$, where CM is the density of litter items per m^2; n is the number of litter items recorded; w and l are the width and length of the sampling unit, respectively [12]. The number of items per 100 m stretch was also calculated. The beach cleanliness was assessed through the Clean Coast Index (CCI): $CCI = CM \times K$, where CM is the density of litter items per m^2; and K is a constant that equals to 20 [13]. According to the CCI scale values from 0 to 2 indicate very clean beaches, 2–5 clean, 5–10 moderately clean, 10–20 dirty, and >20 extremely dirty beaches.

Starting and ending coordinates, as well as estimated area of transects are given in Table 1, while in Figs. 2 and 3 investigated transects are presented.

3 Field Work

Field work was done on 4th October 2018, 24th December 2018, and 22nd May 2019 on both beaches. All collected litter was categorized in field in main litter categories: plastic, rubber, textile, glass, ceramics, processed wood, metal, paper, sanitary waste, medical waste, paraffin/wax. Detailed sub-categorization was done at the Institute of Marine Biology, and each litter item was categorized according to the MEDPOL protocol, counted, and weighted (Figs. 4 and 5).

Fig. 2 Transect on Jaz beach (Source: Google earth)

Fig. 3 Transect on Blatna beach (Source: Google earth)

4 Results

4.1 October 2018

Obtained results indicate a fairly high level of beach pollution by solid waste. On Jaz beach a total of 3,494 items/100 m of marine litter were collected, with total weight of 4.78 kg, while on Blatna beach a total of 1,186 items/100 m were collected, with total weight of 13.66 kg. Natural wood was present with 52 items/100 m and

Fig. 4 Marine litter sampling on Blatna beach (Photo by S. Gvozdenović)

Fig. 5 Categorization of sampled litter (Photo by S. Gvozdenović)

0.22 kg/100 m for Jaz, and 20 items/100 m and 0.19 kg/100 m for Blatna beach transect.

Abundance of marine litter was calculated to be 0.87 items/m^2 and 0.79 items/m^2 on Jaz and Blatna beach, respectively. According to CCI, both beaches belong to dirty beach (CCI = 17.4 and CCI = 15.81 for Jaz and Blatna beach, respectively).

The largest percentage share of litter belongs to artificial polymer materials (APM) on both beaches, with a slightly largest share on Jaz beach (95.35%) compared to Blatna beach (89.02%). After APM, dominant litter groups are metal

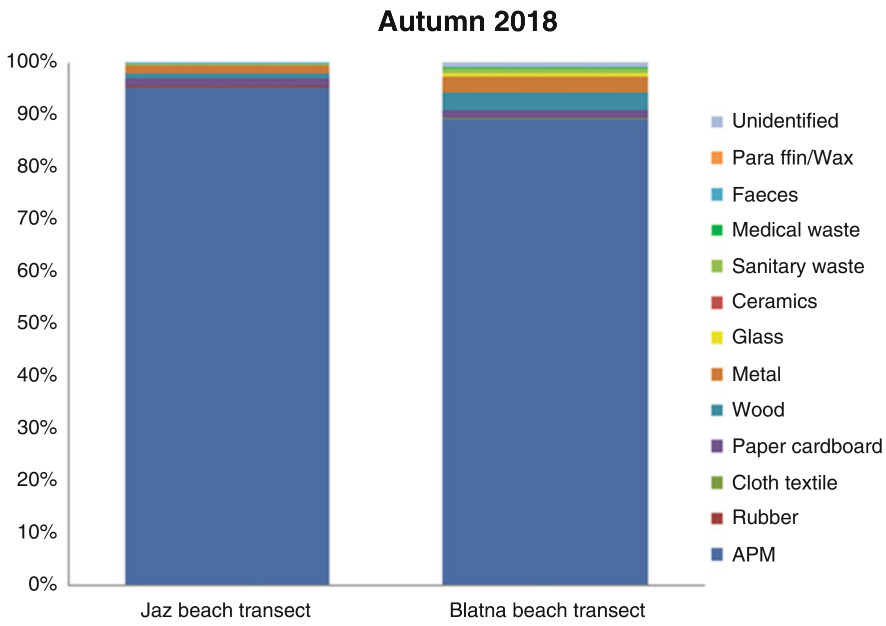

Fig. 6 Percentage share of main litter categories collected on 100 m transects on both beaches during autumn 2018

(1.42%) and paper cardboard (1.45%) on Jaz beach, and processed wood (3.43%), metal (2.91%), and paper cardboard (1.63%) on Blatna beach (Fig. 6).

Dominant litter items on both beaches were cigarette butts and filters, which belongs to plastic/polystyrene. Dominant litter items by size belongs to plastic pieces with size range from 2.5 cm up to 50 cm – cups, food trays, food wrappers, drink containers. In total it was collected 3,154 and 755 cigarette butts and filters, 43 and 93 plastic pieces with size between 2.5 cm up to 50 cm on Jaz and Blatna beach, respectively.

4.2 December 2018

During the winter period, in total, it was found 382 items/100 m with total weight of 23.66 kg on Jaz beach and 778 items/100 m with total weight of 35.1 kg on Blatna beach. Abundance of marine litter was estimated to be 0.09 items/m^2 and 0.51 items/m^2 on Jaz and Blatna beach, respectively. Natural wood was present with 78 items/100 m and 1.115 kg/100 m for Jaz, and 211 items/100 m and 3.951 kg/100 m for Blatna beach transect.

According to CCI, Jaz beach belongs to clean beach (CCI = 1.9), while Blatna beach belongs to dirty beach (CCI = 10.37).

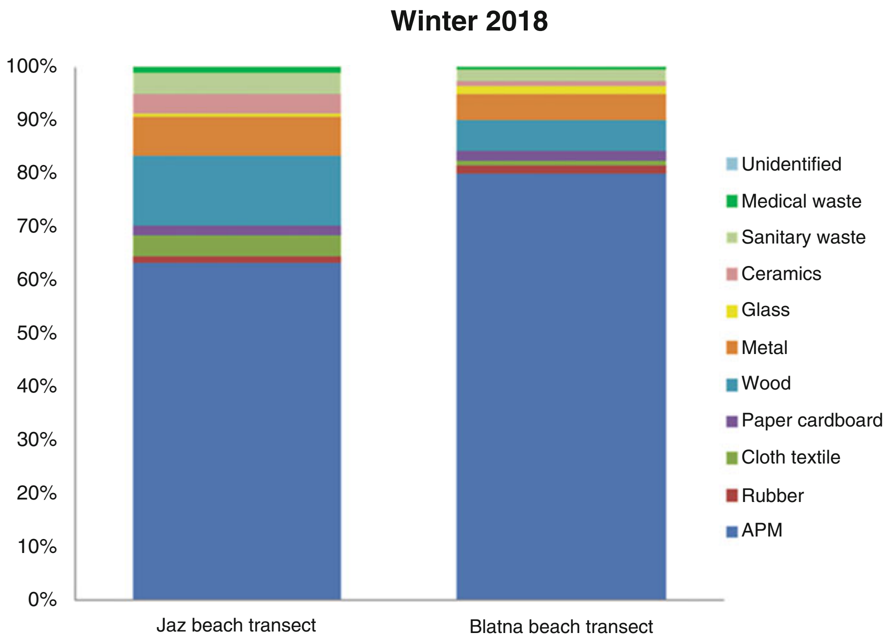

Fig. 7 Percentage share of main litter category collected on 100 m transects on both beaches during winter 2018

As well as during the autumn sampling, results showed largest percentage share of APM on both beaches, with a slightly largest share on Blatna beach (63.08% and 80.07%). After plastic, dominant litter groups were processed wood (13.08% and 5.91% on Jaz and Blatna beach, respectively) and metal (7.32%, 4.75% on Jaz and Blatna beach, respectively) (Fig. 7).

Dominant litter item during winter period on Jaz beach transects were plastic/polystyrene pieces from 2.5 cm up to 50 cm. Dominant litter items by size belongs to wood pallets and plastic caps and lids (including rings from bottle caps/lids). In total it was collected 59 of plastic/polystyrene pieces from 2.5 cm up to 50 cm, 48 wood pallets and 38 plastic caps and lids (including rings from bottle caps/lids).

Dominant litter items on Blatna beach transects were also plastic/polystyrene pieces from 2.5 cm up to 50 cm. Dominant litter items by size belongs to plastic caps and lids (including rings from bottle caps/lids) and plastic drink bottles. In total it was collected 148 plastic/polystyrene pieces from 2.5 cm up to 50 cm, 114 plastic caps and lids (including rings from bottle caps/lids), and 102 plastic drink bottles.

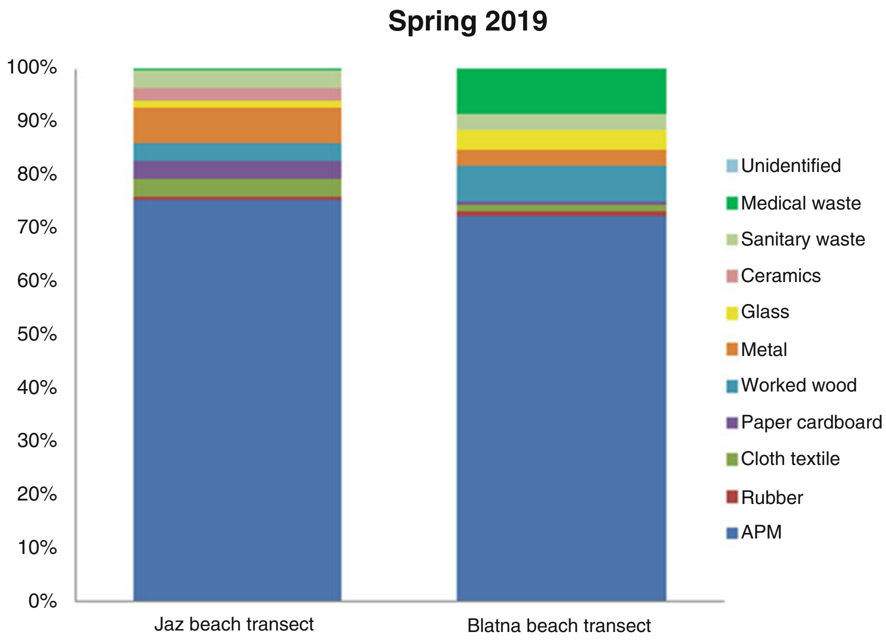

Fig. 8 Percentage share of main litter category collected on 100 m transects on both beaches during spring 2019

4.3 May 2019

During the spring period, results showed higher pollution by marine litter on Blatna beach. In total, it was found 409 items/100 m with total weight of 19.97 kg on Jaz and 1895 items/100 m with total weight of 38.47 kg on Blatna beach. Abundance of marine litter was estimated to be 0.102 items/m^2 and 1.263 items/m^2 on Jaz and Blatna beach, respectively. According to clean coastal index, Jaz beach belongs to clean beach (CCI = 2.05), while Blatna beach belongs to extremely dirty beach (CCI = 25.26).

The largest percentage share of litter belongs to APM on both beaches (75.3% and 72.3% on Jaz and Blatna beach, respectively). After plastic, dominant group on Jaz beach was metal (6.84%), while on Blatna beach it was medical waste (8.6%) (Fig. 8).

Dominant litter items on Jaz beach were plastic caps and lids (including rings from bottle caps/lids). Dominant litter items by size belong to plastic/polystyrene pieces from 2.5 cm up to 50 cm and plastic drink bottles. In total it was collected 58 plastic caps and lids (including rings from bottle caps/lids), 46 plastic/polystyrene pieces from 2.5 cm up to 50 cm, and 36 plastic drink bottles.

Dominant litter items on Blatna beach transects were plastic/polystyrene pieces from 2.5 cm up to 50 cm. Dominant litter items by size belong to plastic caps and lids (including rings from bottle caps/lids) and wood pallets/processed timber. In total it was collected 496 plastic/polystyrene pieces from 2.5 cm up to 50 cm, 151 plastic caps and lids (including rings from bottle caps/lids) and 121 of wood pallets/ processed timber.

5 Cumulative Data for All Investigated Seasons

Obtained results indicate a fairly high level of beaches pollution by solid waste during all investigated seasons. On Jaz beach during all three seasons it was found in total 4,227 items/100 m with total weight of 48.4 kg, while on Blatna beach it was found in total 3,831 items/100 m with total weight of 85 kg. Average abundance of marine litter during all three seasons was estimated to be 0.35 items/m^2 and 0.85 items/m^2 on Jaz and Blatna beach, respectively. According to CCI Jaz beach belongs to moderately clean beaches (CCI = 7), while Blatna beach belongs to dirty beaches (CCI = 17.14).

The largest percentage share of marine litter belongs to APM on both beaches (Fig. 9) with cumulative percentage of 90.6% and 79.11% of total litter on Jaz and Blatna beach, respectively. After plastic, dominant group of marine litter on Jaz beach was metal (2.48%), while on Blatna it was worked wood (5.58%) (Fig. 9).

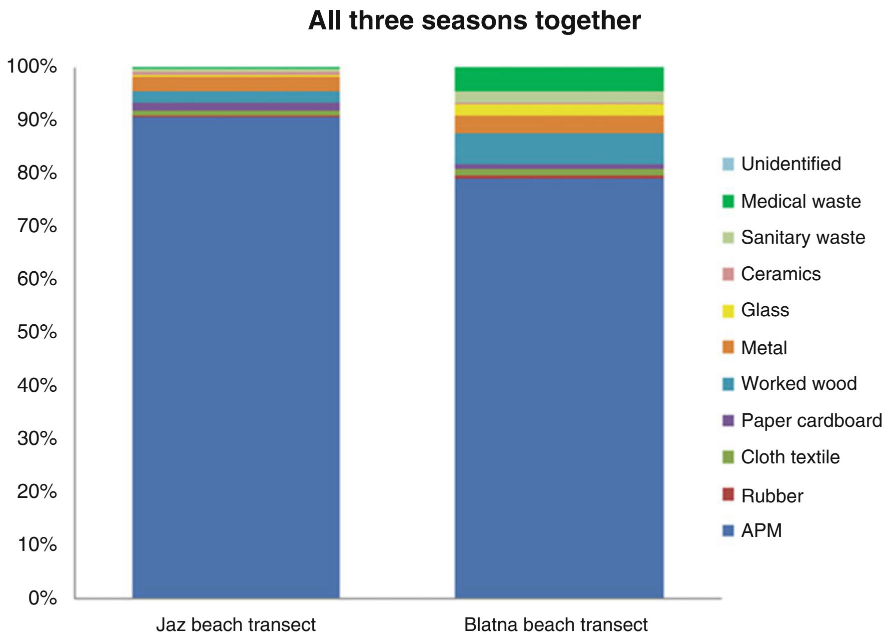

Fig. 9 Percentage share of main litter category collected on 100 m transects on both beaches during all three seasons

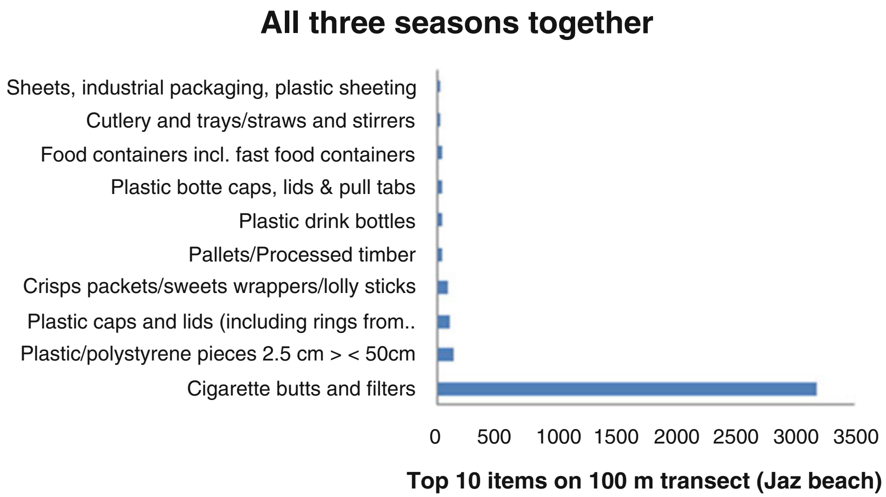

Fig. 10 Top 10 items found on Jaz beach during all three seasons

Dominant litter items on both beaches were cigarette butts and filters. Dominant litter items by size on Jaz beach belong to plastic/polystyrene pieces from 2.5 cm up to 50 cm and plastic caps and lids (including rings from bottle caps/lids). In total it was collected 3,181 of cigarette butts and filters, 148 plastic/polystyrene pieces from 2.5 cm up to 50 cm, and 109 plastic caps and lids (including rings from bottle caps/lids) (Fig. 10).

Dominant litter items by size on Blatna beach belong to plastic/polystyrene pieces from 2.5 cm up to 50 cm and plastic caps and lids (including rings from bottle caps/lids). In total it was collected 775 cigarette butts and filters, 737 plastic/polystyrene pieces from 2.5 cm up to 50 cm, and 292 plastic caps and lids (including rings from bottle caps/lids) (Fig. 11).

6 Discussion

The results of this research indicate the dominance of plastic polymers in relation to all other groups of marine litter on beaches. During all three seasons, the average share of APM was 90.6% and 79.11% of total litter on Jaz and Blatna beach, respectively, which is in line with previous investigations conducted in the Adriatic-Ionian region where on an aggregated level of total counts of litter items in all surveyed beaches in the region the amount of plastics reached 91% [14]. During the research conducted in several Mediterranean countries (Italy, Greece, France, Spain, Albania, and Turkey) in winter 2017/2018 APM was present with 82% in total litter count [15]. The results of the percentage share of the main categories of beach litter in Greece, which were obtained during numerous volunteer actions of

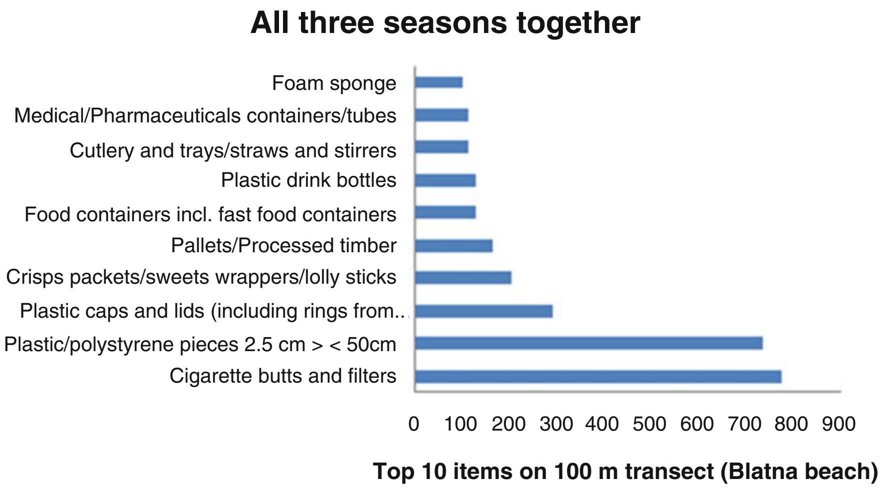

Fig. 11 Top 10 items found on Blatna beach during all three seasons

cleaning 80 beaches, showed that plastic was the most abundant litter material found on the surveyed beaches (43–51%) [16]. Those results are in accordance with previous investigations which showed that plastic is the most common material observed due to its durability, wide usage, and high disposal rates [17].

Of the three seasons surveyed, the largest amount of litter was found during autumn sampling, then during spring, while the smallest amount of litter was found during winter sampling. These results are in line with the research conducted on Montenegrin beaches during 2015, when the largest amount of litter was found during the summer and autumn [18].

When it comes to the number of litter items per 100 m of the investigated transect, in this research it was found in the range of 382–3,494 items/100 m, while abundance was in range from 0.09–1.263 items/m^2 (average 0.604 items/m^2). The average beach litter density of 0.67 items/m^2 (average: 658 items/100 m; range: 219–2,914 items/100 m) was also found within the study for the Adriatic and Ionian macro-region [14]. Same research showed that aggregated results on national level in Adriatic-Ionian region showed that the beaches most affected are those surveyed in Croatia (2.91 items/m^2); followed by beaches in Slovenia (0.50 items/m^2); Montenegro (0.37 items/m^2), Italy (0.28 items/m^2), Greece (0.24 items/m^2), Albania (0.22 items/m^2), and Bosnia and Herzegovina (0.17 items/m^2).

More recent data on beach litter pollution in the Adriatic Sea indicate a significantly high level of pollution in Croatia with a mean abundance of 3.35 items/m^2 with dominance of APM with total share of 93.86% [19].

Although larger amounts of litter on beaches which are exposed to the open sea can be explained by the circulation pattern of surface currents in the Adriatic Sea [19], in our study significantly larger amounts of litter were found on the beach which is not under the influence of the open sea (Blatna beach). However, during the research conducted in the period 2014–2015 on the same beach (Blatna beach) it was estimated twice less pollution by marine litter compared to the beach that was under the influence of the open sea [18].

The analysis of the general flow of sea currents shows that in winter, in front of the Montenegrin coast, the general flow of current along the entire depth is parallel to the coast and directed from south-east to north-west. In summer, the movement of sea mass has the opposite direction, and the general flow of current is in sector east to south-east. Such characteristics of sea currents in front of the Montenegrin coast will not affect the transport of marine litter from the sea to the coast, but will transport it parallel to the coast or further from the coast. The exception may be to some extent the area between Budva and Petrovac due to geographical and climatological characteristics, especially in summer when the mistral partly blows towards the coast and can cause transport from the open sea to the bays and coves.

In addition to the general cyclone circulation, eddy currents are present in the Adriatic, especially the southern Adriatic cyclonic vortex, but also eddy currents around the Jabučka Valley. These eddy currents are most likely the cause of the greater accumulation of waste that has been determined for the area of the South-eastern Adriatic, especially the southern coast of Croatia and Montenegro [20]. The spatial variability of marine litter is high, depending on population levels, coastal usage, hydrodynamics, riverine drainage, and shipping traffic [2].

A survey of marine litter on beaches located in a part of protected marine areas, which was conducted during the winter season 2017–2018 in several Mediterranean countries, showed that the average litter density was calculated to be 0.61 items/m^2. The abundance of litter items expressed in items/m^2 was found to be the highest in Alyki Kitrous (Greece) with a density of 6.45 items/m^2 (12.896 items/100 m). The second highest abundance of litter items was recorded at Cala Palme (Italy) with the average number of items being 1.07 items/m^2 (535 items/100 m) [15].

The situation in the Mediterranean is similar to that in the Adriatic Sea. In Spain, during almost a decade of monitoring of beach litter, it was found that the average number annual litter items on these beaches varied between 88 and 1,016 items/100 m. Plastic was the most dominant fraction, varying between 38% and 83% [21]. Nevertheless, the research was conducted within the project ACT4LITTER Marine Litter Watch Month relating to the research of beach litter within marine protected areas, showed that Spain is one of the countries with the lowest amount of litter with 0.03 items/m^2 (46 items/100 m) [15].

As in our survey, cigarette butts and filters are among the most frequent litter items found on beaches in several areas in Europe [21]. During the research conducted in 2014–2015, the same item was most abundant in Montenegro, Greece, Bosnia and Herzegovina, and Slovenia as well [14]. This situation is a consequence of bad behavior of beach visitors and lack of adequate containers for disposal of smoke-related items.

The comparative results discussed in this chapter can serve to assess the extent to which certain countries have contributed to the reduction of beach litter over the years. Namely, in accordance with UNEP Decision IG.22/10 relating to the implementation of the regional plan for marine litter (Marine Litter Regional Plan in the

Table 2 Comparative data of beach litter abundance (N of items/m^2) in the Adriatic-Ionian region

Country	N of items/m^2 2014/2015	N of items/m^2 2017/2018	References
Albania	0.22	0.13	Vlachogianni et al. [14]; Vlachogianni [15]
Croatia	2.92	3.35	Vlachoianni et al. [14]; Mokos et al. [19]
Italy	0.28	0.76	Vlachogianni et al. [14]; Vlachogianni [15]
Greece	0.24	1.68	Vlachogianni et al. [14]; Vlachogianni [15]
Montenegro	0.37	0.60	Vlachogianni et al. [14]; present paper
Slovenia	0.49	0.32	Vlachogianni et al. [14]; Vlachogianni [15]

Mediterranean) Marine litter baseline values and Marine litter environmental targets are set. The goal is to reduce the amount of marine litter on beaches in such a way that the main indicator is the percentage of reduction, by 2024 there will be a reduction in waste on beaches of 20%.

From the discussed results it is clear that in almost all countries of the Adriatic-Ionian Sea there has been an increase in the amount of marine litter on the beaches, except for Albania and Slovenia (Table 2).

However, these results must be taken with caution, because the research was not done at the same locations and dynamics of the research was different. Certainly, it can be assumed that the growing trend of marine litter on the beaches of the Adriatic-Ionian region is evident. This fact leads to the conclusion that there is a significant lack of concrete measures to reduce the amount of beach litter, but also a lack of more intensive dynamics of monitoring the state of marine litter on beaches. This situation may lead to an underestimated assessment of the amount of litter, what was already suggested by some past studies [22].

Although there are regular beach cleanup activities in Montenegro, especially of those beaches that are rented during the year; although the Public Enterprise for Coastal Zone Management of Montenegro is investing heavily in cleaning and enhancing the coast and beaches; although there is a significant number of international projects dealing with marine litter and organizing various workshops and educational activities, it is clear that beaches are extremely negatively impacted by marine litter and that solving this problem is a complex problem, which requires first and foremost alignment of legislation and urgent response of the competent institutions. Before establishing marine litter management measures at beaches and the marine environment, it is necessary to set targets, taking into account national and regional political and socio-economic contexts.

Monitoring the qualitative and quantitative status of marine litter has become increasingly pronounced in all countries of the world over the last decade. Although there are already numerous data on the degree of waste pollution in different parts of the marine ecosystem, very little data and calculations refer to the sources and amount of waste (especially plastic) that reaches the sea from the land on an annual basis. Jambeck et al. [23] estimated that between 4.8 and 12.7 million tons of waste reached the oceans in 2010. By a detailed analysis of the data provided for 192 countries of the world (http://jambeck.engr.uga.edu/landplasticinput), we found that the percentage of litter that reaches the sea is in the range of 15–40% of the total plastic waste that is poorly managed. Guided by this principle, it can be roughly estimated that the amount of plastic waste that reaches the sea in Montenegro during 2010 was in the range of 662–1766 tons per year. If there is no improvement in land-based waste management, it is projected that by 2025 this amount will increase to values in the range of 1,086–2,897 tons of waste that will end up in the Montenegrin Sea on an annual basis.

The impact of tourism on beach litter generation has been the subject of numerous studies. On the southern Brazilian coastal zone it has been established that tourism is the main source of marine debris and that beach contamination depends on beach visitor density [24]. On the other side, analyses of marine litter at 99 beaches in Cuba showed that impact of tourism on the amount of marine litter on beaches is mostly related to management for tourist purposes rather than those for environmental or sanitary policies [25]. Research conducted in Australia showed that the greatest source of beach litter was tourist-related, with this source also influencing debris loads on nearby uninhabited islands [26].

In the Mediterranean Sea, the increased coastal population and tourism are considered the major causes of the high amounts of litter recorded [27, 28]. Prevenios et al. [29] showed that regardless of the source of litter items, the natural drivers affect both the amount and composition of litter found on Mediterranean beaches, while the amount of litter deposited is clearly affected by the net effect of the wind-wave regime in combination with the orientation of the beach.

Previous analyses of beach litter in Montenegro during all seasons (winter, spring, summer, and autumn) showed that the maximum number of plastic items was found in summer, but with the lowest weight share [18], which points to the fact that during the tourist season a significant amount of small-item plastic waste is discarded on beaches. Beach litter surveys conducted at the regional level (including Montenegro) during all four seasons showed that of the total litter items collected, 33.4% originated from shoreline sources, including poor waste management practices, tourism, and recreational activities [30]. At national level in Adriatic area, the highest percentage of items originating from shoreline sources was recorded in Bosnia and Herzegovina (82%), followed by Montenegro (73.7%) [30].

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Heavy Metals Toxicity in Sediment and the Marine Environment

Danijela Joksimović, Ana Perošević-Bajčeta, Branka Pestorić, Rajko Martinović, and Neda Bošković

Contents

Abstract This study presents a review of available data on heavy metal contents in sediments collected along the Montenegrin coast, starting from 2005 to recent years. The aim was to evaluate the pollution level of Montenegrin coastal sediments by determining the concentrations of heavy metals (Fe, Mn, Zn, Cu, Ni, Pb, Cr, Cd, As, and Hg). The pollution status was evaluated using the contamination factor, pollution load index, and geo-accumulation index, as well as the statistical methods, such as cluster analysis (CA). This study showed that concentrations of individual metals at some locations were extremely high. Mean metal concentrations (mg/kg) in sediment samples during whole investigated period were in the following order: Fe > Mn > Zn > Cr > Ni > Pb > Cu > As > Hg > Cd. The calculated contamination factor and pollution load index values indicated enrichment by either natural processes or anthropogenic influences. According to contamination factor (CF), the contents of Zn, Pb, Ni, Cr, and Hg are responsible for very high contamination. Extreme Igeo values were found for Zn, Cu, Pb, and Cd (strongly or strongly

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to extremely polluted) for the sediment samples from the location Port of Bar in 2011. Also, the location Ada Bojana was characterized as strongly to extremely polluted with Ni in 2019, and Porto Montenegro was extremely polluted with Hg during 2016 and 2019 with the Igeo values of 6.18 and 6.28, respectively. Locations with the highest PLI values in surface sediments were Porto Montenegro (2018–2019) and Port of Bar (2011, 2014). Cluster analysis grouped the examined metals into two main clusters, indicating possible similar origins of the elements within the same cluster.

Keywords Assessment, Heavy metals, Montenegrin coast, Pollution, Sediment, The Adriatic Sea

1 Introduction

In recent decades, industrial liquid and human waste discharges have caused many problems for the environment. The pollution of aquatic systems by heavy metals is one of the most challenging pollution issues due to the toxicity, abundance, persistence, and subsequent bio-accumulation of heavy metals. Sediment contamination is a particular issue of concern in aquatic ecosystems. Also, marine pollution by heavy metals from anthropogenic sources is the most dangerous in the case of sediment contamination [1]. The toxicity of sediments can be defined as the ecological and biological change caused by sediment contamination [2]. Even when contaminant concentrations can be accurately measured (as it is the case when measuring metal ion concentrations), chemical analyses do not provide information on their bioavailability or the possibility of their adverse effects [3]. Heavy metals are the most persistent pollutants and less bioavailable than others because they cannot degrade under natural conditions, so the impacts of toxic metals are observed at places that are significantly away from the source [4–6]. Precisely because of this, the analysis of the distribution of heavy metals in sediments could provide proof of anthropogenic impact, allowing more consistent assessment of spatial and temporal contamination since sediments show less variation in time and space [7–10]. There are some published data about the sediment quality in the South Adriatic Sea – Montenegrin coast [11–13]. Also, there are still unpublished data about elements distribution in sediments by depth too, but only at a few locations selected according to projects goals. This paper aims to give a brief overview of the most essential data about heavy metals in sediments of the Montenegrin coast. Also, already published data will be compared with the recent research.

2 Heavy Metals

Environmental pollutants continue to be a worldwide concern and one of the significant challenges faced by the global society. Due to the rapid development in industrialization and activities on the shore, the discharge of heavy metals in the Montenegrin coastal environment has increased. Even though heavy metals are natural components of the Earth's crust, their current concentrations observed in coastal waters are the consequence of the growth of industrial, agricultural, and urban activities since the 1980s [14]. Metals in traces reach the sea from the atmosphere (rain, dust particles, and other precipitation) or they can be washed away from the land and reach the sea through rivers loaded with both atmospheric and wastewater. Industrial wastewater is also one of the major sources of metals in marine environments. Thus, coastal and industrialized areas are the most endangered when it comes to the high metal contents in the sea compared to the natural levels [15].

Human activities have led to increased contaminant concentrations in the environment [15, 16]. As a consequence of their circular flow in nature, heavy metals have a great impact on both the environment and human health [17]. They are very resistant, and they can be toxic even when they are present in trace amounts. Determination of their distribution in sediments, seawater, and biota is of great importance for environmental pollution studies.

International Union of Pure and Applied Chemistry [18] defines trace elements (TEs) as elements with an average concentration lower than about 100 part per million (ppm) or lower than 100 μg/g. Although there is no specific definition of heavy metal, it has been usually defined as a naturally occurring element having a high atomic weight and high density which is five times greater than that of water [19]. There is no exact and precise definition, but the term "heavy metals" is widely used. Earlier, the term "heavy metals" referred to trace elements. This is still being discussed, given that, e.g., Al and Ni are not heavy metals or that As and Se are not metals at all [20]. Heavy metals include several physiologically essential elements, such as Fe, Cu, Zn, Mn [21], very toxic, such as Pb, As, Hg, Ni, Cd, Sb, Sn, and less toxic (Au, Ag, Mo, Cr, and Co). Among the radioactive elements, U, Pu, and Po belong to the group of heavy metals [22]. Although these metals are abundant in rocks and mud, their concentrations are low due to their limited solubility. The atmosphere is usually the source only for Fe, Mn, Pb, and perhaps Co [23]. Because of their toxicity, persistence and accumulation in nature, and circulation in biosphere, heavy metals are hazardous pollutants of the environment and occupy a special place in environmental pollution studies. Heavy metals are often cumulative toxins that have strong effects on living organisms. The accumulation of toxic substances in the food chain can result in increased concentrations at higher levels of the chain [6].

2.1 Heavy Metals in Sediment

Heavy metals contamination is becoming a serious issue of concern around the world and one of the significant challenges in modern human society. Environmental contamination by heavy metals is a threat to the environment due to the increase in the use and processing of heavy metals during various activities in industry and because of the rapidly growing population. Soil, water, and air are the major environmental compartments which are affected by heavy metals pollution. The presence of these pollutants in aquatic ecosystems is the consequence of both natural processes and human activities. The most significant natural sources of metals are clean water systems exposed to various impacts during long periods of formation and metamorphosis of rocks in drainage basins. Decomposition of plant and animal residues also contributes to a small but significant input of metals into both surface water and sediment. The coastal zone is one of the most frequent areas disturbed by human activities like population growth, the development of small-scale and large-scale industries, harbour expansions, tourism-related activities on the coast, discharge of urban and industrial wastewater, and numerous recreational and commercial activities [24, 25]. These impacts potentially affect human health and well-being in both the short- and the long-term [26, 27].

Marine pollution and the loss of marine biodiversity affect the viability of marine ecosystems, the availability of fish stocks, and the potential for the discovery of new pharmaceutical compounds and other marine natural products from marine bioprospecting. Sediments contain both natural and anthropogenic components. The study of sediments can provide an understanding of how pollutants and particles are transported, recycled, and deposited in seawater. This research should be complemented by monitoring hydrodynamic and meteorological processes that have a significant impact on sedimentation.

The aim and nature of sediment and biota monitoring are different from water monitoring. Sediment monitoring and assessment of its quality are most often carried out in order to determine the extent to which sediment is a reservoir and a secondary source of contaminants in surface waters. Research studies can be conducted to determine the status of sediment quality and its impact on the environment, but also on human health through the study of various interactions in the ecosystem. Assessment of sediment quality is often limited to chemical characterization. In general, separate determination of pollutants and their concentrations cannot provide sufficient information to determine possible antagonistic effects and interactions between pollutants or the time-dependent availability of these substances to aquatic organisms. To control the contamination of marine sediments and to protect marine biological resources, the standards of marine sediment quality according to heavy metal contents are established. These standards are defined by directives of the European Union and various developed countries (Canada, the Netherlands, the UK, and others) [28–32].

Various methods, including enrichment factor [30, 33], index of geo-accumulation [34, 35], pollution load index [36], and potential ecorisk index [37, 38], are applied

Fig. 1 The Montenegrin coast – South Adriatic Sea – map of the studied area

in order to assess the contamination and ecological risk of heavy metals from sediments. Since each method has its limitations, to obtain the risk assessment of heavy metals from sediments, multiple methods should be used [39, 40]. In this study, the surface sediments were collected to analyse the concentrations of heavy metals (Fe, Mn, Zn, Cu, Ni, Pb, Cr, Cd, As, and Hg) and compared with data from previous research studies conducted in the coastal areas of the Montenegrin coast. Also, three different methods for the assessment of sediments metal contamination were used.

The first survey regarding heavy metals present in sediments began in the 1980s and focused on the area around Ada Bojana, as the most vulnerable spot on the Montenegrin coast. More complex research of heavy metal concentrations started at the end of the twentieth century in Boka Kotorska Bay and the beginning of the twenty-first century in the open area of the coast. This study includes available data on heavy metal contents in sediments collected from five sites along the Montenegrin coast, starting from 2005 to recent years. The sampling sites were: Porto Montenegro (S1), Žanjice (S2), Budva (S3), Port of Bar (S4), and Ada Bojana (S5) (Fig. 1). The significant amounts of heavy metals deposited in sediments of the Montenegrin coast are a consequence of industry influence, discharge or overflow of wastewater, rainfall–runoff, and inflow of impacted groundwater to streams and springs. For the last few years, Ada Bojana is one of the most popular tourist places on the Montenegrin coast with much attractive content for young people. Port of Bar is one of the largest ports on the eastern side of the Adriatic, with trading, passenger traffic, and industrial function. Port of Budva is an urban and tourist city located in the middle of the Montenegrin coastline with the number of inhabitants which multiplies several times in the summer period. Porto Montenegro is a favoured tourist place with the small marinas and big touristic luxury complex. The location Zanjice is in the vicinity of Zanjice beach, which is situated at the entrance to the Bay from the open sea. All activities which describe these sites have contributed to trace elements accumulation in coastal sediments. In other words, anthropogenic activities in the area over the last decades have a damaging effect on the marine ecosystem.

According to published studies, started in 2005–2006 in the open area of the Montenegrin coast (Zanjice, Port of Budva, Port of Bar, Ada Bojana), (Fig. 1), Fe concentration was 1.99–40.3 $\times$ 10^3 mg/kg; Mn 135–984 mg/kg; Zn 10.1–46.2 mg/kg; Cu 6.1–20.7 mg/kg; Ni 15.7–267 mg/kg; Pb 0.1–5.2 mg/kg; Cd 0.1–0.8 mg/kg; As 0.1–19.6 mg/kg; and Hg 0.01–0.03 mg/kg [11–13]. The research at these sites continued in 2010, and the results obtained during that research indicated significant differences in heavy metal concentrations in sediments from the investigated locations [12, 13]. Concentrations of elements for the period from 2010 to 2016 were [12, 13]: Fe 9.6–33.4 $\times$ 10^3 mg/kg; Mn 288–715 mg/kg; Zn 19.6–1,596 mg/kg; Cu 3.8–103 mg/kg; Ni 2.94–229 mg/kg; Pb 0.9–719 mg/kg; Cr 2.5–130 mg/kg; Cd 0.15–4.73 mg/kg; As 1.11–39.1 mg/kg; and Hg 0.01–14.2 mg/kg. This period, as well as the recent research (2018–2019), besides the locations in the open area of the coast, included one location from Boka Kotorska Bay, Porto Montenegro. Based on the research conducted during 2018–2019, the concentrations of elements ranged from: Fe 10.2–51.4 $\times$ 10^3 mg/kg; Mn 362–1,301 mg/kg; Zn 27.2–449 mg/kg; Cu 10.8–58.1 mg/kg; Ni 38.6–640 mg/kg; Pb 11.2–159 mg/kg; Cr 64.6–661 mg/kg; and Hg 0.03–15.2 mg/kg. According to these results, it can be concluded that significant amounts of heavy metals are deposited in sediments of the Montenegrin coast. In coastal sediments at investigated sites, the most present metals are Zn, Pb, Ni, Cr, As, and Hg. If we compare the obtained results, some locations distinguished by a significantly higher concentration of certain elements comparing to other locations within the investigated period, which is presented in Fig. 2.

For example, in the period from 2005 to 2016, at the location Ada Bojana, concentrations of Fe and Mn had the maximum recorded values of 40.3 $\times$ 10^3 mg/kg and 984 mg/kg, respectively, in 2006, Fig. 2. Compared with these maximum values, the concentrations of Fe and Mn in the period 2018–2019 were higher and ranged up to 51.4 $\times$ 10^3 mg/kg and 1,034 mg/kg, respectively. The specific characteristics of the area, natural movement of water masses, and sediment transport during different seasons can explain high values of metals at this site, especially Fe, compared to the natural levels [41–43]. Regarding the values obtained for these elements during the whole investigated period, Fe and Mn contents increased in the period 2018–2019 in comparison with 2005–2016. The increased values of these metals are especially pronounced at the sites Ada Bojana and Porto Montenegro for Fe, i.e. Ada Bojana, Port of Bar, and Port of Budva for

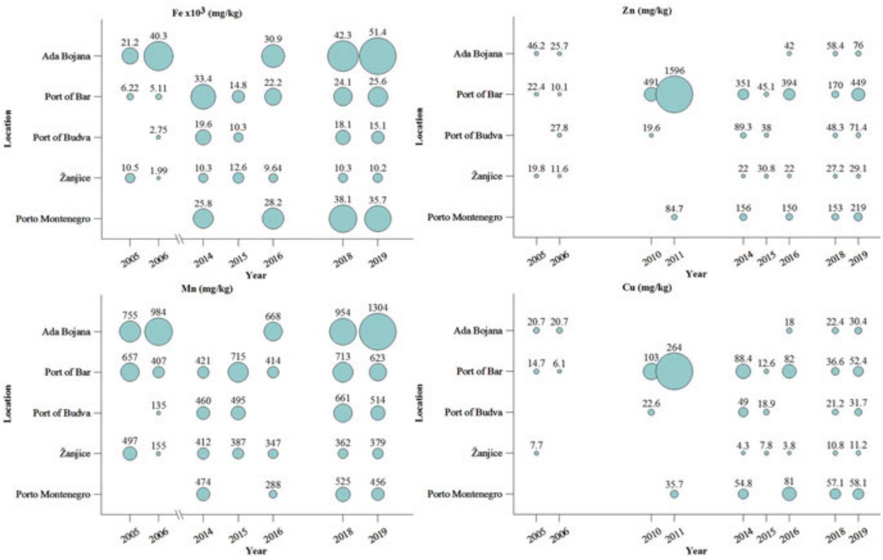

Fig. 2 Metal concentrations in surface sediments during the investigated period

Mn. However, Fe content decreased at the Port of Bar and Port of Budva in 2018–2019, compared to its content in 2014. Also, at the location Žanjice, it was noticed a decrease of Mn content in the same period, Fig. 2.

The highest concentrations of Pb, Zn, Cu, and Cd (719 mg/kg, 1,596 mg/kg, 264 mg/kg, and 4.73 mg/kg, respectively) were found at the site Port of Bar in 2011. At this site, high concentrations of Zn and Pb were also found in 2010, 2016, and 2019. Compared to previous research (2005–2016), the concentrations of Pb and Zn in 2019 increased at the location Ada Bojana and Porto Montenegro. Also, the contents of Cu were mostly equal or lower during 2018–2019, except at Ada Bojana and Žanjice where the obtained values were slightly higher than in the period 2005–2016.

During the whole study period, the highest Ni concentrations were recorded for the site Ada Bojana, with the maximum concentration in 2019 (640 mg/kg), Fig. 2. The concentrations of this element in sediment samples were on average higher in the entire area during 2018 and 2019, compared to the previous period. Due to the position of Ada Bojana (at the downstream of the river) and extensive discharging of urban industrial waste (pickling, tinning, etc.) which affects metal transformations, concentrations of Ni in sediments at this site were higher than at other sites [41, 42]. In general, highest Cr concentrations in sediment samples were found during 2018–2019. The extremely high concentration of Cr was found at the site Ada Bojana (661 mg kg) in 2019, but it was also high in 2018 (298 mg/kg). However, high Cr contents in comparison with the natural levels [43] were found at all sites, Fig. 2. The concentration of As was the highest in sediments at the location Porto Montenegro (39.1 and 39.0 mg/kg) during 2014 and 2016, while the maximum

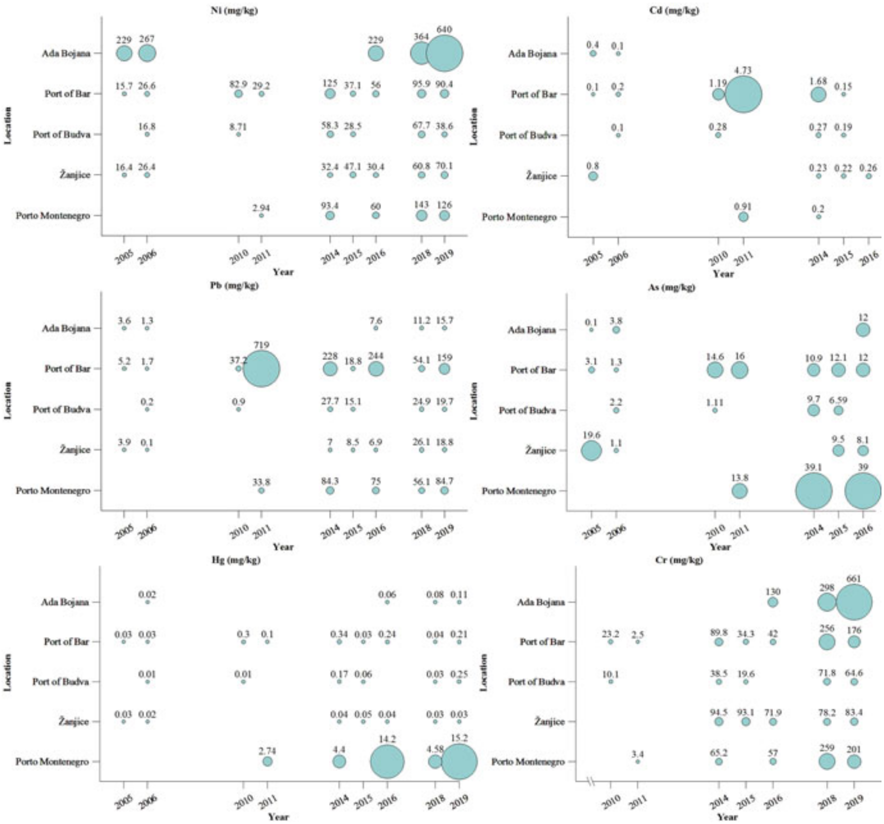

Fig. 2 (continued)

values for Hg were recorded at the same location during 2016 and 2019 (14.2 mg/kg and 15.2 mg/kg, respectively). High concentrations of As, but also of Zn and Cu (in comparison with the natural levels), are often the consequence of the anthropogenic pollution (industrial, agricultural, and liquid discharges). Regarding Hg temporal trends, besides the extreme values in 2016 and 2019, concentrations at the site Porto Montenegro were high during the whole investigated period, while at other sites Hg contents were significantly lower, Fig. 2. Due to human activities, Hg can easily reach the offshore regions through wet and dry atmospheric deposition.

Regarding the whole studied period, the obtained mean values of the heavy metals in sediment samples decreased in the following order: Fe > Mn > Zn > Cr > Ni > Pb > Cu > As > Hg > Cd. The majority of elements at all examined sites showed a significant increase in concentrations during the period 2018–2019 compared to data from 2005 to 2016. Average concentrations of most elements (Fe, Zn, Cu, Pb, Cd, As, and Hg) in surface sediments from the Montenegrin coast were higher than those in surface sediments from the South

Adriatic Sea [43–45], while concentrations of Mn, Cr, and Ni were similar or even lower than the average concentrations in surface sediments of South and Central Adriatic [43, 46]. Extreme concentrations of certain elements occasionally occur at some locations, so this is one of the reasons for the increased values compared to the average concentrations of surface sediment in the South Adriatic. Compared to the results from other parts of the Adriatic Sea, our results were in the same range as the results obtained for the different parts of the Adriatic [11, 13, 47–58]. The Montenegrin coastal waters are still under the influence of anthropogenic eutrophication (sewage, domestic, and agricultural wastes, effluents from industry, ports and shipping area, nautical tourism) and the repercussions of industrial pollution, which are still visible [13, 59, 60].

3 Assessment of Metal Contamination

To evaluate degree of contamination in the sediments, three parameters were used: Contamination Factor (CF), Pollution Load Index (PLI), and Geo-accumulation Index (Igeo).

3.1 Contamination Factor

Degree of contamination can be carried out using the Contamination Factor (CF). This index enables the assessment of sediment contamination taking into account the content of certain heavy metal from the surface of the sediment and values of background concentrations. Contamination factor is calculated according to Tomlinson et al. [61].

$$\mathrm{CF} = \mathrm{C}_{\mathrm{metal}}/\mathrm{C}_{\mathrm{background}}$$

In this study as the background concentrations for the majority of elements, average trace element contents in surficial sediments from the South Adriatic were used [43], except for Cd background concentration, where an average surficial sediment concentration from the Central Adriatic was used [46]. $\mathrm{CF} < 1$: low contamination factor; $1 \leq \mathrm{CF} < 3$: moderate contamination factor; $3 \leq \mathrm{CF} < 6$: considerable contamination factor; $\mathrm{CF} \geq 6$: very high contamination factor.

The calculated average values of the contamination factor were greater than 1 for the majority of the investigated elements. That indicates enrichment by either natural processes or anthropogenic influences [51, 62]. The CFs for the elements in the sediment samples from 2005 to 2019 showed great varieties ranging from 0.009 (Pb), 0.01 (As), and 0.02 (Ni) to the extreme values for Hg, Cd, Pb, and Zn. The highest CF values, which indicated the most extreme contamination [61], were found in 2019 at the location Porto Montenegro for Hg (114), and in 2011 for Cd (67.5), Pb (65.4), and Zn (21.0) at the location Port of Bar. Considering all the investigated metals, the increasing order of CFs is the following: Mn < Fe < Ni < Cr < Cu < As < Zn < Pb < Cd < Hg. The extreme values of the CFs (>1) for all the measured metals may be attributed to the anthropogenic activities such as urbanization, industrialization, and agricultural runoff, especially in the case of Cd and Zn enrichment [63].

3.2 Pollution Load Index

The Pollution Load Index (PLI) that refers to heavy metal concentrations was also used [61]. This index was used to assess the degree of anthropogenic metal contamination for the specific location [64]. It is calculated from the n-CFs, obtained for all the metals using the formula:

$$\mathrm{PLI} = (\mathrm{CF}_1 \times \mathrm{CF}_2 \times \mathrm{CF}_3 \times \cdots \times \mathrm{CFn})^{1/\mathrm{n}}$$

PLI value of zero indicates excellence; a value of one indicates the presence of only the baseline level of pollutants, and values above one would indicate progressive deterioration of the site and estuarine quality [61].

The pollution load index is used for comparison among areas and can provide some information about the quality of the environment [65]. The calculated pollution load index (PLI) values of metals in sediments of the Montenegrin coast ranged from 0.09 to 2.88. Figure 3 presents the average values of PLI for the studied region. According to the obtained CF values, Hg, Cd, Pb, Zn, and As are the major contributors to the sediment pollution in the Montenegrin coast. Locations with the highest PLI values in surface sediments were Porto Montenegro (2018–2019) and Port of Bar (2011, 2014).

3.3 Geo-Accumulation Index (Igeo)

Another criterion to the assessment of contamination with heavy metals in sediments is the geo-accumulation index. Classification by geo-accumulation index is used to determine the levels of contamination or accumulation of metals in sediments of a study area. Proposed by Müller [35] this index is calculated by comparing current concentrations with preindustrial levels [66]:

$$\mathrm{Igeo} = \mathrm{Log}_2\,[(\mathrm{C}n)/1.5\,(\mathrm{B}n)]$$

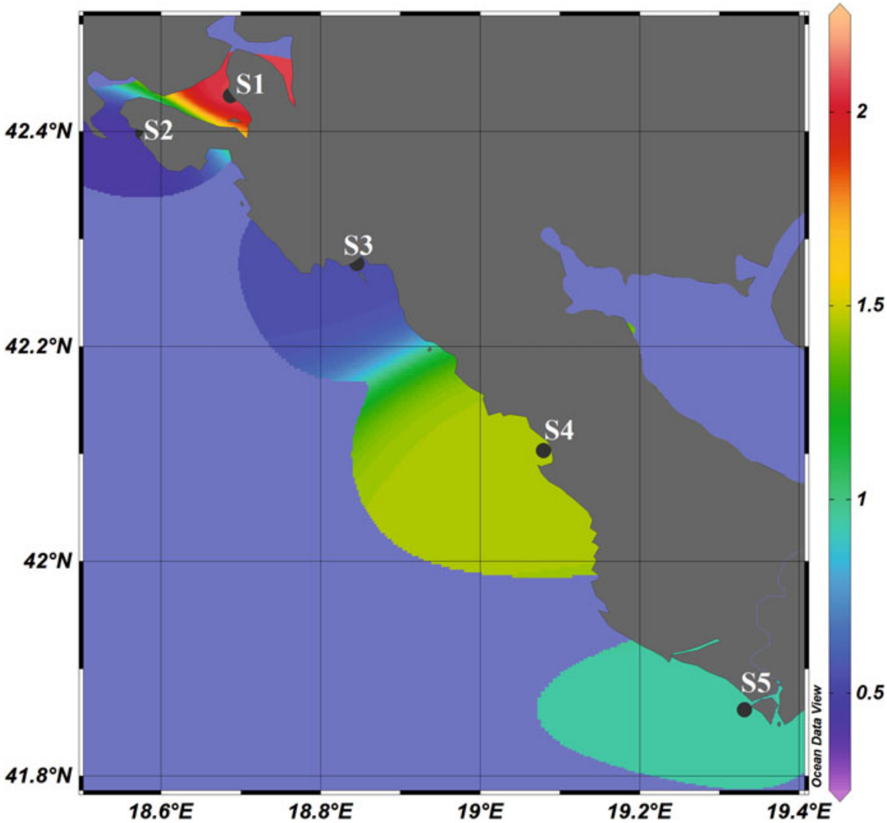

Fig. 3 The spatial distribution of the average values of pollution load index on the Montenegrin coast

where C*n* is the measured concentration of the examined metal "*n*" in the sediment and B*n* is the geochemical background concentration of the metal "*n*" (average surficial sediment contents – South and Central Adriatic) [43, 46]. Seven classes of sediment pollution can be identified based on the Igeo values [35]: 0 – unpolluted, 0 to 1 – unpolluted to moderately polluted, 1 to 2 – moderately polluted, 2 to 3 – moderately to strongly polluted, 3 to 4 – strongly polluted, 4 to 5 – strongly to extremely polluted, and >5 – extremely polluted.

The geo-accumulation index results indicated that the surface sediments were unpolluted to moderately polluted with Fe and Mn, except in the case of Ada Bojana, which was moderately polluted with Mn. According to the results for Cr and As, the entire investigated area was practically unpolluted or unpolluted to moderately polluted, except the site Ada Bojana, which was classified as moderately polluted, Fig. 4. Igeo values suggested that the investigated sites were mainly grouped as unpolluted or unpolluted to moderately polluted. Extreme values were found for Zn (4.07), Cu (3.13), Pb (4.51), and Cd (3.72) for the sediment samples from the same

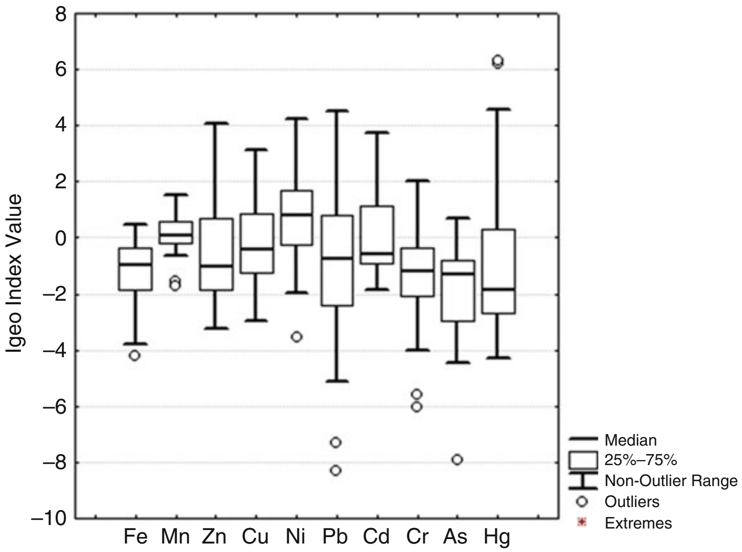

Fig. 4 Box plot for the geo-accumulation index of surface sediments

site (Port of Bar in 2011). The location Ada Bojana was characterized as moderately to strongly polluted with Ni in 2005, 2006, and 2016, strongly polluted in 2018, and strongly to extremely polluted in 2019 (with the calculated Igeo values of 2.73, 2.95, 2.73, 3.40, and 4.21, respectively). Regarding sediments Hg contamination, only the location Porto Montenegro was strongly polluted (Igeo 3.81 (2011)), strongly to extremely polluted (Igeo 4.5 (2014–2018)), and extremely polluted during 2016 and 2019 with the Igeo values 6.18 and 6.28, respectively. However, Igeo values for Zn, Cu, Ni, Pb, and Cd classified almost the entire investigated area in the range from unpolluted to strongly polluted.

The combination of Igeo and PLI in this study gave us a comprehensive understanding of the risks of heavy metals in the surface sediments of the Montenegrin coast. Also, the results showed that the differences between the values of these indices are negligible. The contents of Cu, Zn, Pb, Cd, Ni, and Hg were increased as a result of anthropogenic activities in this area, e.g. industrial activities, atmospheric deposition (maritime traffic, vehicle emissions, and oil combustion), use of protective dyes for ships and boats, aquaculture, nautical tourism, coastal runoff [67–70].

Cluster Analyses (CA) were performed to investigate the grouping of heavy metals in the sediments on the Montenegrin coast. The results, obtained as a dendrogram of metal clustering, are presented in Fig. 5. It can be seen that metals are grouped into two main clusters. Cluster 1 consists of Mn-Ni-Cr-Zn-Cu-Pb and cluster 2 consists of Cd-Hg-Fe-As. The first cluster is divided into three separate branches. Manganese presents the first branch, the second one contains Ni and Cr, while the third branch contains Cu and Pb, which are connected to Zn. The connections between essential Cu and Zn, as well as between Cr and Ni, were expected.

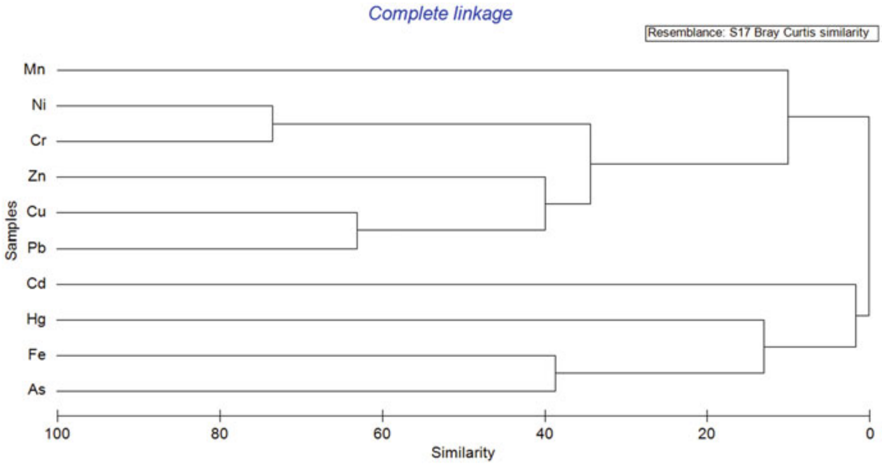

Fig. 5 Metals cluster analysis dendrogram for sediment samples

Also, the fact that these elements are connected with Mn can be explained by naturally high contents of these elements in sediments. However, the connection of all of these elements with Pb indicates an anthropogenic impact. High concentrations of these metals can be found in marine service areas, such as Porto Montenegro and Port of Bar, as the consequence of the removal of old paint layers from the boat hulls [68, 71, 72]. Cluster 2 indicates similarity between toxic elements, Cd, Hg, and As, which are also connected with Fe, Fig. 5, and therefore with lithogenic sources [72, 73].

4 Conclusions

Comparing the results obtained for heavy metals (Cu, Ni, Fe, Mn, Cr, As, Pb, Zn, Cd, and Hg) collected at five sites on the Montenegrin coast in the period 2005–2019, it can be concluded that anthropogenic impacts are probably the main factors contributing to the differences observed for these samples. Extreme metal values in sediment samples were recorded in 2011 and 2019, while metal concentrations in other years of research were lower and similar. PLI showed that the studied area could generally be classified as contaminated, while Igeo values suggested that the investigated sites were mostly unpolluted or unpolluted to moderately polluted. Extreme PLI values were recorded at the locations Porto Montenegro and Port of Bar (2.81 and 2.88, respectively), while for other locations the values were lower. Extreme Igeo values for Hg (extremely polluted), Zn, Ni, and Pb (strongly to extremely polluted), and Cu and Cd (strongly polluted) were found in only a few samples. Cluster analysis grouped all examined elements into two main clusters. Strong anthropogenic impacts were recorded near urban areas, ports, marinas, where higher metal concentrations were found.

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Analysis of the Corrosion Resistance of Different Metal Materials Exposed to Varied Conditions of the Environment in the Bay of Kotor

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Contents

Abstract Different parts of the coastal infrastructure that are made of metal are exposed to the varied conditions of the environment, which accelerates the corrosion of the materials and could, thus, increase pollution. Literature examines the degree of

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degradation of metal materials caused by corrosion and the resistance to the influences of the environment the materials are exposed to. The scientific discussion is based on the historical data regarding the key parameters of the sea and atmosphere and the changeable conditions caused by the sequences of ebb and flood tides that are typical for the Bay of Kotor. The paper presents the process of corrosion based on samples of a disc-like alloy of nickel and titanium (NiTi) and a steel fence, depending on the varied conditions of the environment and the length of exposure. The NiTi alloy was exposed to different influences of the sea and atmosphere for 6 months, while the steel fence was exposed continuously to the influences of the coastal atmosphere over a longer period of time. The chemical analysis of the particular parts of the materials and their corrosion phases was conducted by means of Energy Dispersive X-ray (EDX) semi-quantitative analysis. The results obtained from the EDX analysis were further revised by the method of linear regression and a multivariate method, principal component analysis (PCA), in order to define precisely the influences of a corrosive environment on the corrosion of the analysed NiTi alloy. The results acquired from the linear regression analysis prove that the NiTi alloy in every type of environment in coastal conditions corrodes by forming additional oxides. As expected, the corrosion caused by the air is the slowest and the most uniform, while the most intensive dissolution of nickel and titanium is in the sea, where the most heterogenous corrosive surface was registered as well. In relation to the linear regression analysis, the multivariate analysis registered the interdependence of corrosive parameters, as well as the effects of different types of corrosive environment on the degradation of the examined alloy.

Keywords Atmosphere, Bay of Kotor, Characterisation, Corrosion, EDX analysis, Environment, Fe fence, Principal component analysis, Seawater, The Adriatic Sea, The NiTi alloy

1 Introduction

The sustainability and protection of the environment are of the utmost importance and have received a lot of attention in the naval industry over the last decades. The IMO Marpol Convention thus defines clearly all potential pollutants from vessels, such as oils, chemicals, harmful cargo, waste, ballast, exhaust gas emissions, etc. Therefore, researchers aim to discover the optimal characteristics of materials and environmentally friendly surface coatings. The application of the coatings based on tar and other harmful elements are now forbidden. Likewise, a lot of research is conducted in order to measure the exhaust gas emissions in specific protected areas and, thus, preserve the environment [1].

The pollution of the environment can occur directly, through the application of harmful liquids and materials, or indirectly, in the case of malfunction of the materials that can, directly or indirectly, cause damage leading to different kinds of pollution. The application of materials in the naval industry is wide, due to the purpose and specificity of the locations where the materials are used (the depths and surfaces of the sea and atmosphere). For example, while the facilities at the sea depths are exposed to the direct influences of seawater, other vessels and mobile and fixed infrastructures are exposed to the complex influences of the sea and atmosphere throughout the year and, therefore, require the application of materials compatible with the specific conditions of the environment.

Different fixed and mobile coastal infrastructures have a huge influence on the marine ecosystem. Fixed infrastructure is often built of metal materials and represents a dominant part of the coastal infrastructure. Fixed infrastructure includes platforms for oil drilling, ports, shipyards, railways, fuel terminals, roads, seawater bridges, submarine pipelines, etc., as well as different merchant and military ships, yachts, aircraft, petrol boats, fishing boats, etc.

All constructive elements of the infrastructure are made of concrete and a great variety of constructive materials, such as steel, stainless steel, reinforced concrete, plastic, composite materials, etc. Even though metals were used a 1,000 years ago (copper, bronze, iron), it was only during the Industrial Revolution that iron became more widely applied, while its manufacturing was enhanced. Reinforced concrete and carbon steel are the main engineering materials used for the construction of marine installations and equipment. Other metals and alloys applied include aluminium, copper and stainless steel. These materials are exposed to static and dynamic encumbrances, different influences of the environment and global climate changes.

Roberge [2] recognised three aspects of the effects of climate changes: corrosivity in coastal regions, increased threats for marine ecosystems and precipitation patterns, all of which can change the corrosion behaviour of the environment and increase the risk of corrosion damage. In coastal regions, there are a lot of different onshore and offshore installations that are parts of local ecosystems where people live and work. Such regions exhibit the significant influence of man-made infrastructures and marine energy [3].

The environment or, more precisely, the sea affects metal elements during the exposure. Marine energy arises from the permanent motion of the sea's surface due to winds, waves and tides, which can occur twice per day and affect the coastal area and its facilities and installations [3].

Seawater consists of the solutions of many organic and inorganic particles in suspension. The sea affects metal constructions through the content of salt of (3.5%), oxygen dissolved, temperature and conductivity. The algae, bacteria and phytoplankton contained in the sea generate about a half of the oxygen in the atmosphere [4]. Seawater affects the stability of materials and engineering structures through the physicochemical processes of absorption, penetration, dissolution, hydration, hydrolysis, oxidation, carbonation, erosion, corrosion and degradation. The dominant presence of water therefore requires the application of the modern technologies for prevention, protection and control [5].

The seawater in coastal areas, along with climate changes, exerts a dominant influence on the degradation of different coastal infrastructures. Furthermore, different industrial and agricultural pollutants flow through coastal areas, ports and their surroundings, thus damaging structures, different mobile or fixed installations, equipment and machinery. In that way, different chemical, biological and thermal characteristics of those effluents damage the structures and affect the entire coastal environment, corrosion process and its types and mechanisms.

Corrosion is a dominant degradation process of metal structures. The corrosion of metal structures in coastal regions is an electrochemical process that occurs on metal surfaces through interaction between the surface and the constituents of saline water and its conductivity. Corrosive metabolisms, which emerge through biofouling by the fauna and flora, accelerate the anodic and cathodic electrochemical reactions that cause corrosion [6]. Consequently, corrosion products such as rust, oxides and salts pollute the sea.

Furthermore, corrosion and pollution are pernicious processes that impair the quality of the environment and the durability of the marine structures and construction materials [7]. Even the low levels of water pollutants harm human health, aquatic life and seawater quality. The prevention and control of corrosion therefore relies on pollution prevention [5].

Different heavy metals (e.g. lead, cadmium, zinc, copper, manganese, iron, mercury, arsenic and barium) tend to accumulate on the sea bottom, pollute the ecosystem, and pose a risk to human health. The previous research presents a list of 276 substances which pollute marine ecosystems and elaborates on the concentration and toxicity details of some of the listed substances (22 antifouling biocides, 32 aquaculture medicinal products and 34 warfare agents) [8].

The control of marine biofouling is achieved through the application of paints and coatings containing special biocides that are liberated in contact with seawater, thus preventing the adhesion of marine fouling organisms. Non-toxic, antifouling coatings which contain polymers with antimicrobial activity were, therefore, developed and applied practically [9].

This research presents the corrosion resistance of different alloys (NiTi, Fe-based) exposed to the conditions of the sea, tides (the sample is twice exposed to daily changes in the sea and atmosphere) and atmosphere in the Bay of Kotor. Energy-dispersive X-ray (EDX) semi-quantitative analysis was applied for detection of the chemical composition. Regression analysis and principal component analysis were used for processing the obtained results of chemical elements content in the investigated samples, which allowed for consideration of the corrosion of the samples examined to the specific types of environment in coastal conditions.

2 Different Metal Structures and Potential Pollutants

The Bay of Kotor is a unique fjord in the Adriatic Sea and one of the most attractive cruise ship destinations in the Mediterranean. Additionally, Kotor is the third port in the Adriatic Sea in terms of the statistical records of the total transit of passengers, whose variation between 2014 and 2015 was 41.96%, and 202.45% between 2010 and 2015 [10].

Besides the Port of Kotor, the Port of Risan has a local significance, while the Port of Zelenika has an international significance as the first port for the vessels entering the Bay. During 2019 almost 5,000 nautical vessels, and more than 500 cruise ships, entered the Bay of Kotor. The number of vessels is increasing constantly.

Over recent decades, numerous marinas were built in the Bay. The accommodation capacities reach almost a 1,000 berths for all types of vessels, including mega yachts. Some of the marinas offer repair services such as mechanical repairs, blasting, cleaning, painting, etc. Although these works increase the risk of pollution, the application of contemporary methods and measures could protect the sea from potential pollution.

A lot of cruise ships have modern technologies but also impose the risk of air pollution and the intrusion of non-native aquatic species. During high season, numerous vessels visit the Bay of Kotor and stay in marinas or in winter berths during off season, whereby the surface coatings of hulls or the discharge of effluents and oils may harm the environment.

On the other hand, in the Bay of Kotor, there are no offshore installations, transit ports, shipyards, railways, highways, fuel terminals or similar fixed installations. Old shipyards are closed, merchant vessels are forbidden, and there is no industry in the Bay.

3 The Corrosion of Metal Materials in Seawater

All vessels that navigate in coastal, shallow waters and the open sea are affected by three different conditions of the environment. The first is seawater, into which the parts of hulls are immersed. The second is the atmosphere above the sea's surface. The third zone can occur twice per day due to sea water and atmosphere exchange. In that regard, the paper presents the changes of the chemical composition of the metal materials that are exposed to the specific conditions of the sea and atmosphere. The conditions of the environment exert a dominant influence on the degradation of materials. The following discussion will, therefore, examine the specific influences of the environment, as well as the influences of the region in which the experiment was conducted.

3.1 The Influence of Seawater and the Atmosphere

The impact of a shallow sea and atmosphere on vessels is huge, since vessels navigate only on the surface. Various characteristics of seawater (biological, chemical and physical characteristics) and the atmosphere (humidity, temperature and pollutants) can accelerate the corrosion processes on vessels.

Table 1 The key influences of the seawater and atmosphere analysed in the paper

Parameter	The seawater	The atmosphere
Temperature (°C)	+	+
Humidity (%)		+
Conductivity (mS/cm)	+	
Salinity (‰)	+	

Seawater: Different biological, chemical and physical factors have a key influence on the corrosion of metal structures in seawater. The main chemical factors include salinity, the content of the oxygen dissolved, pH and conductivity. Chlorides in seawater cause the formation of corrosive layers, while the concentration of chloride affects the formation of pitting corrosion. The concentration of the dissolved oxygen depends on temperature, flow rate and biological activity. The corrosion rates of active metals (e.g. steel) at a constant temperature in an aggressive electrolytic environment such as seawater represent a direct linear function of the concentration of the dissolved oxygen. However, oxygen has a greater effect on corrosion than temperature in cases when temperature and oxygen content vary (which is typical for seawater). Seawater is almost neutral ($4 < pH < 10$), and pH value does not play an important role when it comes to the corrosion of steel. In this case, the layers of oxygen and hydrogen tend to remain on surfaces, so corrosion is, therefore, independent of pH [11]. Finally, conductivity increases with temperature. The dependence between conductivity and temperature is linear and triggers an increase in conductivity of 2% per Kelvin [12].

Temperature, flow rate and pressure are the main physical factors of seawater. Temperature on the sea's surface affects corrosion rates notably and varies between −2°C at the poles and 35°C on the equator. Based on natural and artificial seawater, Mercer and Lumbard proved that corrosion increases at temperatures above 10°C and then decreases gradually as the temperature reaches boiling point [13]. While the increasing flow rate of seawater particles can increase the corrosion rate, the pressure of seawater does not have a significant influence on corrosion of metal structures in shallow seawater.

Atmosphere: Humidity, temperature and specific air pollutants are three important factors which can influence the corrosion of metal structures. While the increase in temperature and humidity accelerates corrosion, specific air pollutants determine the direction of corrosive processes.

Table 1 presents the key influences of seawater and the coastal atmosphere analysed in the paper. The influences presented are relevant for the Bay of Kotor, i.e. the environment types where the experiments were conducted on the degradation of alloys caused by changeable environmental conditions.

3.2 *The Specific Influences of Seawater and the Atmosphere in the Bay of Kotor*

The parameters of the sea and atmosphere in the Bay of Kotor were researched widely in the past. The examination of seawater was conducted between 2010 and 2017 by the Institute of Marine Biology of the University of Montenegro [14, 15], while the parameters of the atmosphere were a part of the climatological data [16]. Figure 1 presents the locations where the experiments were conducted and the locations of the previous research on the parameters of seawater.

The paper summarises the data indicating the key parameters of seawater on the surface, at depths of 0.5 and 5 m, as well as the characteristic parameters of the atmosphere, based on the available data.

Considering the data on the average, maximum and minimum monthly temperatures of seawater, it is evident that there are no significant aberrations in the seawater temperature on the surface and at depths of 0.5 and 5 m. The difference was less than 1°C, with the exception of February, March, October and November, when the aberration exceeded 1°C and reached 2.9°C. The difference between the average values of temperature in two locations in the Bay is usually around 1°C. These observations indicate that, regardless of the difference in the location and

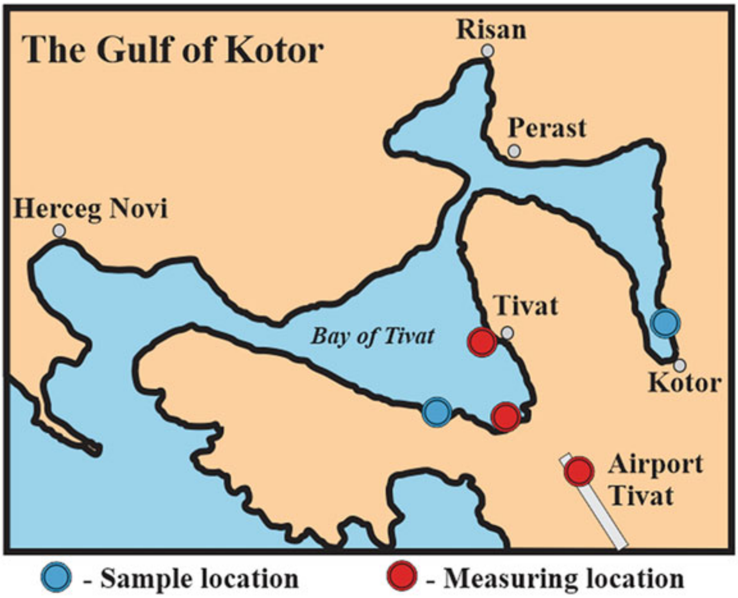


Fig. 1 The map of the Bay of Kotor with sample locations and environmental data stations

depths observed, the aberrations in seawater temperature in the Bay of Kotor correspond to approximately the same reference values [17].

The data about conductivity show a negligible difference between the locations and depths observed, except in February and October, when the variations in conductivity are during the rainy season [17]. Salinity is lower on the surface in comparison with the values recorded at the depth of 5 m, which is a consequence of the rainy season and the increase in freshwater. More significant aberrations were recorded during February and October, when, due to increased precipitation, the inflow of freshwater increased and thus reduced the salinity in all locations [17].

Air temperatures are, on average, always above zero, with a tendency of reaching 40°C during summer. The winds in the area observed and increased humidity throughout the year contribute to the climatic conditions that affect corrosive processes of all metal structures seriously, both at the sea and near it [17].

Based on the differences in the parameters of seawater and the atmosphere, the following Fig. 2 will present all the recorded influential factors. The data presented enable comparison of the temperature values for two locations where environment data were collected.

The comparison between the mean of the average values of the sea and air temperatures in the locations observed shows that the average monthly temperatures of the sea are higher than the average temperatures of the air. The increase in the monthly temperature values varies between 0.8°C for August and 10.3°C for December. Likewise, the maximum temperatures of the sea are considerably lower than the maximum monthly air temperatures that vary between 0.2°C in December and 10.9°C in March. The minimum sea temperatures are, on the other hand, significantly higher than the minimum air temperatures that vary between 12.0°C in October and 22.6°C in December. This indicates notably lower aberrations in the sea temperature in comparison with the air temperature [17].

4 Materials and Methods

4.1 Materials

Corrosion processes in seawater and the coastal environment have, prevalently, electrochemical character and depend mainly on the conductivity of seawater, salinity, temperature and other environmental factors.

The analysis of the chemical composition of metals (alloys) during a long exposure to varied influences of the environment represents the basis for the analysis of the degree of metal degradation and the corrosion products which are potential pollutants of the environment in the coastal area of the Bay of Kotor.

The initial as-cast NiTi alloy (Fig. 3a) with a diameter of 12 mm was separated into three pieces and analysed during 6 months of exposure to three types of environment – seawater, the tidal zone and the atmosphere. Additionally, the analysis included a typical steel fence (Fig. 3b) that was exposed to the conditions

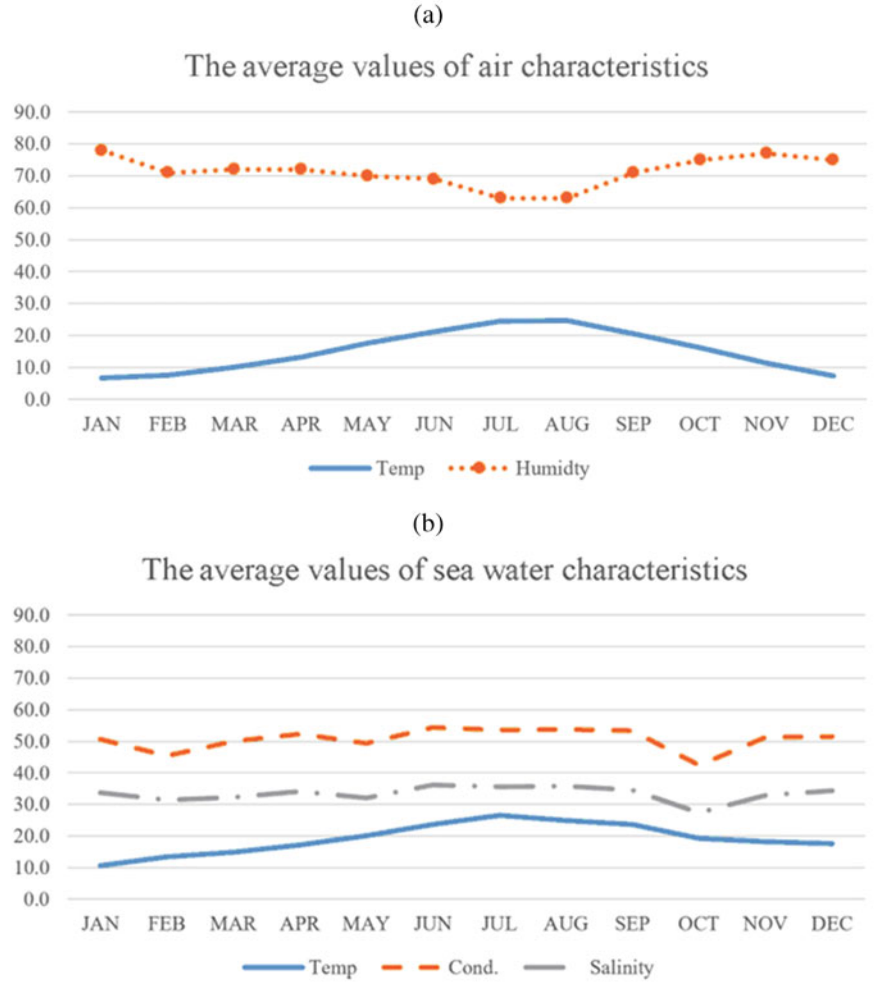


Fig. 2 Seasonal variability of the air (temperature and humidity) – (**a**) and water (temperature, conductivity, salinity) – (**b**) characteristics in the Bay of Kotor according to [14, 15]

of the atmosphere near the sea for years. The sample of the fence is a part of the fence that was protected by a surface coating and exposed to the intensive influences of the sea and waves for more than a decade. Although the chemical composition of the alloy was not available, the scanning of the uncorroded part of the fence revealed the data about the chemical composition of the sample presented in Table 2.

The results of inductively coupled plasma (ICP) analysis (performed to identify and measure the range of chemical elements) and the X-ray fluorescence (XRF) composition analysis (an excellent technology for qualitative and quantitative analysis of material composition) of the compositions of the NiTi and steel samples are shown in Table 2 [18–21].

Fig. 3 Materials: (**a**) The NiTi alloy as cast, (**b**) steel fence structure in the coastal area, (**c**) corroded steel fence

Table 2 Weight percentage composition of the studied alloy

	% Ni		% Ti		% C	% Fe
Sample	ICP	XRF	ICP	XRF	EDX	EDX
NiTi	55.4	55.2–55.5	44.6	44.4–44.8		
Steel fence sample					2.62	97.39

All results are in weight percentage

4.2 Methods

Figure 4 shows the conceptual model of the research. The paper relies on two phases of data analysis. The first phase involves a semi-quantitative analysis of the chemical

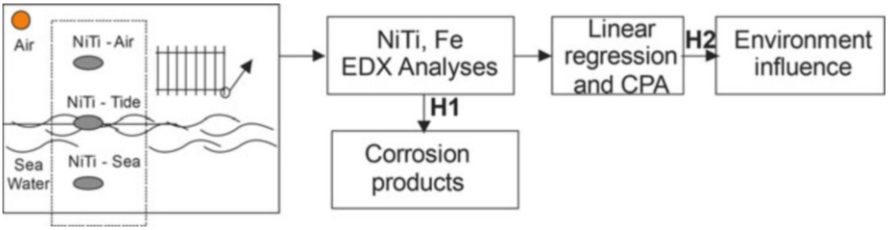


Fig. 4 The scheme of the conceptual model of the research

compositions of metals and determines the corrosive products on the studied samples. The second phase is based on the application of linear regression and multivariate principal component analysis for the examination of the data about the chemical compositions of corroded metals.

4.2.1 Semi-quantitative Analysis (Chemical Composition)

The chemical composition of the alloy selected is determined through the application of electron microscope and semi-quantitative analysis. Namely, a high-resolution field emission scanning electron microscope enables extremely high magnifications (up to a million times) in high resolution (1 nm). The microscope contains an energy dispersive X-ray spectroscopy (EDX) – Oxford INCA 350 – for microchemical analysis, and the Schottky electron source, which emits electron beams of small diameters and high density.

In addition to conductive materials and due to good resolutions at low voltage, non-conductive samples and materials with low atomic number can also be observed in high or low vacuum (up to 130 Pa). The microscope is equipped with a detector for secondary (topographic contrast) and backscattered electrons (topographic and Z-contrast). Furthermore, the microscope is intended for the characterisation of conductive and non-conductive samples and enables a qualitative and quantitative microchemical analysis of single points, selected areas on surfaces and a qualitative linear analysis. Additionally, the usage of the microscope facilitates the surface distribution of elements (mapping analysis), as well as analysis of the elements from beryllium to uranium.

The EDX semi-quantitative analysis determined the chemical composition of the materials after corrosion, as well as the content of elements on the surface of the examined samples. The chemical composition of the metal surfaces was scanned for each sample up to seven spectrums per sample under the magnification of 70 μm, 100 μm, 200 μm i 300 μm. The Minimum value is the minimum value of an element for all of the spectrums of the samples excluding zero values. The Mean values including zero values. This calculation for Mean values was choosen as the different sea salt element (S, Cl, Ca, etc.) may not be naturally presented in all of the spectrums.

4.2.2 Data Analysis

Data analysis was conducted through two phases. The first phase included the systematisation of the data from the EDX analysis in order to obtain the distribution of the chemical compositions of metals. The second phase was based on the data analysis through linear regression and the principal component analysis (PCA).

The EDX analysis focused on the samples of steel fence, corroded steel fence and three samples of the NiTi alloy found in the sea, tidal zone and atmosphere. Each sample underwent the EDX analysis – each sample number was examined, and the specific number of spectrums was observed for each sample. Table 3a, b shows the specific numbers of samples and spectrums for the NiTi alloy, steel fence and corroded steel fence.

In contemporary science, multivariate methods such as cluster analysis (CA) and principal component analysis (PCA) are among the most frequently used mathematical methods for the qualification and classification of the experimental data obtained and for the determination of the relationships between the data [22–24]. These methods are considered suitable, as they enable successful classification of a large number of data of different origins, as well as the identification and elimination of redundant information [25]. Chemometric calculations were made by the Statistics 13.5.017 software (StatSoft Inc., Tulsa, OK, USA). The Origin 6.1 software was used for the processing of the obtained experimental results.

Table 3 The number of samples and spectrums for: (a) the NiTi alloys in the sea, tidal zone and atmosphere, (b) steel fence and corroded steel fence

(a) NiTi (as cast)

Air	Magn.	No. of spec.	Tide	Magn.	No. of spec.	Sea	Magn.	No. of spec.
Sample 1	200	Spec 1–6	Sample 1	200	Spec 1–5	Sample 1	200	Spec 1–7
Sample 2	100	Spec 1–6	Sample 2	100	Spec 1–7	Sample 2	100	Spec 1–7
Sample 2	70	Spec 1–6	Sample 3	70	Spec 1–5	Sample 3	70	Spec 1–7
						Sample 4	200	Spec 1–7

(b)

Steel fence sample:	Magn.	No. of spec.	Corroded steel fence sample:	Magn.	No. of spec.
Sample 1	100	Spec 1–6	Sample 1	200	Spec 1–8
Sample 2	200	Spec 1–4	Sample 2	200	Spec 1–7
Sample 3	200	Spec 1–2	Sample 3	100	Spec 1–6
Sample 4	200	Spec 1–6	Sample 4	200	Spec 1–8
Sample 5	200	Spec 1–6	Sample 5	300	Spec 1–12
			Sample 6	300	Spec 1–10

For this research, PCA was performed on the matrix, in which experimentally obtained corrosion parameters from the EDX analyses were variables (columns), while the different parts on the observed alloy sample (spectrums) represent rows. The markings used were sea (S), air (A) and tide (T). The first number behind the words indicates a sample, and the second is a spectrum number inside the sample. The matrix data were standardised before the calculation, in order to ensure an equal importance of all the analysed parameters.

5 Results and Discussion

The comprehension of various influences of the coastal environment has a crucial importance and contributes to the selection of adequate measures for corrosion protection. Moreover, the understanding of the compositions of the corrosion products reveals the potential influences of those products on pollution.

An adequate evaluation of the influences of the coastal environment on corrosion requires the consideration of the key physical and chemical parameters (temperature, salinity, conductivity, etc.) of the materials affected by corrosion. Figure 2 shows the parameters of the sea and atmosphere that are relevant for the Bay of Kotor and observed over a long period of time prior to the research.

The experiment with the NiTi alloy was conducted between September 2018 and May 2019 and showed that the average temperatures of the sea and atmosphere were below 20°C during the period of observation, while the average monthly temperatures of the sea were higher than the average temperatures of the air. The difference between temperature values varies between 0.8°C for August and 10.3°C for December.

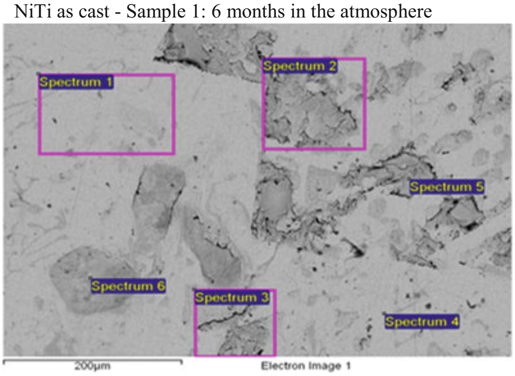
The salinity of the sea decreases on the surface between September and May, due to the rainy season and the inflow of freshwater. Likewise, the same period is also characterised by the decrease in conductivity, whereby the impact on the intensity of the electrochemical process of corrosion was reduced as well. Therefore, higher sea temperatures in the period observed and other influences of the sea (salinity and conductivity) render the corrosion processes in the sea significantly faster than the corrosion processes in the atmosphere.

The steel fence was, for years, constantly exposed to the dynamic influences of the sea and coastal atmosphere, which intensified the emergence of corrosion products (Fig. 3c) due to a long period of changes in the dynamic weather conditions of the environment.

5.1 The Results of the Analysis of the NiTi Samples

The NiTi samples, which were exposed to the air, were analysed by the EDX detector. The microstructure and the obtained results of chemical analyses are presented in Fig. 5. Due to a very restricted difference between the basic sample

NiTi as cast - Sample 1: 6 months in the atmosphere



Spectrum	% O	% Ti	% Ni	Total
Spectrum entire	0.00	46.70	53.30	100.00
Spectrum 2	7.53	51.89	40.58	100.00
Spectrum 3	6.27	49.81	43.93	100.00
Spectrum 4	0.00	45.71	54.29	100.00
Spectrum 5	0.00	62.04	37.96	100.00
Spectrum 6	11.92	46.21	41.87	100.00
Max.	11.92	62.04	54.29	
Min.	6.27	45.71	37.96	
Mean	4.29	50.39	45.32	100.00

Fig. 5 The view of the analysed places of NiTi as a cast sample, where EDX analyses were carried out, with corresponding values of the obtained EDX spectrums

Table 4 The results of the EDX analyses for as-cast NiTi after 6 months of exposure to tidal zone (Samples 1–3)

Sample 1 NiTi Spectrums 1–5	O	Na	Si	Cl	Ca	Fe	Ti	Ni	Total
	%								
Max.	78.57	2.93	7.36	1.38	1.21		41.73	48.43	
Min.	9.14	2.71	0.70	1.38	1.21		6.07	3.86	
Mean	47.87	1.13	1.82	0.28	0.24		23.64	25.03	100.00
Sample 2 NiTi Spectrums 1–7	O	Na	Si	Cl	Ca	Fe	Ti	Ni	Total
	%								
Max.	71.76	3.05	0.92			1.14	41.18	46.50	
Min.	11.56	1.17	0.72			1.14	13.79	11.10	
Mean	39.29	1.59	0.34			0.16	27.98	30.64	100.00
Sample 3 NiTi Spectrums 1–5	O	Na	Si	Cl	Ca	Fe	Ti	Ni	Total
	%								
Max.	89.01	3.61	4.64	0.97			49.39	40.16	
Min.	24.61	3.61	0.79	0.97			1.78	25.21	
Mean	44.13	0.72	1.09	0.19			30.01	23.86	100.00

All results are in weight percentage

and the sample that was exposed to the atmosphere for 6 months, the paper exposes only Sample 1, exposed to the air with the total of six spectrums of NiTi.

Table 4 shows the results of the EDX analyses (the average, minimum and maximum values for each sample) that refer to the sample which was exposed to the changeable conditions of the sea and atmosphere, i.e. the changeable conditions of the ebb and flood tides, besides the specific involvement of elements in each of the spectrums examined, and due to the considerable heterogeneity and range of the database investigated. The view of the analysed places of as-cast NiTi where EDX analyses were carried out is presented in Fig. 6.

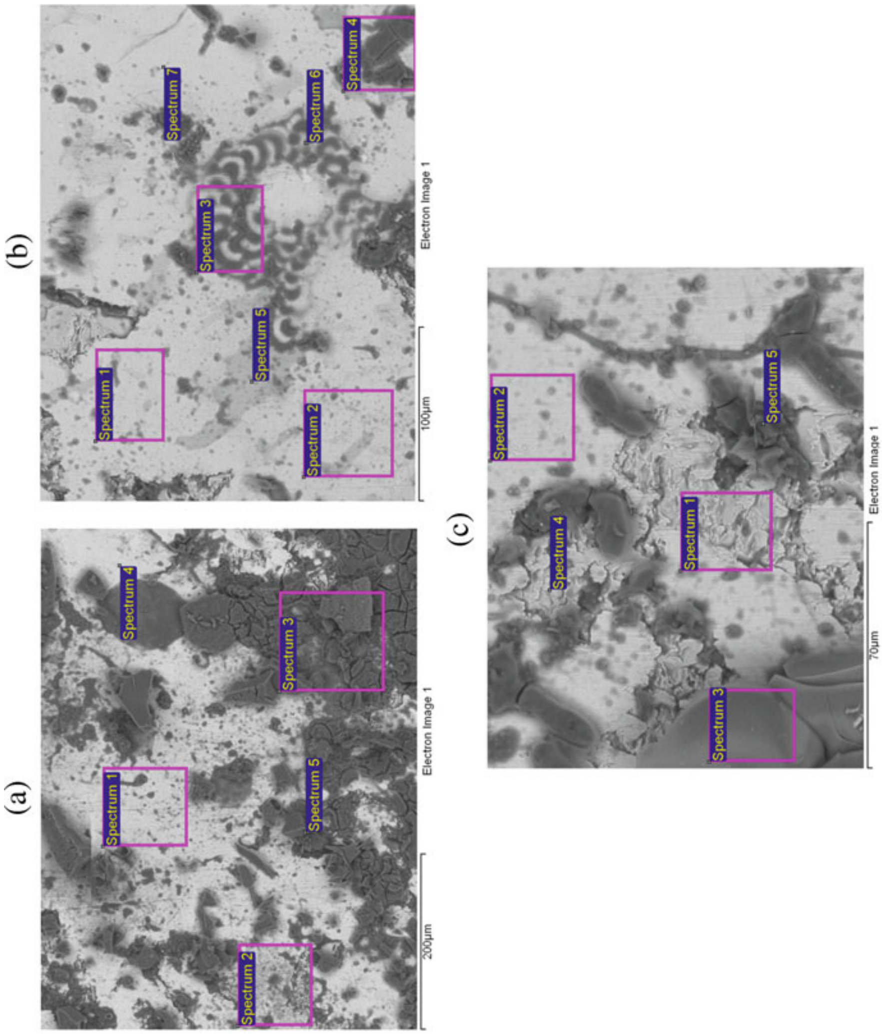


Fig. 6 The view of the analysed places of as-cast NiTi after 6 months of exposure to the tidal zone, where EDX analyses were carried out: (**a**) Sample 1 under magnification of 200 μm, (**b**) Sample 2 under magnification of 100 μm, (**c**) Sample 3 under magnification of 70 μm

Figure 7 shows the microstructure and places of four NiTi samples where EDX analyses were performed. The samples illustrated were exposed to the influences of the sea for 6 months. Chemical composition of constituting elements was determined for each spectrum, and the minimum, maximum and average values for each sample are shown in Table 5.

The comparison of the images illustrating the surface of the NiTi alloy after exposure to the influence of the air (Fig. 5), flood tide (Fig. 6) and the sea (Fig. 7) shows that the thickest layer of deposits is registered on the surface exposed to the sea. The results from the EDX analysis (Table 5) showed that, besides the emergence of nickel and titanium as corrosion products, additional inorganic salts are also formed on the surface of alloy. The analysis of the chemical composition of the surface indicated that the inorganic salts include mostly the species based on sodium, calcium and magnesium, which are formed in chlorides, silicates and, less frequently, sulphates. The presence of a flood tide causes changes in the chemical composition of the surface, because salts, except sodium and silicon, were not registered (Table 4). This means that flood and ebb tides flush the salts off the metal surfaces.

On the surface of the alloy exposed to the air, inorganic salts other than oxides were not registered (Fig. 5). All of this indicates that the environment affects the chemical composition of metal surfaces after corrosion greatly. In order to provide additional information about the impact of different types of corrosive environment on the degradation of the NiTi alloy in coastal conditions, the linear regression analysis was used to correlate the data obtained for the basic composition of the surface after corrosion. Among the results obtained by the EDX analysis, the most important corrosion effects were identified through the observation of the changes in nickel, titanium and oxygen content in the alloy exposed to different types of corrosive environment.

Figure 8 illustrates the changes in nickel (a), titanium (b) and oxygen (c) content on the surface of the NiTi alloy after 6 months of exposure to different types of corrosive environment.

The linear regression analysis correlates the data about the total content of metal to the content of oxygen obtained through the EDX analysis for every environment examined (Fig. 9). The aim of such analysis was to check if there is a quantitative dependence between the solubility of metals and the amount of the oxygen formed during corrosion.

As depicted in Fig. 9a, the amounts of both metals measured after corrosion is linearly dependent on the amount of oxygen detected (Eq. 1).

$$\mathrm{Ti} + \mathrm{Ni}\ (\%) = 67.494 - 0.657\mathrm{O}_2\ (\%) \quad R = -0.986 \quad \mathrm{sd} = 3.160$$
$$N = 54 \quad P < 0.0001 \tag{1}$$

The linear dependence between those parameters signals that the corrosion of both metals in the alloy occurs prevalently through the formation of oxides in any tested environment. The fact that the coastal environment is characterised by a large

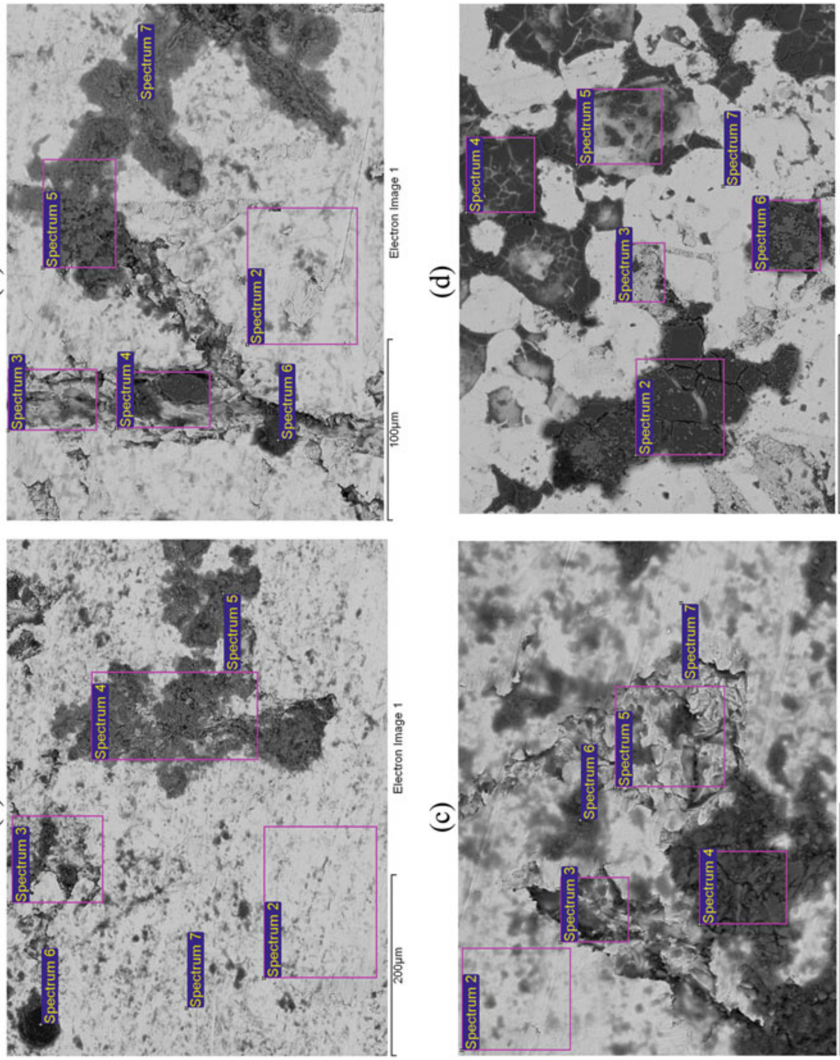


Fig. 7 The view of the analysed places of as-cast NiTi in the sea where EDX analyses were carried out: (**a**) Sample 1 under magnification of 200 μm, (**b**) Sample 2 under magnification of 100 μm, (**c**) Sample 3 under magnification of 70 μm, (**d**) Sample 4 under magnification of 200 μm

Table 5 The results of the EDX analysis for as-cast NiTi after 6 months of exposure to the influences of the sea (Samples 1–4)

Sam.1 NiTi Spec. 1–7	O	Na	Mg	Si	P	S	Cl	K	Ca	Ti	Fe	Ni	Total
	%												
Max.	49.41	32.14	6.17	2.02	1.87	6.26	47.76	3.24	2.63	44.57	1.39	54.50	
Min.	9.67	1.84	0.69	0.81	1.87	0.38	0.79	0.64	0.74	17.69	0.85	3.31	
Mean	18.89	12.84	1.57	1.30	0.27	0.95	11.62	0.55	0.73	24.48	0.61	26.19	100.00
Sam.2 NiTi Spec. 1–7	O	Na	Mg	Si	P	S	Cl	K	Ca	Ti	Fe	Ni	Total
	%												
Max.	50.29	26.78	4.75	14.19		4.80	31.93	4.34	2.53	41.67	3.33	45.99	
Min.	2.13	1.70	0.73	1.07		4.80	0.42	0.54	0.54	1.25	0.86	9.07	
Mean	23.27	10.26	1.28	3.75		0.69	7.61	0.78	0.73	26.10	0.94	24.61	100.00
Sam.3 NiTi Spec. 1–7	O	Na	Mg	Si	P	S	Cl	K	Ca	Ti	Fe	Ni	Total
	%												
Max.	55.02	7.94	2.76	1.74		1.75	1.24	0.49	17.64	41.69	0.96	50.34	
Min.	6.95	1.87	0.58	0.44		0.75	0.40	0.49	0.69	6.86	0.89	5.05	
Mean	27.32	4.03	1.59	1.08		0.67	0.37	0.07	3.33	31.43	0.26	29.85	100.00
Sam.4 NiTi Spec. 1–7	O	Na	Mg	Si	P	S	Cl	K	Ca	Ti	Fe	Ni	Total
	%												
Max.	61.62	10.31	3.98	4.91		0.48	2.86	0.56	2.50	44.54	1.46	54.00	
Min.	21.33	1.99	1.06	0.91		0.39	0.47	0.56	0.51	8.29	0.84	8.74	
Mean	38.43	4.97	1.86	1.93		0.19	1.46	0.08	1.01	24.46	0.67	24.94	100.00

All results are in weight percentage

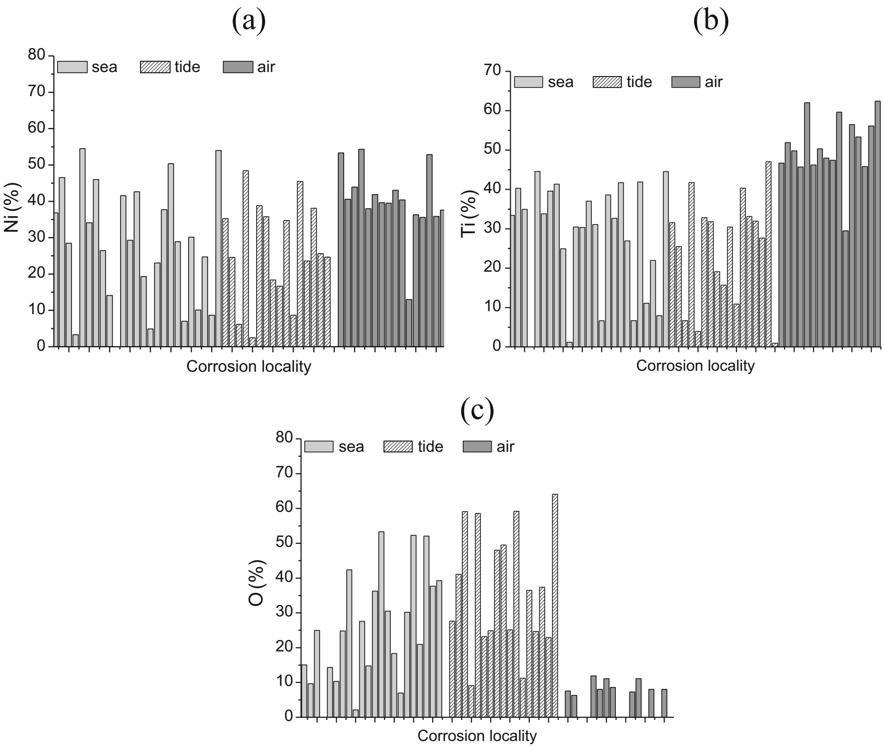


Fig. 8 The content of (**a**) nickel, (**b**) titanium, and (**c**) oxygen after corrosion of NiTi alloy in the different types of corrosive environment

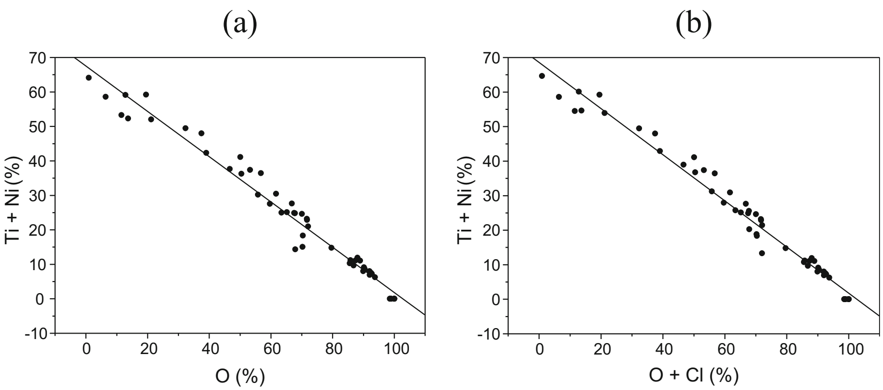


Fig. 9 The change in the total amount of metals (Ni and Ti) in NiTi alloy. (**a**) In relation to oxygen content, and (**b**) in relation the content of oxygen and chloride

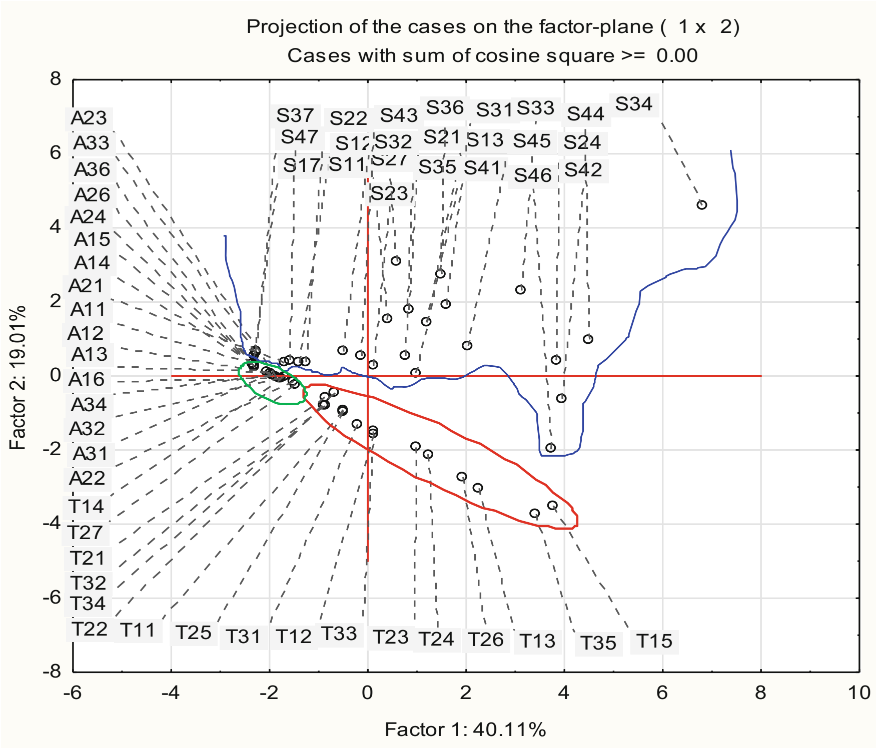


Fig. 10 Score plot as a result of PC1 versus PC2

amount of chloride ions in the sea and a smaller amount in the air raises the question if chloride ions contribute to the corrosion of the examined metals. In order to resolve the question, the total amount of metal obtained by the EDX analysis was correlated to the total amount of oxygen and chloride (Fig. 9b and Eq. 2).

$$\mathrm{Ti} + \mathrm{Ni}\ (\%) = 68.545 - 0.668\ \mathrm{Cl} + \mathrm{O_2}\ (\%) \quad R = -0.989$$
$$\mathrm{sd} = 2.837 \quad N = 55 \quad P < 0.0001 \qquad (2)$$

The linear dependence obtained suggests that, besides the formation of oxides, which emerge as a dominant corrosion product during the exposure of the alloy to the coastal environment, the formation of chlorides is also possible.

The multivariate analysis, PCA, was applied in order to collect additional information about the key environmental factors that have a dominant impact on the corrosion on the alloy. Figure 10 exhibits the distribution of the tested corrosive environment.

As illustrated in Fig. 10, two main components identify corrosion behaviour (with certain exceptions) of the alloy depending on the characteristics of the environment the alloy is exposed to. It should be noted that the PCA, with equal precision,

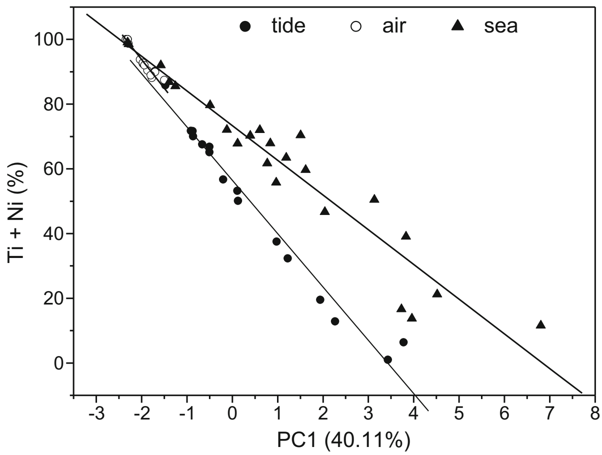


Fig. 11 The relationships between PC1 and the total content of metal (nickel and titanium) after corrosion

registers the existence of a small difference between the corrosion behaviour of the alloy when exposed to flood tide (T red circle) and the air (A green circle), as well as the notably different influence of the sea (S blue line) on dissolution.

Figure 10 also shows that values and PC1 are the least dispersed when it comes to the impact of the air, while the most dispersed values are registered for the impact of the sea. Such distribution of the PC1 values suggests similar behaviour to the amount of metal obtained through the EDX analysis of different environment types. Therefore, the obtained PC1 values are correlated to the total amount of metals (the sum of nickel and titanium) which is registered through the EDX analysis on the surface of metals after corrosion (Fig. 11).

Figure 11 shows that PC1, functioning as the change in the total amount of metal, forms three separate linear dependencies, whereby each dependency describes the behaviour of the alloy in the given corrosive environment (Eqs. 3–5).

Tide

$$\mathrm{Ti} + \mathrm{Ni}\ (\%) = 56.468 - 16.500\ \mathrm{PC1} \quad R = 0.986 \quad \mathrm{sd} = 4.679 \quad N = 17 \quad P < 0.0001 \tag{3}$$

Sea

$$\mathrm{Ti} + \mathrm{Ni}\ (\%) = 73.353 - 10.756\ \mathrm{PC1} \quad R = 0.958 \quad \mathrm{sd} = 7.640 \quad N = 23 \quad P < 0.0001 \tag{4}$$

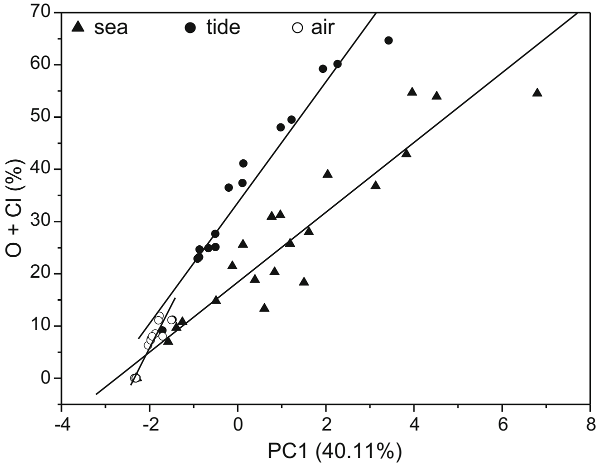


Fig. 12 The relationships between PC1 and total content of anions (oxygen and chloride) after corrosion

Air

$$Ti + Ni\ (\%) = 58.190 - 17.808\ PC1 \quad R = 0.976 \quad sd = 1.120$$
$$N = 16 \quad P < 0.0001 \qquad (5)$$

On the one hand, such dependency proves that the newly formed variable PC1 describes the corrosion of both metals in the alloy, and, on the other hand, the dependency signals that the multivariate method of analysis can detect the difference in the impact of the examined environment type on the corrosion trend of the NiTi alloy.

Since the linear regression analysis confirmed the existence of the linear dependency between the amount of metal corroded and the oxygen and chloride formed on the surface of the alloy, a further idea was to check if PCA can connect the anions emerged with the degree of corrosion (Fig. 12). In order to test such assumption, the PC1 values were correlated with the total content of oxygen and chloride.

As is notable in Fig. 12, PC1 forms a linear dependency with the total content of oxygen and chloride altogether (Eqs. 6–8), which is also applicable to the total content of metal (Fig. 11).

Sea

$$Cl + O\ (\%) = 18.391 + 6.684\ PC1 \quad R = 0.942 \quad sd = 5.678 \quad N = 22$$
$$P < 0.0001 \qquad (6)$$

Tide

$$Cl + O\ (\%) = 33.62 + 11.568\ PC1 \quad R = 0.974 \quad sd = 4.02 \quad N = 16$$
$$P < 0.0001 \qquad (7)$$

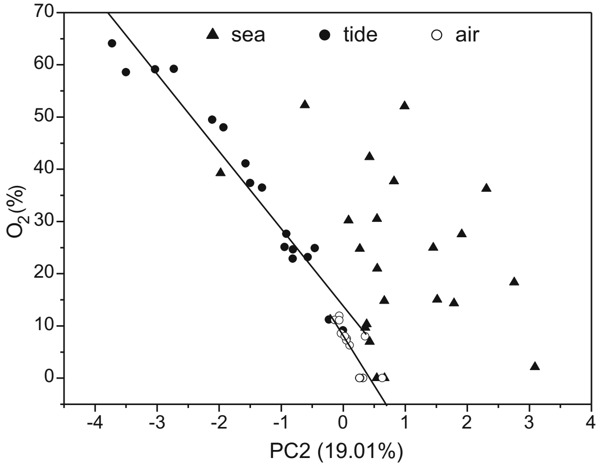


Fig. 13 The correlations between PC2 and the oxygen amount after corrosion

Air

$$Cl + O\ (\%) = 38.932 + 16.580\ PC1 \quad R = 0.950 \quad sd = 1.546$$
$$N = 16 \quad P < 0.0001 \tag{8}$$

In relation to the linear regression analysis, the multivariate analysis detects not only interdependencies of corrosive parameters but also reveals the varied influences of the specific types of corrosive environment on the degradation of the alloy. This is confirmed by the existence of a separate linear dependency between the total content of metals and the total content of anions, represented by the PC1 values for each specific corrosive environment.

A further idea was to use PCA in the attempt to separate the effect of oxide formation from the effect of chloride formation during the corrosion of the alloy in different types of environment. The score plot in Fig. 10 indicates that, besides PC1, the PC2 value also plays an important role for the description of corrosion behaviour of the alloy. This is verified by the comparison of the PC2 values with the amount of oxygen formed on the surface of the alloy after corrosion (Fig. 13).

As depicted in Fig. 13, PC2 is in linear correlation with the oxygen amount during the corrosion of the alloy exposed to the air and flood tide (Eqs. 9 and 10).

Tide

$$O\ (\%) = 13.815 - 14.806\ PC2 \quad R = 0.971 \quad sd = 4.260 \quad N = 17$$
$$P < 0.0001 \tag{9}$$

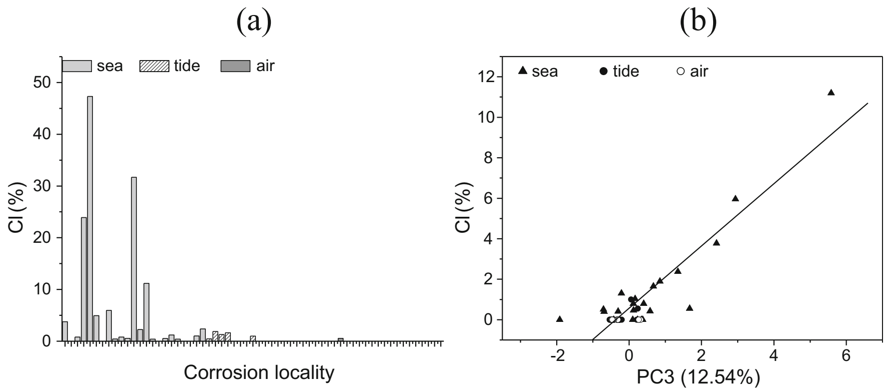


Fig. 14 The content of chloride. (**a**) After corrosion in the environment examined. (**b**) The correlation between PC3 and the amount of chloride

Air

$$\mathrm{O}\ (\%) = 8.108 - 19.065\ \mathrm{PC2} \quad R = 0.816 \quad \mathrm{sd} = 2.863 \quad N = 16 \quad P < 0.0001 \tag{10}$$

According to Fig. 13 and Eqs. (9)–(10), the PC2 values describe the formation of oxides on the surface of the alloy exposed to the influences of the air and flood tide properly. However, this is not relevant for the sea, because the sea is, besides the formation of oxides, also characterised by the formation of chlorides that are not characteristic for the air and flood tide. The EDX analysis for chloride ion confirms this finding (Fig. 14a).

The EDX analysis registered a considerable amount of chloride only on the alloy that was immersed into the sea, which is visible in Fig. 14a. Considerably smaller chloride amounts are registered in flood tide, while on the alloy exposed to the influence of the coastal atmosphere chlorides are nonexistent. A significantly smaller amount of chloride ions on the surface of the alloy exposed to the movements of seawater (tides) can be explained by the rising and falling of seawater, which flushes the formed compounds off the surface.

The data about the chloride content in every environment, obtained by means of the EDX analysis, are compared with the PCA results, in order to detect the influence of chloride content on the corrosion of the alloy (Fig. 14). A linear dependence is registered only between the chloride content in the sea and the PC3 values (Fig. 14b and Eq. 11).

$$\mathrm{Cl}\ (\%) = 0.567 - 1.537\ \mathrm{PC3} \quad R = 0.903 \quad \mathrm{sd} = 1.139 \quad N = 22 \quad P < 0.0001 \tag{11}$$

The linear dependence between these values suggests that, besides the dominant formation of nickel and titanium oxides, a small amount of metal forms chlorides during the corrosion of the NiTi alloy exclusively in the sea. This does not happen in the air and ebb and flood tides.

5.2 *Results from the Sample of a Steel Fence*

The research focused on a total of five samples of the steel fence structure, with up to six spectrums and under magnification of 100 and 200 times. Additionally, the research included six samples of the corroded parts of the metal structure, with up to 12 spectrums and magnification of 100, 200 and 300 times (Fig. 15). The results of the EDX analysis, which include the minimum, maximum and average values of all samples (Samples 1–5) of the steel fence, are presented in Table 6. The view of four out of five samples is presented in Fig. 15.

As is evident in Fig. 15a–d, and Table 6, the fence that was exposed to the influences of the coastal environment has a high degree of corrosion. Interestingly, a considerable amount of the carbon, whose origin may be inorganic, is observed in most spectrums. However, carbon can also indicate the presence of organic substances such as the algae that, over time, are deposited on the surface of the metal. Additionally, the examination also detected small amounts of molybdenum and sulphur. Sulphur can have both inorganic and organic origin. The inorganic origin of sulphur is related to sulphates, while the organic origin indicates the presence of algae. Since the original composition of steel is not detected, it is assumed that molybdenum constitutes steel as an alloying element.

The corroded steel fence presented in Fig. 16 encompasses six samples under magnification of 100, 200 and 300 times. The number of spectrums was between six and 12 per sample, as shown in Table 7.

As the data exposed in Fig. 16a–f and Table 7 show, the EDX analyses of the corroded part of the fence reveal the existence of extremely strong electrochemical corrosion on the metal that was without anti-corrosive protection and exposed to the influences of the coastal environment for years. Every EDX spectrum of the more corroded sample exhibits a considerable amount of oxygen and carbon as the products of the influences of organic substances, i.e. algae, which is also the case for the less corroded part of the fence (whose corrosion protection lasted longer). Unlike the less corroded part, the corroded sample is characterised by additional inorganic salts such as magnesium, calcium, aluminium and silicon, which are observed along with sodium, chloride and sulphur species. It is assumed that the inorganic salts became incorporated into the existing corrosion products, which formed a thick layer on the surface of the metal (Fig. 16a–f). Phosphorus and zinc were registered on two samples only and are considered a residue of a decayed anti-corrosive coating.

The results from the EDX analyses were examined for both fences in order to obtain additional information about the differences in the condition of the surface of

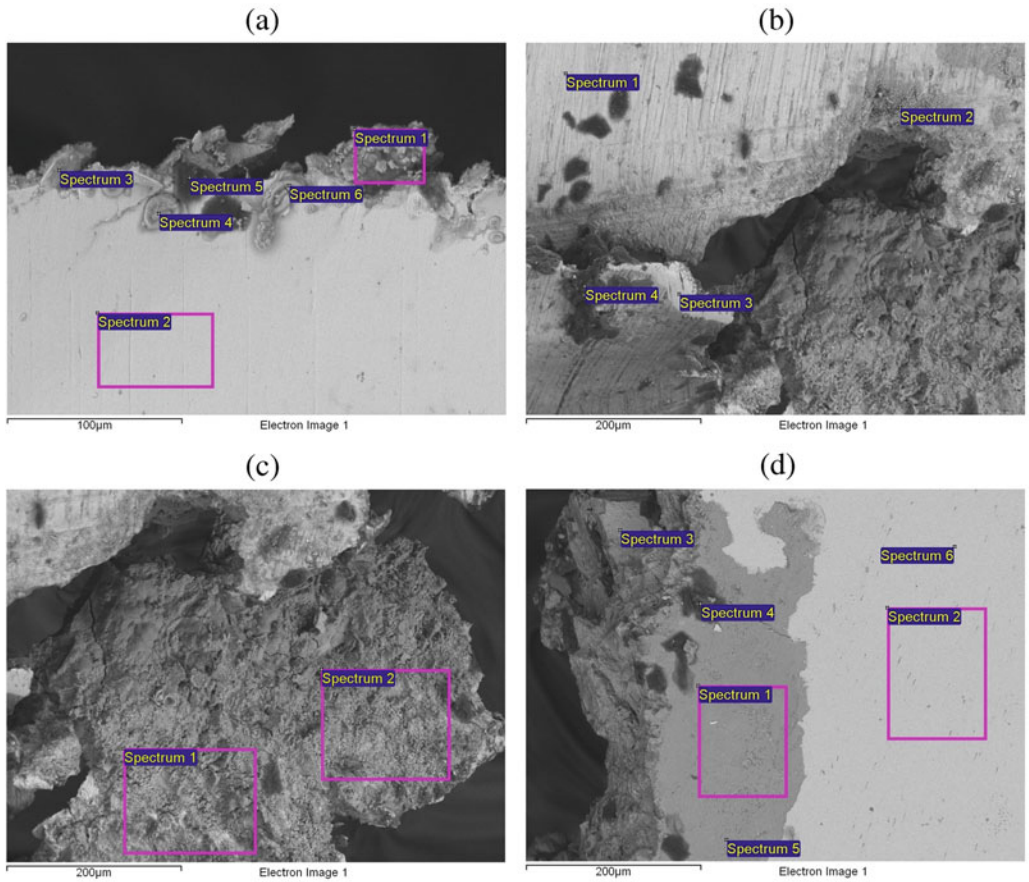


Fig. 15 The view of the analysed places of the steel fence and the corresponding EDX-spectrum locations: (**a**) Sample 1 under magnification of 100 µm, (**b**) Sample 2 under magnification of 200 µm, (**c**) Sample 3 under magnification of 200 µm, (**d**) Sample 4 under magnification of 200 µm

Table 6 The samples of steel fence (1–6) with the corresponding minimum, maximum and average values

Sample 1 steel fence Spectrums 1–6	C	O	Na	S	Cl	Fe	Mo	Total
	%							
Max.	64.09	36.63			2.47	99.89	2.11	
Min.	0.11	8.58			0.85	8.49	2.11	
Mean	14.49	21.77			1.27	62.12	0.35	100.00
Sample 2 steel fence Spectrums 1–4	C	O	Na	S	Cl	Fe		Total
	%							
Max.	61.33	19.25	0.68	3.41	14.01	86.77		
Min.	13.23	7.16	0.68	3.41	2.44	10.70		
Mean	25.98	9.07	0.17	0.85	4.11	59.81		100.00
Sample 3 steel fence Spectrums 1–2	C	O			Cl	Fe		Total
	%							
Max.	12.40	19.01			1.59	71.78		
Min.	11.06	16.27			0.89	67.00		
Mean	11.73	17.64			1.24	69.39		100.00
Sample 4 steel fence Spectrums 1–6	C	O		S	Cl	Fe		Total
	%							
Max.	11.00	37.23		5.08	39.27	99.82		
Min.	0.15	0.03		5.08	3.01	55.65		
Mean	2.33	12.40		0.85	7.64	76.79		100.00
Sample 5 steel fence Spectrums 1–6	C	O			Cl	Fe		Total
	%							
Max.	8.15	39.97			4.00	98.77		
Min.	1.23	22.9			0.39	51.49		
Mean	4.84	21.16			1.34	72.66		100.00

All results are in weight percentage

the fence that was less corroded and the surface that was substantially corroded after a long exposure to the coastal atmosphere.

Figure 17 indicates the change in iron content on different parts of the less corroded fence (**a**) and on different parts of the extremely corroded part of the fence (**b**).

As expected, Fig. 17 confirms that the amount of iron on the surface of the extremely corroded fence (b) is lower and more heterogeneous than on the surface of the less corroded fence (a).

The observation of the amount of oxides formed on these surfaces (Fig. 18) indicates the similarity between the content of oxides and the corrosion trend of iron. Namely, on the surface of the less corroded fence, (a) the amount of oxides is either nonexistent or lower than on the corroded sample (b). On the corroded fence, however, the amount of oxides is extremely high on all observed parts.

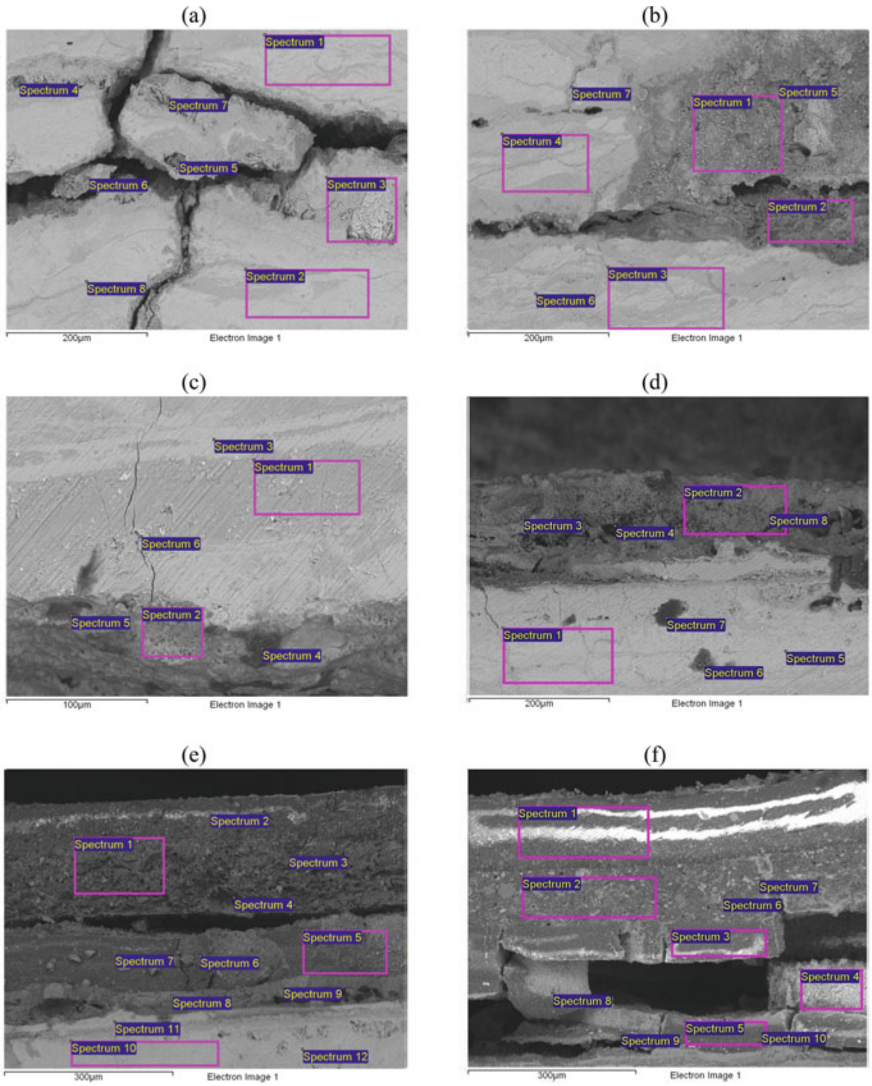


Fig. 16 The view of the analysed places of the corroded steel fence and corresponding EDX spectrum locations: (**a**) Sample 1 under magnification of 200 µm, (**b**) Sample 2 under magnification of 200 µm, (**c**) Sample 3 under magnification of 100 µm, (**d**) Sample 4 under magnification of 200 µm, (**e**) Sample 5 under magnification of 300 µm, (**f**) Sample 6 under magnification of 600 µm

The results of the EDX analyses of those elements are interrelated for both fences, in order to determine the existence of quantitative dependence between the amount of iron corroded and the amount of oxides formed (Fig. 19 and Eqs. 12–13).

Table 7 The results of chemical compositions obtained by EDX analyses for samples 1–6 with the corresponding maximum, minimum and average values of metal elements

Sam.1 Cor.Fe Spectrum 1–8	C	O	Na	Mg	Al	Si	P	S	Cl	Ca	K	Ti	Fe	Zn	Tot.
	%														
Max.	10.11	39.68	1.60	2.12		85.01			2.04				84.82		
Min.	2.24	1.65	0.19	0.04		0.07			0.05				4.83		
Mean	4.65	22.98	0.86	0.68		18.32			0.60				51.91		100.00
Sam.2 Cor.Fe Spectrum 1–7	C	O	Na	Mg	Al	Si	P	S	Cl	Ca	K	Ti	Fe	Zn	Tot.
	%														
Max.	13.29	49.64	4.82	7.55					4.34	10.63			60.12	2.93	
Min.	2.14	33.27	0.44	0.45					0.40	0.02			15.46	0.18	
Mean	7.58	41.89	2.35	3.56					2.03	4.13			37.88	0.58	100.00
Sam.3 Cor.Fe Spectrum 1–6	C	O	Na	Mg	Al	Si	P	S	Cl	Ca	K	Ti	Fe	Zn	Tot.
	%														
Max.	58.51	40.08	2.24					1.80	9.26		8.53		97.17		
Min.	1.27	0.33	0.26					0.07	0.10		0.07		4.74		
Mean	10.60	20.89	0.77					0.37	1.80		1.49		64.10		100.00
Sam.4 Cor.Fe Spectrum 1–8	C	O	Na	Mg	Al	Si	P	S	Cl	Ca	K	Ti	Fe	Zn	Tot.
	%														
Max.	62.41	46.67	8.70		2.63	9.73	1.35	1.01	19.29	2.73	4.89		75.73		
Min.	1.79	11.92	0.23		0.11	0.02	0.07	0.01	0.42	0.02	0.22		1.66		
Mean	17.57	28.70	1.76		0.55	1.70	0.41	0.35	3.33	0.69	1.17		43.77		100.00
Sam.5 Cor.Fe Spectrum 1–2	C	O	Na	Mg	Al	Si	P	S	Cl	Ca	K	Ti	Fe	Zn	Tot.
	%														
Max.	52.18	44.09	2.37	5.97	1.95	8.58		1.55	3.30	2.42		15.69	57.27		
Min.	2.44	18.88	0.30	0.15	0.11	0.09		0.08	0.05	0.08		0.07	0.58		
Mean	22.33	35.80	1.32	1.27	0.42	1.14		0.39	1.14	0.96		3.17	32.06		100.00

(continued)

Table 7 (continued)

Sam.6 Cor.Fe Spectrum 1–10	C	O	Na	Mg	Al	Si	P	S	Cl	Ca	K	Ti	Fe	Zn	Tot.
	%														
Max.	55.45	50.31	5.54	5.22	1.19	5.99	2.18	2.13	6.25	6.81		6.62	39.84	3.75	
Min.	7.01	38.66	0.06	0.14	0.30	0.02	0.20	0.01	0.25	0.14		0.12	0.08	0.10	
Mean	30.49	42.23	1.51	1.98	0.51	1.39	0.73	0.36	1.82	1.85		2.74	13.48	0.91	100.00

All results are in weight percentage

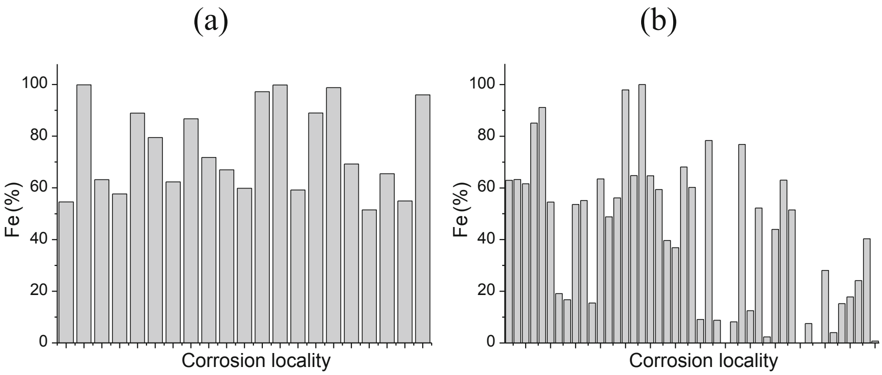


Fig. 17 The content of iron. (**a**) On the less corroded fence surface. (**b**) On the more corroded fence surface

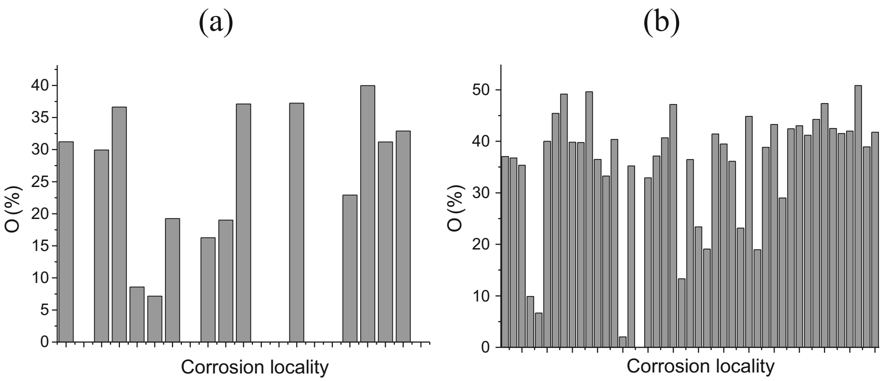


Fig. 18 The content of oxygen. (**a**) On the less corroded fence surface. (**b**) On the more corroded fence surface

Less corroded steel fence

$$\text{Fe}\ (\%) = 93.511 - 1.059\ \text{O}\ (\%) \quad R = 0.950 \quad \text{sd} = 5.505 \quad N = 21 \quad P < 0.0001 \tag{12}$$

Corroded steel fence

$$\text{Fe}\ (\%) = 102.642 - 1.355\ \text{O}\ (\%) \quad R = 0.891 \quad \text{sd} = 9.910 \quad N = 21 \quad P < 0.0001 \tag{13}$$

Figure 19a, b shows that the dependency of the corrosion of iron in relation to oxygen content has the same trend (linear dependence) on both fences. This linear

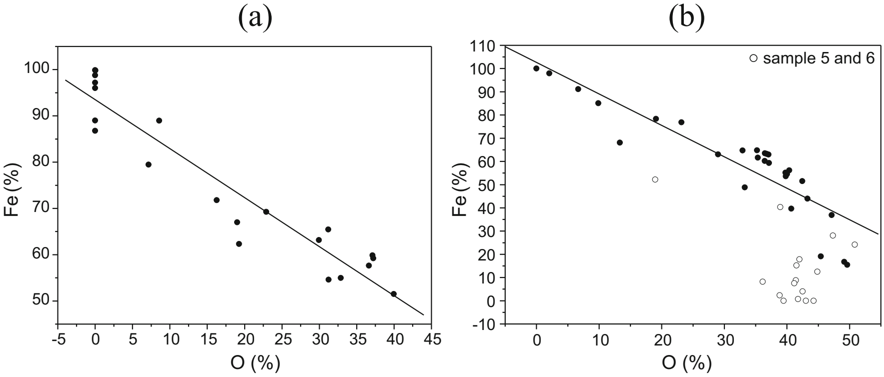


Fig. 19 The change in the amount of iron in relation to oxygen (**a**) On the less corroded fence surface, (**b**) On the more corroded fence surface

dependence is, however, irrelevant for spectrums 5 and 6 on the more corroded fence, which may be the consequence of the fact that, during a long and intensive corrosion, inorganic salts containing oxygen (e.g. silicates, carbonates, etc.) became incorporated into the formed iron oxide. Thereby, the relation changes between oxygen and the content of iron.

6 Conclusions

The paper analysed the influences of different types of environment in coastal conditions on the degree of corrosion of the NiTi alloy, as well as the varied corrosion degrees of the steel fence that was exposed to coastal conditions of the Bay of Kotor for years.

Based on the obtained results and deep analysis, it can be concluded that both metals of the NiTi alloy are less susceptible to corrosion when exposed to the air, stronger degradation was registered during the tidal action, while the most intensive dissolution of nickel and titanium is in the sea. The most heterogeneous surface after corrosion was also registered in the sea. The application of the linear regression analysis confirmed that the corrosion of the NiTi alloy occurs mainly through the formation of oxides and certain amounts of chlorides, regardless of the type of environment. The PCA results indicate that PC1 describes properly the corrosion of both metals in the alloy. Moreover, the PCA results confirmed that the applied multivariate method of analysis, unlike linear regression, detects large and small differences in the effects of the examined environment types on the corrosion trends of the NiTi alloy.

The EDX analysis of the Fe-fence exposed to the coastal conditions for years reveals a high level of corrosive degradation, which is followed by the deposition of algae on the surface. The linear regression of the data examined confirmed that

Fe-oxides are dominant corrosion products during the degradation of the Fe-fence, whereas the corrosion product on the more corroded Fe-fence contains various inorganic salts as well.

The findings of the paper have multiple significance. Firstly, the understanding of the impact of the coastal environment on the corrosion of different alloys studied is extremely important for the selection of adequate measures for the corrosion protection of marine materials. Secondly, it is very important to know the content and relation between corrosion products and potential pollutants. This research should motivate further investigation of other metal marine materials and their corrosion behaviour in different environmental conditions, in order to determine corrosive processes and environmental influences on the degradation of metal marine materials.

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Legal Regime for the Protection of the Marine Environment Against Pollution from Vessels in Montenegrin Adriatic Waters

Jelena Nikčević and Nikola Mandić

Contents

Abstract Pollution of the marine environment from vessels, caused directly by the discharge of various substances into the sea or indirectly through the atmosphere, is a serious global problem. In addition to the international legislative framework for the prevention of pollution from vessels, adopted by the International Maritime Organization (IMO), the obligation of each state is to establish efficient and effective legal mechanisms, which will through their implementation ensure the protection and preservation of the sea and marine environment. Being an ecological state,

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Montenegro has a clear commitment to protect and preserve the sea from pollution from vessels. In that sense, Montenegro has created its own legal framework which represents a solid basis for further upgrading and improvement of legal solutions on the protection of the sea from vessel-sourced pollution. The importance of the Montenegrin legal regime lies in the fact that it represents an important mechanism for the protection of the coastal sea of Montenegro, which complements and improves the entire legal regime for the protection of the Adriatic Sea.

This paper presents and analyzes the existing regulation on the protection of the sea from pollution from vessels. In addition, the provisions of individual legal texts are compared with international regulations in order to assess their compliance with conventional solutions and provide guidelines for improving the existing Montenegrin legislation.

Keywords Law, Marine environment, Pollution from vessels, Protection of the sea, Regulation

1 Introduction

Protection of the sea from vessel-sourced pollution is a complex issue which the international community has been facing with for ages. One of the key mechanisms for protection of the marine environment from pollution is an established legal framework which, when obeyed and enforced, can contribute to the preservation and protection of the marine environment. However, notwithstanding the global/international legal regime where the *International Maritime Organization* – IMO takes a leading part, the separate role of each country is of particular importance [1].

Being a coastal state itself, Montenegro gives special importance to the protection and preservation of the sea. That is especially visible through acceptance and ratification of many international conventions on the protection of sea from pollution, but also through the creation of its own legal regime striving to ensure universal, permanent, and efficient protection of its territorial sea as well as of the Adriatic coast overall.

After the renewal of its independence, Montenegro was given the opportunity to create its own legal regime and therefor to contribute to the improvement and protection of the sea, i.e. of the marine environment. Montenegro set off its own legal framework, on the one hand, by adding rules on marine protection into general legislation, i.e. into laws governing different areas of society (environment, nature, maritime sector, maritime safety, maritime zones, ports, yachts, etc). On the other hand, in 2011 the specialized law was enacted – Law on the Protection of the Sea from Pollution from Vessels, whereby the protection of the sea against pollution from vessels is directly regulated. It is for the first time within the national framework that the protection of the sea against pollution from vessels which sail or are located within the internal waters and territorial sea of Montenegro is regulated by a separate law.

The Montenegrin Legislator opted not to use the possibility for enacting more rigid/strict legislation than what is required at the international level, even though such option follows up the said international instruments and leaves space for building up more efficient marine environmental protection system at the national level. The analysis of the legislation makes clear that the Legislator's intention was to implement solutions from the international conventions into the national legislation and therefor significantly empower the Montenegrin legal framework for the protection of sea from pollution. However, in the legal system of Montenegro, there is the Law on the Protection of the Sea from Pollution from Vessels, still, it is very present a need to amend existing laws towards their improvement and further harmonization with international and EU regulations.

In this paper, special notice is given to solutions on the protection of the sea from vessel-sourced pollution through the prism of the existing Montenegrin legislation. The purpose is to indicate the importance of the Montenegrin legislation for the protection of the sea from pollution, not only for Montenegro, but also for its neighborhood – primarily the members of the Adriatic region. However, it also highlights deficiencies of some legal solutions in place. The first part of the paper gives a brief overview of the institutional framework and administrative capacities of Montenegro in terms of marine protection from the pollution from ships. In its second and third part, the strategic documents brought by Montenegro are considered, as long as they have implications for preservation of marine environment, whether direct or indirect. Furthermore, it is pointed therein at the international conventions which Montenegro adhered to. Forth part of the paper is dedicated to reviewing the existing legal instruments in order to draw attention to the Montenegrin legislative framework, but also to protect and improve the marine environment. Finally, concluding considerations are given.

2 Institutional Framework and Administrative Capacity

The competence over the creation of institutional framework for the marine environmental protection against pollution from vessels in Montenegro belongs to the *Ministry of Transport and Maritime Affairs*, *Administration for Maritime Safety and Port Management* and *Environmental Protection Agency.*

Ministry of Transport and Maritime Affairs is responsible for maritime transport. It performs the administrative activities related to maritime transport, safety of inland and international navigation, and safety of maritime transport. It defines indicators, monitors pollution, and undertakes urgent measures in case of pollution. It is responsible, inter alia, for adopting and implementing a legislative framework within the field of marine environmental protection. In that sense, a special role is given to the *Directorate for Implementation of Standards for Prevention of Sea Pollution and*

Inland Navigation and Directorate for Supervision in International and Inland Waterways Transport [2].

The Directorate for Implementation of Standards for Prevention of Sea Pollution and Inland Navigation takes care about implementation of standards set within the IMO Conventions and EU Directives in terms of maritime safety and protection of marine environment from pollution from vessels. In such sense, the competence of the Directorate, inter alia, spreads over-drafting of laws and byelaws in the area of marine environmental protection regarding the vessel-sourced pollution. The Directorate cooperates with IMO, EU bodies, and other organizations which are directly or indirectly connected with environmental protection. Following up the previous, the Directorate for Supervision in International and Inland Waterways Transport is in charge of the control over the vessels. A special importance is given to the Port State Control Officiers – PSCO whose duties are to inspect the national and foreign ships in territorial waters of Montenegro and to investigate their compliance with the IMO international conventions and the EU Directives, in terms of safety of navigation and protection of the marine environment.

Administration for Maritime Safety and Port Management is an operative body which steps in when the pollution occurs within the Montenegrin territorial waters. There is a *Department for Protection of Sea from Vessel-Sourced Pollution* within the *Administration* which is in charge of implementation of the *National Plan for Emergent Reaction in the Event of Sea Pollution from Vessels* from 2011 [3], monitoring and enforcement of national and international regulations on protection of marine environment from vessel-sourced pollution and organizing activities and cooperation with the Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (*REMPEC*) [4], IMO, and other organizations.

Environmental Protection Agency is an administrative body having competence over the environmental protection affairs in Montenegro. The main aims of the Agency are set as follows: protection and improvement of the environment in Montenegro, implementation of laws and regulations within the area of environmental protection, as well as informing the public and national and international organizations of the environmental situation in Montenegro. The Agency cooperates with numerous organizations and countries regarding environmental protection and also delivers expert tasks including: monitoring of the environment, producing reports and analysis, licensing, performing inspection, and other tasks determined by the law.

From the point of view of the marine environment as a part of the environment overall, it can be said that the Agency takes charge of protection and preservation of the sea; however, referring to the vessel-sourced pollution of the sea the Agency does play an important role at all.

3 Strategic Documents

With regard to the subject matter, although the Law on Environmental Protection [5] in Article 29 clearly imposes such obligation of the state, there is no separate Strategy on Protection of Marine Environment which would define the principles, aims, and measures to obtain a good environmental status of the marine environment. The reason for that can be traced to the passive attitude of competent authorities, but also it is due to the fact that there is no official database relevant for defining such strategy [6]. Still, there are some strategic documents which have implications to perseverance and protection of the environment and therefor are of importance: *Transport Development Strategy – Montenegro 2019–2035* [7], *National Strategy for Sustainable Development by 2030* [8], and *National Strategy on Integrated Coastal Area Management from 2015 to 2030* [9].

Transport Development Strategy – Montenegro 2019–2035 determines the status of all means of transport and also defines the infrastructure, organizational, and operational goals of development of transport systems. Having been set by the Strategy as strategic goals, on one side there are concepts of security and safety of all means of transport, and on the other, ecological sustainability, all of them in a function of marine environment protection. *National Strategy for Sustainable Development by 2030* determines the principles, strategic goals, and measures for achieving long-term sustainable development of Montenegrin society. It defines the management of coastal resurces of Montenegro, recognized as one of the most important resources and representing tremendous potential for innovations and development of Montenegrin society. *National Strategy on Integrated Coastal Area Management from 2015 to 2030* treats, among others, the questions which require integral and multisectoral approach and coordinated harmonization of priorities. The consideration of adequate management of garbage and wastewaters given in this Strategy has direct repercussions on the protection of the marine environment. Certainly, the overall spatial, economic, and social development of the coastal area of Montenegro largely depends on adequate management of municipal garbage and wastewaters.

Very important strategic document for the subject matter is the *Special Purpose Spatial Plan for the Coastal Zone of Montenegro*, enacted in 2018 [10]. The Coastal Zone covers local sea waters (about 2.540 km^2), the whole coast about 310 km long, and a narrow part of mainland as defined by the Law on the Coastal Zone (surface about 58km^2) [11–13].

It should be noted that in 2019 the *Ministry of Transport and Maritime Affairs,* for the first time within the national framework, accessed to production of the *Strategy of Maritime Commerce of Montenegro until 2030*, which sets out “maritime economy growth based on green economy principles” as one of the leading strategic principles.

The strategic documents listed above, although important for the protection and preservation of the sea, do not form clear and sufficient groundwork for determining the principles of Country’s action in the area of marine environmental protection.

Hence, it is necessary to launch a special strategy (or strategies) which will systematically comprehend the main segments of marine environmental protection. In that sense, it could be seen as justifiable if, after the adoption of the *Strategy of Marine Environmental Protection,* the authorities start considering the creation of special strategies, such as Strategy on Ballast Water Management or Strategy on Protection from Pollution from Vessels within the area of Boka-Kotor Bay. Mainly because there are many parts of environmental protection which should be dealt with in a special and detailed manner, but also for a reason that, even when the *Strategy of Marine Environmental Protection* is brought to life, there is a fear that many questions will be left uncovered, such as the protection from pollution from vessels within the area of Boka-Kotor Bay. It should be emphasized that the Boka-Kotor Bay is a highly sensitive area [14] protected by UNESCO for its natural beauty and cultorological and historical importance, which is, however, pretty much exposed to pressure of numerous cruise ships arrivals, which potentially have a negative environmental impact thereto [6]. A special attention should be drawn and one systematic and thoughtful approach given to the problem of sea pollution from ballast water, which as a global problem could not bypass the Montenegrin part of Adriatic coast [15, 16].

Nevertheless, encourages the fact that Montenegro enacted the *Law on the Prevention of Sea Pollution from Vessels* [17], and that the special *Law on Marine Environmental Protection* which is currently being drafted and is expected to come into life during 2020. Previous indicates also that the lawmaker noticed the scope and complexity of the subject matter and the need to be regulated by special laws. Let us hope that administrative bodies will have the same or at least similar approach when setting up the relevant strategies.

4 The Ratified International Treaties

According to Article 9 of the Constitution of Montenegro [18]: “the ratified and published international agreements and generally accepted rules of international law shall make an integral part of the internal legal order, shall have the supremacy over the national legislation and shall apply directly when they regulate relations differently than the national legislation.” In relation to sea pollution from vessels Montenegro is a member of the following Conventions: UN Convention on the Law of the Sea (UNCLOS 1982); International Convention relating to Intervention on the High Seas in Cases of Oil Pollution Casualties (INTERVENTION 1969); Protocol to the International Convention relating to Intervention on the High Seas in Cases of Pollution by Substances other than Oil (INTERVENTION PROT 1973) as amended; Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (LC 1972) as amended; International Convention for the Prevention of Pollution from Ships, 1973 (MARPOL, 1973) as modified by the Protocol of 1978 relating thereto, and its Annexes from I to VI (MARPOL 73/78); and Convention concerning Minimum Standards in Merchant Ships, 1976.

In 2011, Montenegro ratified the following treaties: International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004; International Convention on the Control of Harmful Anti-fouling Systems on Ships, 2001; International Convention on Civil Liability for Bunker Oil Pollution Damage, 2001; International Convention on Civil Liability for Oil Pollution Damage, 1992; International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage, 1992; Protocol of 2003 to the International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage; and International Convention on Liability and Compensation for Damage in connection with the Carriage of Hazardous and Noxious Substances by Sea,1996 [19, 20].

In addition to the ratification of the numerous Conventions, Montenegro tends to empower the regional cooperation in terms of protection and preservation of the marine evironment, ackonwledging the fact that regional cooperation was shown to be a very proper method in addressing the important questions [21]. Therefore, Montenegro is a full-power party to the *Barcelona Convention for the Protection of the Mediterranean Sea Against Pollution* [22]*,* which represents, together with the following protocols, a legal framework for the implementation of the *Mediterranean Action Plan, MAP,* whereby the regional cooperation between Mediterrenian States has been developing in order to repress pollution in the Mediterranean sea [23]. Notably, since 2011, Montenegro has been striving to join [24, 25] one of the 9 regional agreements on the Port State Control – *Paris Memorandum of Understanding on Port State Control – Paris MoU*, whose purpose is to protect the sea from vessel-sourced pollution by elimination of the ships which do not comply with international standards (the so-called the substandard ships) [26–28]. In 2015 Montenegro ratified *Paris MoU* [29] and its full implementation is expected to be done with the amendments to the *Law on Maritime Navigation Safety* [30], by the end of 2020.

5 Current Legal Regime in Montenegro for Prevention of Sea Pollution from Vessels

All legal acts touching the protection of the marine environment from pollution which are in force in Montenegro can be divided into 3 segments. The First segment consists of 2 groups of legislation. The first group is formed by the legislation referring to marine environmental protection, based on the treatment of marine environment as an integral part of natural environment. Maritime transport legislation forms the second. It is about legal acts dealing with various aspects of maritime branch, but in some parts they touch upon the protection of marine environment from pollution. The Second segment is made of legislation with a direct effect on the protection of marine environment. It is a legislation regulating maritime safety, with a purpose not only to protect life (passengers and the crew) and property (ship and cargo) at sea, but to some instance, to protect also the marine environment from the pollution caused by ships. The legislation governing the protection of the sea from vessel-sourced pollution, i.e. regulating the pollution prevention, forms a Third segment thereof.

The legislation placed in First and Second segment are general legal acts containing norms from various branches (depending on the subject matter) including also the marine environmental protection regulation (more or less). It is the legislation placed in Third segment the one fully specialized and dedicated to the marine environmental protection from the vessel-sourced pollution.

5.1 Legislation on Natural: Environmental Protection

It is prescribed by the Montenegrin Constitution that each person has a right to healthy environment. Protection and preservation of the environment is a duty of everyone, of the State especially, who throughout enactment of laws and establishment of the efficient and effective mechanisms for their enforcement strongly contributes to the preservation and protection of the environment (Article 23 of the Constitution). Apart from the Constitution, basic Laws which establish for the State and other subjects a duty of care for the environment and its preservance and protection are the Law on Nature Protection [31] and Law on Environment [5]. These Laws have taken a general approach towards the marine environment considering it as a part of environment overall, which is understandable having in mind their general character and environmental protection as a main subject matter.

The Law on Nature Protection prescribes the protection of the nature as a whole, including the areas with highly esthetic value and natural diversities having a special impact on human health, culture, education, science, tourism, and generally people's life within the Montenegrin society. With one general provision, the Law protects the marine habitats by prohibiting the actions and activities which could destroy them. The perseverance of the biological diversity is provided by enforcement of certain measures (Article 19 of the Law).

Together with the principles, instruments, and measures for protection of the environment and sustainable development set out therein, the Law on Environment also recognizes the need of having a strategy on marine environmental protection (Article 29). Pursuant to Article 18 of the Law, the protection of the sea and coastal area as a part of natural habitat is ensured with systematic monitoring of marine and coastal ecosystems and implementation of certain measures, with aim to: reduce or eliminate/remove the pollution, preserve the specific marine and coastal areas, protect marine resources, prevent air-sourced marine pollution as well as the one from vessels (including pollution caused by dumping), prevent cross-border pollution and pollution caused by big accidents and remove its consequences.

5.2 Maritime Transport Legislation Dealing with Protection of the Sea from the Vessel-Sourced Pollution

More detailed provisions on marine environmental protection are contained in maritime transport legislation. It is a legislation regulating navigation, division of the sea and subsoil of Montenegro, ports, yachts, and safety of navigation. Some parts of the provisions are dedicated to the protection and preservation of the sea, namely: Law of the Sea [32], Law on Ports [33], Law on Yashts [34], Law on Exploration and Production of Hydrocarbons [35], and Law on Maritime Navigation Safety [30].

The *Law of the Sea* regulates the marine and submarine territory of Montenegro and the internal maritime waters, territorial sea, exclusive economic zone, continental shelf, ban on entering ports, stopping and pursuing vessels.

Pursuant to Article 192 UNCLOS, the Law of the Sea of Montenegro in its Articles 2 and 3 imposes a duty of a State to protect, preserve, and improve the marine environment. With such legislative technique, the legislator has not introduced absolute prohibition of all kinds of marine pollution. A contrario, Article 9 of the Law gives rise to possibility of scientific research in certain maritime zones, whereby various types of pollution could occur. Such possibility, contemplated also in Articles 193 and 194 of UNCLOS, directly requires a State to undertake special measures to prevent, reduce, and control the pollution, if it occurs. Having in mind the international character of the marine environmental protection and the duty of compliance with Article 197 of UNCLOS, the Law of the Sea, in Article 2 (4) and (5) prescribes the duty for Montenegro to cooperate with its neighbors and to promote such cooperation in order to prevent and minimize marine pollution.

It is envisaged in the Law of the Sea that relevant provisions on the protection and perseverance of the marine environment are kept within the articles which separately regulate the right of innocent passage and maritime zones.

In that sense, according to Articles 16 and 17 of the Law, all foreign vessels are allowed to transverse the territorial waters of Montenegro, provided that such passage is innocent. Passage is innocent so long as it is not prejudicial to the peace, good order, or security of Montenegro. If a foreign ship willfully and seriously pollutes the marine environment, the passage is not innocent and according to Article 25 of the Law, such ship will be ordered to sail away from the territorial waters of Montenegro immediately. For the sake of maritime safety and marine environmental protection, pursuant to Articles 20 and 22 of the Law and in compliance with Article 22 of UNCLOS, Montenegro has discretionary right to designate sea lanes and traffic separation schemes and to prohibit as well the navigation in certain areas (for specific types of ships or for ships carrying specific types of cargo).

When it comes to the Exclusive Economic Zone of Montenegro, Article 35 (1) and (2) calls for respect of international and national regulations on marine environmental protection during the marine scientific research and exploitation, but also during the navigation in the area. Within the EEZ, the national authorities have duty to undertake all the necessary measures (physical inspection, hot pursuit, and judicial proceedings) to exercise their sovereign rights which include: exploring and exploiting, conserving and managing the natural resources, and production of energy from the water, currents, and winds.

It should be acknowledged that Montenegrin EEZ (with 7.745 km^2 surface) [36] has been subjected to scientific research of hydrocarbons [37] since 2009, implicating the special legal regime determined therefor. When putting it into the context of pollution prevention, the *Law on Exploration and Production of Hydrocarbons* and *Rulebook on Environmental Protection Requirements to be Met in the Course of Hydrocarbons Operations* [38] appear as essential, defining tasks and measures which shall be undertaken in the course of research and production of hydrocarbons, all with the purpose of the protection of environment. Additionally, Article 60 (1) precisely states that, during the research and production of hydrocarbons: "…the Concessionaire shall be obliged to undertake all measures to prevent adverse impacts on specific segments of the environment: air, atmosphere, soil, water resources and sea, as well as the living world.…"

According to Article 39 of the Law of the Sea, it is allowed to explore and exploit natural resources on Montenegrin continental shelf, as well as to lay down the installations, provided that prescribed conditions are met. Use and discharge of dangerous and noxious substances and oils necessary for the research conducting shall be done in a manner that minimizes the negative impact on the environment and maritime ecosystem of the continental shelf, in line with the Law and international regulations. The competent authorities have a duty of cooperation in undertaking measures necessary to prevent pollution in marine protected areas, which could emerge from the activities on the continental shelf.

Law on Ports and Law on Yachts are also general laws which deal with the protection of marine environment throughtout several provisions thereof. Pursuant to Article 26 (1) and (2) of the Law on Ports, the port beneficiary is obliged to adequately equip the port with facilities for receiving and handling waste, all with aim to prevent pollution of the sea or of the port area. In that sense, ports are not allowed to discharge and dispose of the waste – solid or liquid, oil or oil residues, cargo remains from ships, or any other substances which pollute the environment – into the sea or at the coast, except at locations containing machinery, equipment, and devices especially designed for receiving and handling these materials. Pursuant to the same Article, paragraph 3, natural person or legal entity who uses the machinery, equipment, and devices has a duty to undertake all measures necessary to prevent discharge and dispose of the oil and the oil residues, i.e. to prevent speeding out those substances at the sea or onto the coast. When the natural person or legal entity pollutes the sea, the competent authorities will order them to immediately stop with the pollution and to remove the harmful effects. In case that a person or entity disobeys the order, the inspection will order the cleanup, for the cost of the pollutant.

Regulations on the protection from marine pollution are also contained in the Law on Ports – within the part on concessions. In that respect, concession which constitutes a basis for concession grant, inter alia, has to contain the environmental impact assessment (Art.18 para. Points 5 and 13), while the concession contract shall be consisted of obligations of the consessionaire regarding the safety and security, transport of dangerous substances and environmental protection, as well as of rights and duties on regarding the measures of ensuring general safety and security, protection of health and environment, together with liability for damages caused by endangering general safety, security. and the environment (Art.20 parag.2 p.10 and 16). The concession shall be taken away from its holder if the performance of the concession activity endangers the environment, human health, or marine protected areas (Art.22 par.2 point 3).

2007 Law on Yachts which regulates nationality, identification, registration, and other questions relating to yachts [39] also contains the provisions on prevention of marine pollution from yachts in Article 33 thereof. In that sense, it stipulates a prohibition of discharge and dumping of oil and oily water, waste, garbage, and other substances that pollute the environment from yachts. 2015 Amendments thereto introduce a requirement for the yacht master or yacht manager to immediately notify the administrative body if oil and oily water, waste and garbage, and other pollutants are discharged into the sea, with the exact position of the yacht. Yachts must be equipped to prevent pollution of the sea by oils and oily waters, waste and garbage, as well as containers for their storage, which will be emptied in appropriate shore reception equipment, in accordance with national regulations and the requirements of international conventions. In case of violation of the said provisions, the perpetrator shall be fined with the 500–20.000€ fine, according to Article 28, para.16, 17, and 19. It is stipulated by para.5 of the same Article that the crew and passengers of the yacht shall be familiar with the instructions on the prevention of marine pollution. However, it is questionable, how will the passengers become familiarized therewith? Who is responsible for introducing them? It remains unclear why the legislator did not provide for persons responsible in case when passengers failed to be familiarized with the "instructions on the prevention of marine pollution," given that the term "shall" was used in the formulation.

In the context of this paper, of particular importance is the Law on Safety of Maritime Navigation as a crucial piece of legislation representing the legal framework for safe navigation, which is a prerequisite for the protection of the sea from pollution from vessels. The Law on Safety of Maritime Navigation regulates all segments of maritime safety (ship safety, cargo safety, occupational safety, and navigation safety) in direction of avoiding maritime accidents and related pollution of the sea [30, 40].

Montenegro seeks to ensure (both as a flag and a port state) compliance and implementation of the requirements of international conventions in order to prevent and reduce marine pollution. On the one hand, they relate to ships flying the Montenegrin flag, and on the other, to foreign ships docking in ports or anchorages of Montenegro.

In that sense, ships flying the Montenegrin flag must be seaworthy. Pursuant to Article 49 of the Law on Safety of Maritime Navigation, a ship is seaworthy in certain categories of navigation and for a certain purpose, provided that she meets the requirements of ratified and binding international conventions and laws, in relation to, inter alia*,* prevention of vessel-sourced environmental pollution. Whether the ship meets the requirements of international conventions, i.e. whether it is seaworthy according to Art. 51 of the Law, shall be determined upon the technical supervision. Technical supervision in Montenegro is performed by an administrative body or organization recognized by the European Commission for technical supervision and statutory certification of seagoing ships. After the technical inspection, the ship is issued the appropriate ship's documentation and books evidencing that the she meets the requirements. Considering that the ship must be seaworthy during the whole voyage [40]. Article 58 of the Law stipulates that the shipowner is obliged to maintain the ship and its equipment in a condition that ensures her seaworthiness. Failure to maintain the ship and its equipment sufficiently to ensure the seaworthiness of the ship is considered to be a maritime offense in Article 144, para.1, point 27 of the law, and negligent shipowner or agent shall be fined with 1.500–20.000 € fine.

In relation to foreign ships and their crew docking in ports or anchorages of Montenegro, the Montenegrin Port State Control Officers (PSCO) perform port state control during which they take into account whether foreign ships meet the requirements for protection of the sea from pollution from ships, all with aim of marine protection and safety enhancements [24, 25]. Provisions on port state control are contained in Part XIV – "Supervision," in Articles 183 to 198 of the Law.

5.3 De Lege Lata Solutions According to the Law on Protection of the Sea from Vessel-Sourced Pollution

Regulations which are completely dedicated to protection and preservation of the sea from pollution and which directly address questions of prevention and control over the sea consist of the following acts: Law on Protection of the Sea from Vessel-Sourced Pollution (in addition: *The Law on Protection of the Sea* or *the Law*) and *National Plan for Emergent Reaction in the Event of Sea Pollution from Vessels.*

It is for the first time within the national legislative framework that a separate law provides a regulation of vessel-sourced marine pollution. The aim of this Law is to prevent, minimize, and up to maximum extent eliminate marine pollution. It regulates the protection of the sea from pollution from all types of vessel which transverse or are located in the internal waters or territorial sea of Montenegro. While observing provisions of the Law, it can be noted that aspiration of the Lawmaker was to implement international obligation deriving from numerous international conventions. In that sense, Part I of the Law ("General Provisions"), in Articles 1–3, implements some provisions of UNCLOS; Part II (Ship Carrying the Noxious Liquids in Bulk), Part V (Ship Carrying the Noxious Substances in the Packaged Form), Part VI (Sewage), Part VII (Garbage), Part VIII (The Emission of Harmful Substances into the Air), in Articles 4–39 implement provisions of MARPOL; Part IX (Ballast Waters), in Articles 40–48 implements the provisions of Ballast Water Management Convention; Part X (Systems for Preventing of Attachment of Unwanted Organism to the Hull of Ships), in Article 49 implements the provisions of Anti-fouling Convention; in Part XI (Dumping of Wastes), in Article 50, the London Convention is implemented; and in Part XIII (Liability and Compensation for the Damage Caused by Marine Pollution from the Vessels), in Articles 55–58, the CLC is implemented.

5.3.1 Prevention of Pollution from the Vessels

The substances which shall not be discharged into the waters of Montenegro are enumerated in Article 4 of the Law. In that sense, the following actions are forbidden:

– discharge of oil, oily mixtures, bilge water, and oily waste;
– discharge of harmful substances which are temporarily established as such, water from tank washing or other mixtures which contain such substances;
– discharge and disposal of harmful substances in packaged form on the seabed;
– disposal of communal garbage;
– discharge of harmful substances into the air;
– discharge of ballast waters and sediments from ballast tanks if they contain harmful substances, pathogens, and invasive species;
– application of anti-fouling systems if they contain biocide organotin compounds;
– intentional dumping, incineration, and burying of waste and other material on the seabed.

Despite the principal prohibition, there is possibility of undertaking some actions, but only with approval issued by the competent authority in place. Also, the exemptions from the prohibitions are as follows: the actions taken for the reason of safety of a ship or to save lives at sea, activities resulting from damage to a vessel or its equipment, and activities resulting from the prevention of pollution and the elimination of pollution effects. In case of violation of the prohibitions, according to Article 62 of the Law, the perpetrator shall be fined with 1.000–40.000€ fine.

It is of utmost importance for the marine pollution prevention that the relevant authorities have information about ships transporting the harmful substances. Therefore, the Law in Articles 5, 6, and 7 prescribes a duty for the shipper and the operator of such ship to submit the relevant information thereof, together with the time period in which they are required to do so. In Article 3, para.1, point 38, the harmful substances are defined as all dangerous and harmful substances, except oil, which when discharged into the marine environment can cause pollution of the sea and danger for human health.

Montenegrin Lawmaker regulates the information submission done by the operator, distinguishing a situation when the ship is coming from the port of the EU Member State and when it is coming from a port of Non-EU-Member State. Pursuant to Article 7 of the Law, the information shall be submitted 24 h before the ship's departure, that is, no later than the moment of departure of the ship from the previous boarding port, if the voyage lasts less than 24 h.

5.3.2 Prevention of Marine Pollution from Oils and Noxious Substances

Articles 16–27 of the Law regulate the prevention of marine pollution from oils. Following the decision of the international community on the phase-out of single-hulled tankers, Articles 16 and 17 prohibit entry into the waters of Montenegro for the following types of vessels: oil tanker of at least 5,000 GT which does not have a double hull; a Category 1 tanker built by the end of 1982; Category 2 and 3 tankers built by the end of 1984 and an oil tanker carrying heavy fractions of oil as cargo if they do not have double hull. However, this prohibition is not absolute in its nature because it is not applicable to tankers in distress or the ones asking to sail into port of shipyard. Also, it is stated in Article 19 that the prohibition does not apply to tankers carrying heavy fractions of oil as cargo, even though they do not have double hull, say that the transport is carried out in one port area. Articles 21–26 contain the provisions on documentation and equipment which shall be kept on board of tankers, depending on their GT. It is a duty of a master to submit the relevant information to the competent authority and, pursuant to Article 27 of the Law, the information shall be submitted not later than 24 h before the ship's arrival to Montenegrin ports. The relevant information submitted by the master has to include the amount of crude oil and oil residues, waste oil, oil mixtures, and bilge waters, as well as the date and place of their last delivery.

Articles 28 and 29 of the Law regulate chemical pollution by ships or prevention of marine pollution from the noxious substances. In that sense, a ship transporting the noxious liquid substances in bulk shall have special documentation, evidencing that the substances are transported in accordance with international rules. Meanwhile, noxious substances in packaged form which are being transported must be properly packed and labeled. Their packaging shall indicate the technical names of the substances and the fact that packaged substances are pollutants. Such marking shall be prominently displayed and made of waterproof material, with a duration of at least three months from the date of its affixing. The law stipulates the obligation to adopt a by-law that will regulate more closely the conditions on the manner and type of packaging, containers, etc. However, to our knowledge, no such act has been adopted. It must be mentioned that the chemical pollution as the special aspect of pollution in Boka Kotorska Bay needs to be taken into account [41, 42].

5.3.3 Prevention of Marine Pollution from Sewage and Garbage

Protection of the sea from sewage pollution is regulated by Articles 30, 31, and 32, while from garbage is regulated by Articles 33, 33a, and 34 of the Law. The definition of sewage given in the Law rests on Regulation 1, Annex IV, of the MARPOL Convention. Hence, according to Article 3, point 8 of the Law, sewage is a waste that is discharged from ship toilets, medical premises (pharmacies, ship hospitals, etc.) via wash basins, washtubs and drainage openings located in such premises, drainage from spaces containing living animals, and other wastewaters when mixed with emissions.

Pursuant to Article 30 of the Law, every ship up to 400 GT transporting more than 15 passengers and crew members shall have international certificate on prevention of sewage pollution. Furthermore, such ships shall have an incorporated functional and precisely determined system of devices for sewage management. That includes: sewage treatment system; sewage shredding and disinfection system with adequate storage space for the temporary disposal of sewage when the ship is located within three nautical miles of the nearest land and a storage tank of sufficient capacity to store all the sewage up to the point of discharge to the reception and handling facilities at the port, while such contests shall be discharged via standard discharge deck located on the open deck.

Pursuant to Article 3, point 14, garbage is defined as: food waste, excluding fresh fish and parts thereof; wastes generated in the accommodation spaces onboard the ship (paper, rags, glass, metal, bottles, crockery, etc.), excluding sanitary waters; operational wastes (collected onboard during normal maintenance or operations of a ship or used for cargo stowage and handling, cleaning agents, and additives); all types of plastics, cargo residues in accordance with the Annex V of MARPOL, excluding cargo dust remaining on the deck after sweeping or dust on the external surfaces of the ship; cooking oil; fishing gear (a device or part thereof, or a combination of parts, which may be placed on or in the water or on the seabed for the purpose of capture or control for the subsequent capture or harvesting of marine or freshwater organisms), which are generated during the normal operation of ship and can be continuously or periodically disposed of, as well as animal carcasses. It can be noticed that the definition of the garbage contains definition of garbage determined by Regulation I, Annex V of MARPOL.

Pursuant to Article 33 of the Law, it is allowed to discharge a food waste not commuted (garbage) into sea outside the Special Area if is of more than 12 nm distance from the land or more than 3 nm from the land if they are commuted with devices with openings smaller than 25 mm and if the ship is en route. 2014 Amendments brought in Article 33a prohibit garbage discharge from movable or immovable offshore platforms and from ships moored to the platform or when alongside or within 500 m from movable or immovable platforms. There is one exception thereto, that is when movable or immovable offshore platforms are located more than 12 nm from the land and if garbage is commuted with devices with openings smaller than 25 mm.

5.3.4 Air Emissions

Articles 35–39 regulate the issue of air emissions from ships. According to Article 35, it is prohibited to discharge harmful substances into the air, say for the cases of research or exploitation of a seabed or laying the submarine cables and cases of immediate danger for human life and health or for the environment, upon the approval of the competent authority. Article 37 of the Law requires possession of documentation in line with the Annex VI of MARPOL. That means that, the following documents shall be issued for any ship of 400 GT and above: an International Air Pollution Prevention Certificate, an International Energy Efficiency Certificate, and a Ship Energy Efficiency Management Plan (which contains measures to improve energy efficiency of a ship). In addition to these, a ship with a diesel engine of 130 kW or more shall be issued an Engine International Air Pollution Prevention Certificate. Article 39 of this Law stipulates the obligation of any ship to have onboard a Bunker Delivery Note issued by the supplier, together with a sealed representative sample of the fuel oil, stored and kept on board until full consumption of the fuel oil, or up to 12 months from the date of the fuel oil delivery [6].

The use of fuels at vessels docked in ports, navigating in territorial waters and EEZ of Montenegro, or placed within the Emission Control Areas (ECAs) is regulated by the *2017 Regulation on Limit Values for Pollutants in Liquid Fuels of Petroleum Origin* [43, 44]. According to Article 8 of the Regulation, marine diesel fuel may be placed on the market if the sulfur content does not exceed 15 g/kg (1.5% m/m), while marine gas oils may be placed on the market if the sulfur content does not exceed lg/kg % m/m. According to Article 19 of the Regulation, starting from 1 January 2020, the sulfur content in marine fuels on vessels navigating in the territorial waters and the EEZ of Montenegro may not exceed 0.5% m/m.

Bearing in mind the importance of the above provision and long-term consenquences of its violation, especially for the area of Port of Kotor which hosts numerous cruise ships, it is highly recommendable that the provision is fully implemented and enforced. Seems like the legal system of Montenegro does not predict the special punishment for violation of said provision. That is, neither the Law on Air Protection [45] which gave legal grounding to creation of the said Regulation nor the Law on Protection of the Sea from Vessel-Sourced Pollution contains fines for the case when the provision is not respected. Therefore, the intervention of the Lawmaker therein is more than necessary in order to create special penal provisions. Until then, the extensive interpretation of Article 4, para.1, point 5 of the Law on Protection of the Sea, in case of said violations, the perpretrator could be fined with 1.000–40.000€ fine, stipulated by Article 63, para.1, point 5 thereof referring to air emissions.

5.3.5 Prevention of the Pollution of the Sea from Ballast Waters

In order to prevent or at least minimize the transfer of invasive aquatic species into waters of Montenegro, the Law introduced the provisions of prohibition of biological sea pollution. Articles 40–48 stipulate measures and procedures of ballast water exchange for ships which sail into the Montenegrin ports, as well as the procedures of ballast water exchange control and analysis [46].

Pursuant to Article 40 of the Law and in line with Regulation 2, section 8 of Ballast Water Convention (BWM), a shipmaster is obliged to, taking into account safety of navigation and protection of environment, avoid or limit the uptaking of ballast waters in certain areas. Such areas are the ones with toxic mechanisms and pathogens, near industrial outfalls, with extreme differences between high and law tides, high water turbidity due to the operation of ship propulsions, or areas where underwater dredging is conducted, or fish spawning or areas where sea currents collide.

Notwithstanding the general prohibition from Article 4, para.1, point 6 and Article 46, para.1 of the Law, Article 41, in line with Regulation 2, Section 8 of BWM Convention stipulates an obligation for a shipmaster who uptakes the ballast water to comply with certain requirements before sailing into the Montenegrin waters. In that sense, the ballast water exchange shall be conducted at least 200 nautical miles from the nearest land and in water at least 200 m in depth. In cases where the ship is unable to conduct ballast water exchange in accordance with the above rule, such ballast water exchange shall be conducted at least 50 nautical miles from the nearest land and in water at least 200 m in depth. The ballast water exchange performed in such manner shall cover at least 95% of total ballast water kept within the ship. These measures may be evaded if the master of the ship decides that the change of ballast water would endanger the safety of the ship and human life, as well as when there is a danger of marine pollution from harmful substances (Article 42 of the Law). These provisions are in line with Regulation B-4 paragraph 1 points 1 and 2 and Regulation D-1 paragraph 1 of the BWM Convention.

It is not regulated by the Law the situation when it is not possible to undertake the ballast water exchange at any of the safe distances prescribed thereby. In that case, according to Regulation B-4, para.2 of BMW Convention, Montenegro as a port state, with a prior consensus with neighboring and other countries, will determine the areas where ballast water exchange shall be allowed. However, the authorities should be very careful when determining such areas and take into account various oceanographic characteristics, physico-chemical and biological features of the sea and the like, because these indicators can be crucial in deciding whether a certain area can be accepted as the area for ballast water exchange, from an ecological and safety aspect [47].

According to Articles 44 and 45, every ship constructed with ballast tanks which enters the Montenegrin ports shall possess *Ballast Water Management Plan*, while every tanker of at least 150 GT or ship of 300 GT or more shall have *Ballast Water Record Book* on board. These provisions are incompatible with Regulation B-1, Section 1 and Regulation B-2, Section 1 of the BWM Convention which require that every ship holds Ballast Water Management Plan and Ballast Water Record Book onboard.

The Law does not define the Plan, but according to the Convention, the Plan represents a document carried on board and containing a detailed description of activities undertaken for meeting the requirements of ballast water management and approved by the flag state authorities or recognized organizations. Following the Regulation B-1 of BMW Convention, the Law in its Article 44, paragraph 2 particularly emphasizes the information which shall be contained within the Plan: safety procedures for the ship and the crew with regard to ballast water management; actions to be taken in ballast water management; procedures for the disposal of sediments from ballast tanks into the sea and to shore; manner of coordination with the authorities of the state into whose waters such discharge will take place; manner of reporting; designation of the officer on board in charge of ensuring that the plan is properly implemented, and other information of importance to ballast water management. Furthermore, pursuant to Regulation B-2 and Annex D of the Convention, Article 45, para.2 of the Law elaborates that Ballast Water Record Book shall contain: name of the tanker, i.e. ship; IMO number; gross tonnage; flag of the ship and ballast water tank capacities.

Sampling and sample testing of the ballast water, as well as costs thereof, are regulated by Article 46 of the Law. Moreover, according to Article 48 thereof, the port beneficiary is required to conduct the analysis of the sea as to ballast waters in port area and report thereon, as well as to submit such report to the competent authority.

5.3.6 Sea Protection from Harmful Substances in Anti-fouling Systems

When it comes to reduction or elimination of harmful substances in anti-fouling systems used on ship's hull**,** Article 49 of the Law stipulates a duty of certification of certain vessels, which is in line with Articles 10 and 11 of Anti-Fouling Convention (AFS). Hence, vessels sailing into Montenegrin ports, or flying the Montenegrin flag, and having at least 400 GT (fixed and floating offshore platforms are exempted) are requried to possess the Declaration on Anti-fouling System and the receipt for the purchase of the anti-fouling systems. When possessed on board, the named documentation is considered as a proof that the vessel meets the requirements of the AFS Convention. Notwithstanding the previous, it is recommendable to implement other provisions of the AFS Convention via enactment of by-laws and other regulation, especially through creation of technical rules on ship certification.

5.3.7 Dumping of Wastes

Having in mind that marine environment can be polluted by dumping of wastes and other substances from ships, the Law also regulates this source of pollution. It is stated already (supra 4.3.1) that Article 4, para.1, point 8 of the Law gives a general prohibition of dumping, incineration, and burial on the seabed of waste or other substances, with certain exceptions. Certainly, such exceptions shall go along with the ones listed in Article 50. As a matter of fact, with the approval of the competent authority, dumping, incineration, and burial on the seabed of waste or other substances are not prohibited, in case of: sludge generated by dredging; waste fish or organic matter resulting from the processing of fish or other marine organisms; platforms and other structures at sea; of inert chemical uncontaminated geological substances of natural origin in the solid state.

5.3.8 Reception and Handling of Waste, Waste Oils, Cargo Residues, and Ballast Water Sediments in Ports

The law provisions on reception and handling of waste, waste oils, cargo residues, and ballast water sediments in ports are binding upon the port beneficiary on the one hand, and on the other, they impose duties upon the master of the ship sailing into Montenegrin ports. In such sense, pursuant to Article 51 of the Law, the port beneficiary is required to provide the port with facilities for reception and handling of waste, waste oils, and cargo residues from vessels. The port beneficiary is required to have a plan for the reception and handling of waste, waste oil, and cargo residues from the vessel, as provided by Article 52 of the Law.

Obligations for the master of ship entering Montenegrin ports are prescribed by Articles 53 and 54 and they relate to the submission to the Port State Control of the Report on the quantities of waste and the delivery of waste. According to Article 53, the shipmaster is obliged to submit to the Port a Report on the quantities of waste, waste oils, and cargo residues on board, as well as the date and place of last delivery, provided that: the destination port is known, at least 24 h before departure; or the port of call is known, less than 24 h before arrival; or the duration of the voyage is less than 24 h, immediately after departure from the previous port.

According to Article 54, the shipmaster is obliged to deliver waste, waste oil, and cargo residues to the reception and handling facilities before leaving the port, which is in accordance with Art. 26 paragraph 2 of the Law on Ports, unless there is a storage space onboard the ship for storage of waste, waste oil, and cargo residues incurred during the stay in the port.

5.3.9 Liability for Damages in Case of Vessel-Sourced Marine Pollution

Provisions of the Law regulating the liability for damages in case of vessel-sourced pollution are as important as provisions of preventive character elaborated above. Articles 55–58 of the Law regulate the liability for damages caused by oil pollution of the sea or pollution from hazardous and noxious substances. It can be concluded by their analysis that the provisions contemplate the marine pollution caused by the oil from tankers. That means – damages caused by the spill of oil carried onboard as cargo or oil used for propulsion of tankers. However, liability for damages from marine pollution caused by spill of oil used for propulsion and operation of other ships is not covered by the Law, even though Montenegro is a party to the 2001 Bunker Convention. The exception is done in Article 57, para. 2 of the Law which requires that the ship of 1.000 GT or more maintains insurance policy or other financial security (bank guarantee or alike) to cover damages caused by bunker oil, in accordance with the Bunkers Convention.

Pursuant to Article 55 of the Law, the owner of a vessel is liable for pollution damages according to the rule of strict (causal) liability, with possibility to be exonerated therefrom if the shipowner proves that the damage resulted from an act of war or force majeure, the damage was wholly caused by an act or omission done with the intent to cause damage by a third party or it is caused by the negligence of authority responsible. One more exemption should be added thereto. Namely, if the owner of the vessel proves that: the pollution damage resulted either from an act or omission done with intent to cause damage by the person who suffered the damage, the owner may be exonerated wholly or partially from liability to such person.

Notwithstanding the clear provisions on channeling of liability to the owner of the vessel, the Law still enumerates persons against whom the action for pollution damages cannot be brought. Pursuant to Article 55, para.3, such persons are: the servants of shipowner or shipowner's representative, the members of the crew, the pilot, or any other person who, without being a member of the crew, performs services for the ship; shipper of the cargo of any kind (including a bareboat charterer) or any person taking preventive or operational measures. However, the protection of above persons is not absolute, considering that they shall be found liable if the damage resulted from their personal act or omission, committed with the intent to cause such damage, or recklessly and with knowledge that such damage would probably result.

The absence of intent will release such persons from the liability, but that shall not prejudice any right of recourse of the owner against third parties. The said provision is in line with Article 3 of the 1992 CLC and Article 7 of the 1996 HNS Convention, which were ratified by Montenegro.

Pursuant to Article 4 of the CLC and Article 8 of the HNS Convention, when an incident involving two or more ships occurs and pollution damage results therefrom, and when the damage is not reasonably separable, the shipowners shall be jointly and severally liable for all such damage.

Compulsory insurance of shipowner is prescribed by Article 57 of the Law and it is tied up with amount of oil carried as cargo. Therefore, according to the Law and pursuant to the Convention, compulsory insurance is not required for all ships, but only for ships of 2.000 GT or more. Such ships shall have the insurance policy or other type of financial security, such as bank guarantee or the IOPC Funds Certificate. To prove the existence of such insurance in place, the adequate certificate shall be issued in both Montenegrin and English language, including the following information: name of the ship, distinctive number or letters and port of registry; name and principal place of business of the registered owner; IMO ship identification number; type and duration of insurance; name and principal place of business of insurer or other person giving security and place of business where the insurance or security is established; period of validity of the certificate which shall not be longer than the period of validity of the insurance or other security.

The compulsory insurance requirement gives rise to direct action against the insurer or guarantor, under certain conditions. Article 58 clearly states that any claim for compensation for pollution damage may be brought directly against the insurer or other person providing financial security for the registered owner's liability for pollution damage. However, the insurer or guarantor may invoke the defenses (other than bankruptcy or winding up of the shipowner) which the shipowner would have been entitled to invoke, as well as the defense that the pollution damage resulted from the wilful misconduct of the shipowner.

5.4 National Plan for Emergent Reaction in the Event of Sea Pollution from Vessels

In April 2011 the Government of Montenegro brought the National Plan for Emergent Reaction in the Event of Sea Pollution from Vessels. The Plan determines the main principles of actions, tasks, and obligations, together with measures to prevent, minimize, or remove the consequence of the vessel-sourced marine pollution. The main purpose of the Plan is to provide prompt and efficient response to accidents of sea pollution from vessels at the national level. The plan shall be applied in case of a maritime accident that has caused or could have caused pollution in the sea areas, on the seabed, or under the seabed of Montenegro, which include internal waters and territorial sea. The general aim of the Plan is to organize an initial and efficient response in case of oil spills and discharge of harmful substances that adversely affect or could adversely affect the marine environment of Montenegro and its coasts, as well as ensuring national and international cooperation in the Adriatic and Mediterranean Seas.

The plan is based on a graded concept of response. Level 1 includes preparedness and response to small spills that individual facilities or ports can deal with. Level 2 includes preparedness and response to a spill that exceeds the response capabilities of an individual facility or port authority. Level 3 includes large spills that require the mobilization of all available national resources and involves the mobilization of external resources and experts. Priority areas for the implementation of the Plan are protected marine areas and mariculture zones, spawning areas and underwater archeological sites in accordance with the Register of Cultural Heritage.

6 Conclusion

Marine pollution is an important global, regional, and national problem. Adequately designed legal framework which is being implemented in practice is one of the most important mechanisms for effective (efficient) protection of the marine environment against pollution from vessels. Despite the need of having a global legal framework, the role of each state in creating its own legal regime on the protection of the sea against pollution from vessels is extremely important. In fact, each national legal framework is a link that complements the global legal regime, and thus contributes to the protection and conservation of the sea.

The existing legal framework in Montenegro can be viewed through its three segments. The first segment includes general regulations (Law on Environment, Law on Nature Protection, Law of the Sea, Law on Ports, Law on Yachts) which through regulation of natural or environmental environment, Montenegrin sea and submarine areas, ports, yachts, and other issues, in the same time regulate the protection and preservation of the sea, albeit in a general way, while concealing the general legal regime. The second segment includes regulations that indirectly contribute to the prevention of pollution from vessels. These are proposals that define the rights and obligations that Montenegro, as a port state and flag state, must fulfill, in terms of maritime safety (safety of ships, cargo, navigation safety, and occupational safety) and in order to create a preventive legal framework for marine protection. And the third, certainly the most important source of law in the field of protection of the sea from pollution from vessels is a specialized regulation which as its subject has the protection of the sea from pollution from vessels. This is the Law on Protection of the Sea from Pollution from Vessels, which by regulating prevention of pollution (provisions on the construction and equipment of ships, prohibition of discharges into the sea), suppression and limitation of pollution (urgent notification, cooperation in case of pollution), and misdemeanor/criminal sanctions (liability for pollution) forms a solid basis for the protection and preservation of Montenegrin maritime areas.

For the first time within the national legislation, the Law regulates the issue of protection of the sea from pollution from vessels in a comprehensive manner. However, despite the fact that the said Law is the basic law, it is evident from the above that the provisions on the protection and preservation of the sea are also found in other legal acts. Certainly, regulating one area with various legal acts cannot be taken as positive, given that it potentially creates doubts/dilemmas during its enforcement (since they have the same legal force) and cause therefor legal uncertainty. However, such a situation was to be expected and could hardly have been avoided, given the conceptual approach of the Montenegrin legislator when regulating maritime matters (by various legal texts). This situation imposes the need for special expertise in the interpretation of Montenegrin regulations – firstly, from the "vessels" that enter or navigate the waters of Montenegro and to which Montenegrin regulations apply, but also from the competent authorities when applying, amending, and adopting new regulations. Particular attention must be paid to mutual harmonization of the provisions on the protection of the marine environment in the various legal texts.

By creating a legal framework for the protection and preservation of the sea and the adoption/ratification of international conventions related to the protection of the sea, Montenegro shows a clear commitment to preventing marine pollution from vessels. However, it can be seen from the above that in Montenegro, despite the existence of strategic documents in certain areas, no strategy has been adopted to comprehensively and systematically review the situation in the field of marine environment, i.e. which would define basic goals and principles. It could be reasonably expected that first step would be to adopt a strategic document (Strategy for the Protection of the Marine Environment or the Strategy for the Protection of the Sea from Pollution from Vessels or the Strategy for Ballast Water Management) which would analyze the current situation, identify potential problems and their causes, suggest the regulatory instruments to overcome the problems, and only then assess to creation of a legislative framework. Undoubtedly, bringing into life such strategies would encompass and complete the Montenegrin national legal framework on the protection of the sea from pollution.

Alongside the adoption of strategies, following activities should be directed towards further harmonization of national legislation with international standards. The actual implementation and monitoring of legal solutions needs improvement, in order to have a clear definition of the rights and obligations of the competent authorities in this area. It should be added thereto the need for continuous training and education of experts on the issue of marine pollution, as well as raising public awareness through the organization of round tables, workshops, and seminars on the importance of protection and preservation of the sea. From the global aspect, bearing in mind that the protection of the sea cannot be achieved unilaterally, but only through joint cooperation of all countries, it is necessary that Montenegro enhances its cooperation with neighboring countries and numerous international bodies. In fact, only by undertaking certain measures and actions to protect the sea and creating an individual legislative framework at national levels of its coastal states, the Adriatic Sea will be effectively protected from pollution from vessels.

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Changes in Trends of the Seawater Column Parameters and Sediment Elements' Concentrations from 2009 to 2018 in the Marina Located in the Northern Adriatic Sea

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Abstract Assessment of environmental quality within marinas is essential to validate implemented environmental protection measures and to adopt appropriate action plans. Here we present temporal trends over the period from 2009 to 2018 using seasonal analysis of physico-chemical and microbiological parameters in seawater column and measurements of elements' concentrations in surface sediments of the Marina Punat, located in the northern Adriatic Sea, in order to evaluate improvements and deteriorations in marine environmental quality. Environmental monitoring in Marina Punat is carried out four times per year (in May, July, August, and October) at four sampling points (three are within the marina and one is an outside control point). The parameters analysed in situ in a bottom and surface seawater layer are conductivity, dissolved oxygen (DO), pH, mineral oil, total coliform bacteria, faecal coliforms, and intestinal enterococci. The concentrations of elements K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, Ga, As, Br, Rb, Sr, Y, Zr, Sn, Hg, and Pb in surface sediments collected twice per year (in May and August) were analysed in the laboratory by the EDXRF technique. The concentrations of elements in sediments are compared to results from 2005, i.e. prior to full operation of wastewater treatment plants deployed in service areas where boats are repaired and antifouling paints (AFPs) are removed from boats' hulls. There has been a significant improvement in sediment quality in Marina Punat after deployment of the wastewater treatment plants, especially with respect to Cu concentrations close to service areas. An increase in concentrations of V, Fe, Cu, Zn, As, and Pb in surface sediments within the marina due to passive leaching from AFPs is still present. On the whole data set, there were no trends in pH and DO values, however, strongly correlated seasonal trends were observed. The seasonal increase and decrease of DO and pH values in the seawater column are unlikely to be related to the marina's activities. A quick overview of the status of the environmental monitoring in the marinas in Montenegro has been given. This study provides support data for further improvement of management practices in marinas, both in Croatia and Montenegro.

Keywords Adriatic Sea, Antifouling paints, Biocide metals, Marina's environmental impact, Marina punat, Monitoring, Seawater and sediment quality

1 Introduction

Marina Punat (Fig. 1) is located in the Northern Adriatic Sea on the Island of Krk in a relatively closed Bay of Punat. It has existed since 1964 and today has 850 sea berths and 500 places ashore. The Bay of Punat has an oval shape with a maximum length of about 3 km and a maximum width of about 2 km. The maximum depth is 9 m, while the average is 2 m. It is connected to the open sea with 200 m wide sill. The Punat Bay is sheltered from prevailing winds. A relatively weak thermohaline seawater circulation is induced only by high and low tides (with a range of 47 cm), therefore the large perturbations of the sediment bed are not expected. The

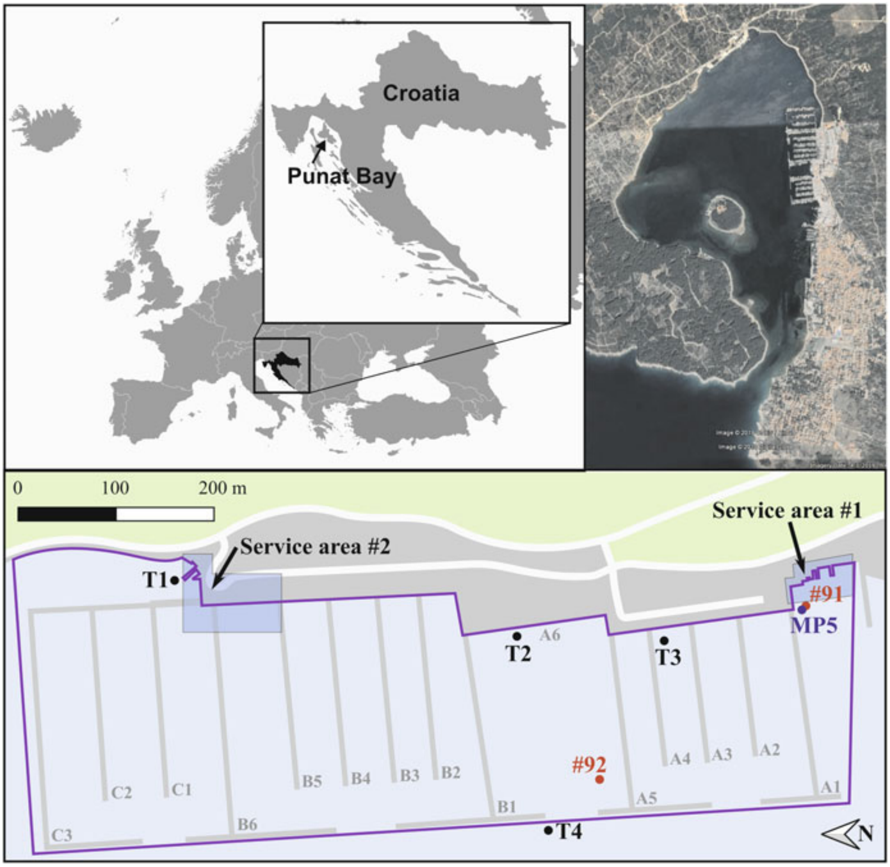

Fig. 1 Monitoring and sampling locations in the Marina Punat. Monitoring points T1–T3 are situated within and monitoring point T4 outside of the marina's area. Locations marked as #91 (service area) and #92 (pier) are sampling points from the study in 2005. The location marked as MP5 is a sampling point at the service area from the study in 2013

direction of currents is often clockwise around the Island of Košljun in the middle of the Punat Bay [1]. Marina Punat possesses certification of the Environmental Management System – ISO 14001 since 2010 and has been awarded the Blue Flag since 1998.

1.1 Impact of Marinas to Seawater Quality

Marinas' impact on the water quality might be expected from nutrient enrichment, bacterial degradation, and mineral oils (petroleum hydrocarbons) pollution [2–5]. Nutrient enrichment and bacterial degradation within closed bays are usually caused by inflow from the sewage system. Such problems might be expected if a marina does not have installed facilities for the disposal of black water tanks and does not impose strict rules concerning this. Neither of this is the issue for Marina Punat which implements the ISO 14001 certification for protection and preservation of the environment, and there are no discharges of sewage waters into the Punat Bay. The other sources of nutrients in the sea are large rivers such as the river Po which is the major contributor of nutrients into the Northern Adriatic [6, 7], storms, land washing (especially of the agricultural land), and aerosol deposition. The leakage of wastewaters from damaged sewage infrastructures from nearby settlements may also be considered as a source of nutrients.

DO depletion might be expected in relation to nutrient enrichment which is followed by increased primary production [8]. The primary production is related to the growth of phytoplankton until all the nutrients are spent in the seawater column, which in the northern Adriatic usually occurs during late spring. Phytoplankton cells sink to the sea bottom after they die and organic matter decomposition takes place, depleting the oxygen from the seawater column. This usually occurs during summer when sea water is warmer and consequently the sea water oxygen capacity is lower, which might result in a rapid DO decrease.

1.2 Impact of Marinas to Sediment Quality

The major environmental problems related to sediment quality in marinas are increased concentrations of biocides such as Cu, Zn, As, and Pb related to washing and leaching of antifouling paints (AFPs) applied to boats' hulls for their protection [9–11]. Biocides protect the boat from fouling (algae, barnacles, and bivalves) [12] which destroy the boat hull and decrease the boat speed. Boat hulls need to be smooth to minimize fuel costs [13, 14]. It has been estimated that several months of accumulation of marine organisms lead to an increase in fuel consumption for more than 45% at the same cruising speed [15]. Besides that, some studies have shown that there are more than 4,000 marine organisms that produce colonies while fouling and are in constant mutual interaction [16]. Antifouling prevention is difficult because it involves protection from different organisms such as bacteria, protozoa, various shellfish, and especially limpets [17]. It has been believed for a long time that AFPs have a damaging influence only to lower marine organisms, but because of the bioaccumulation in higher marine organisms, these chemicals enter the food chain and might have a harmful impact on human health. Other sources of potentially toxic metals and chemicals in marinas' environment are dissolved aerosols from the air and run-off waters from the surrounding area [1].

During the last 10 years, in the period from 2009 to 2018, environmental monitoring has been carried out in the Marina Punat by the Ruđer Bošković Institute, Zagreb, Croatia. Croatian marinas are obliged to conduct monitoring of the seawater column and surface sediments in line with the Croatian regulation for the Water Classification NN 77/98, and recently by the Decree on Water Quality Standards NN 96/19 (former NN 73/13 and NN 80/18), which conforms to the Water Framework Directive 2000/60/EC. The seawater quality indicators used as reference values in Marina Punat are presented in Table 1. There is a growing understanding that human coastal activities cause different levels of environmental degradation and that environmental quality can be maintained at an optimal benefit over the cost level [19]. The goal of Marina Punat is to maintain the environment quality within Category II–III.

2 Material and Methods

2.1 Sampling and In Situ Measurements

Environmental monitoring in Marina Punat is carried out four times per year (in May, July, August, and October) at four sampling points which have different depths: T1–1.5 m, T2–2 m, T3–1m, and T4–4 m. Sampling points T1, T2, and T3 are within the marina area, whilst the point T4 is an external control point (outside of the marina Punat area). The seawater column at each of the monitoring locations was analysed at the surface and the bottom sea layer. DO was measured in situ with the Cole Parmer instrument, Dissolved Oxygen Meter, DO 100 Series. The pH was measured by the Cole Parmer instrument 19,825–00. Electrical conductivity was measured in situ with the YSI 559 instrument. Approximately 1 kg of the surface sediment was taken twice per year (in May and July) at all 4 monitoring locations by the sediment grabber to be analysed by the Energy Dispersive X-Ray Fluorescence (EDXRF) at the Ruđer Bošković Institute. In addition, 0.5 L samples from the bottom and surface layer were taken for microbiological analyses (total coliforms, faecal coliforms, and faecal streptococci) and 1 L was taken from the surface layer for analysis of hydrocarbons. The seawater samples were kept at 4°C until analysed in the Public Health Institute of the Primorsko-Goranska County, Rijeka, Croatia.

Table 1 Indicative limit values of physical, chemical, and microbiological indicators in the seawater column (as defined by former Croatian regulations NN 77/98 and NN 137/08, used for the reference purposes). Sediments categories are proposed according to Caeiro et al. [18]

		Category I	Category II	Category III	Category IV	Category V
Seawater column	*Physical and chemical indicators*					
	pH	6.5-8.5	6.3-6.5 8.5-9.0	6.0-6.3 9.0-9.3	5.3-6.0 9.3-9.5	<5.3 >9.5
	DO (mg O_2/L)	>7	7–6	6–4	4–3	<3
	Oxygen saturation (%)	80–110	70–80 110–120	50–70 120–140	20–50 140–150	<20 >150
	Hydrocarbons (μg/L)	<20	20–50	50–100	100–250	>250
	Microbiological indicators					
	Total coliforms /100 ml	<50	50–500	500–10,000	10,000–100,000	>100,000
	Faecal coliforms /100 ml	<20	20–100	100–1,000	1,000–10,000	>10,000
	Description	Sea suitable for fishing, aquaculture farming, swimming, and recreation	Sea suitable for swimming, recreation and for mullet cultivation	Slightly polluted, should be purified to be used for a particular purpose	Polluted, purification is mandatory before using for any purpose	Polluted, cannot be used for any purpose
Sediments	*Concentrations of metals*					
	Cr (mg/kg)	< 50	[50–100]	[100–400]	[400–1,000]	>1,000
	Ni (mg/kg)	< 30	[30–75]	[75–125]	[125–250]	> 250
	Cu (mg/kg)	< 35	[35–150]	[150–300]	[300–500]	> 500
	Zn (mg/kg)	< 100	[100–600]	[600–1,500]	[1500–5,000]	> 5,000
	As (mg/kg)	< 20	[20–50]	[50–100]	[100–500]	> 500
	Hg (mg/kg)	< 0.5	[0.5–1.5]	[1.5–3.0]	[3.0–10]	> 10
	Pb (mg/kg)	< 50	[50–150]	[150–500]	[500–1,000]	> 1,000
	Description	Clean	Traces of contamination	Low contamination	Contaminated material	Very contaminated material
	Terms of disposal	Marine environment and beaches	Marine environment	Marine environment. (mandatory monitoring)	Landfill (mandatory monitoring)	Landfill (special processing treatment)

2.2 Sediment Analysis

After drying at 105°C, samples were sieved (Ø = 2 mm), homogenized, crushed in a mortar, and then sieved again (Ø = 45 μm) to prepare tablets weighing 2 g and 2.5 cm in diameter. Concentrations of elements K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, Ga, As, Br, Rb, Sr, Y, Zr, Sn, Hg, and Pb have been analysed by the Energy Dispersive X-ray Fluorescence (EDXRF). Philips W X-ray tube was used as a source. Samples were irradiated by the secondary Mo target in a rectangular geometry. A Canberra SiLi detector with an active surface of 30 mm^2, a thickness of 3 mm, beryllium window thickness of 0.025 mm, and with a resolution of 170 eV (FWHM) at 5.9 keV was used for signal collection. Signals were analysed by the Canberra S100 multichannel analyser. The measuring parameters were 35 kV and 35 mA. Samples were analysed in the vacuum chamber. The measurement time was 1000 s. The IAEA QXAS program package, Direct Comparison of Count Rates method, has been used for the quantification of the concentrations of the analysed elements. The IAEA "Sediment Lake", SL-1, has been used as reference material. Relative measurement errors were: K – 7.2%, Ca – 8.1%, Ti – 7.5%, Cr −8.6%, Mn – 4.9%, Fe – 2.5%, Ni – 20.5%, Cu – 20.5%, Zn – 5.1%, Ga – 23.3%, As – 11.1%, Br – 31.0%, Rb – 9.8%, Sr – 5.2%, Y – 7.4%, Sn – 5.3%, Hg – 5.0%, and Pb – 20.5%. Minimum detection limits (MDLs) were: 1 mg/kg for Ga, As, Rb, Y, and Pb, 1.6 mg/kg for Hg, 3 mg/kg for Cu, 5 mg/kg for Cr, Ni, and Br, 10 mg/kg for Fe, and Zn, 13 mg/kg for Mn, 50 mg/kg for Sr, 70 mg/kg for Sn, 80 mg/kg for Ti, and 150 mg/kg for K, and Ca.

2.3 Statistical Analysis

Descriptive statistics were performed for concentrations of elements K, Ca, Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, Ga, As, Br, Rb, Sr, Y, Zr, Sn, Hg, and Pb measured in surface sediments. Spearman Rank Order analysis at a significant level $p < 0.05$ was used to evaluate correlations between physico-chemical parameters measured in the seawater column. Both analyses have been calculated using Statistica 6 software. Linear regression with a 95% confidence interval was calculated for seasonal temporal trends of pH, DO, and conductivity in the seawater column, and V, Fe, Cu, Zn, As, and Pb concentrations in surface sediment, by using Sigma Plot 11.0.

3 Results and Discussion

3.1 Seawater Column

The measurements of pH and DO values were in the focus of the assessment of temporal trends in the Marina Punat seawater column. It is known from various studies that the sea pH level is decreasing and will have a negative trend for about 0.15–0.35 on a global level in the next 100 years [20]. Even though this is a small difference, it represents an increase of 26% in the concentration of hydrogen ions [21]. When carbon dioxide dissolves in the ocean, it increases the hydrogen-ion concentration, lowering the ocean pH. Many organisms whose skeleton is made of calcium carbonate such as coccolithophores, foraminifera, and shells may be impacted by lower pH in the seas, especially deep-sea organisms which are more sensitive to pH changes [22]. Besides, one of the main drivers of marine respiration which involves the exchange of O_2 and CO_2 between sea and atmosphere is marine primary production. Phytoplankton contributes to more than 90% of total marine primary production [23] and converts close to 40% of the total fixed carbon dioxide to biomass per year [24]. Thus, the primary bioproduction, i.e. nutrification status of the sea, has a direct effect on pH and DO values. In this study, we have tried to assess the marina's impact on the values of those parameters.

The results of physico-chemical indicators in the seawater column over the period from 2009 to 2018 for Marina Punat are shown in Fig. 2, while Spearman Rank Order analysis at a significant level $p < 0.05$ between physico-chemical parameters is shown in Table 2. Since the measurement depth was only 1–4 m there has been no significant difference between values measured close to the surface and near the bottom of the seawater column.

As mentioned above, the measurements of DO and pH parameters in the marine environment might be used as an indication of marine primary productivity. DO and pH values in this study did not show any trends for the whole data set, however, seasonal trends over spring, summer, and autumn were very well expressed. DO values were statistically significantly correlated to pH showing a positive trend in spring, negative in summer, and a very weak negative trend in autumn. This can be explained by phytoplankton blooms in spring when the Adriatic seawater is rich in nutrients. They take CO_2 from the sea and produce O_2, thus increasing the pH and DO values in the seawater column in spring. In summer, when the majority of nutrients are spent, they die and sink on the sea bottom. The decay of organic material takes place, rapidly consuming the oxygen dissolved in seawater. As a consequence, both pH and DO values decrease, which is the process that occurs also in autumn although at a slower rate. From this sequence of events, it can be concluded that marine primary production is increasing in Punat Bay. Perhaps the cause of this is the increase of N inputs [25, 26] in the Northern Adriatic Sea which has been reported by Djakovac et al. [27]. However, Djakovac et al. [27] discuss that P, which is decreasing in the Northern Adriatic since 2000, infer the limit to phytoplankton growth resulting in the accumulation of dissolved N due to reduced

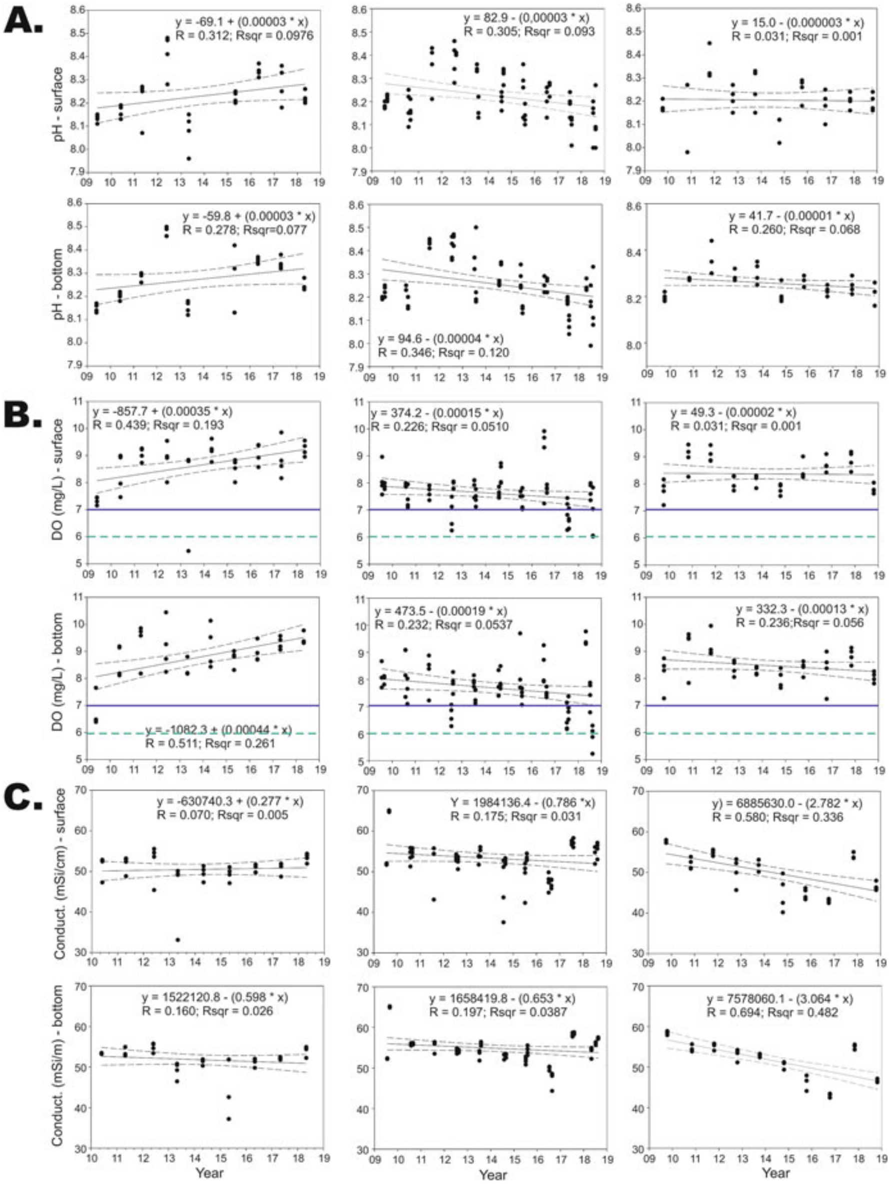

Fig. 2 Seasonal trends in surface and bottom seawater column layers for (**a**) pH, (**b**) DO (mg/L), and (**c**) Conductivity (mSi/cm^2) measured in situ in spring (May, 1st column), summer (July and August, 2nd column), and autumn (October, 3rd column) at T1-T4 locations in the period from the beginning of 2009 to the end of 2018. The solid blue line marks DO limit value for Category I/II and dashed green line marks DO limit value for Category II/III

Table 2 Spearman Rank Order analysis at a significant level $p < 0.05$ used to evaluate correlations between physico-chemical parameters measured in the seawater column of the marina Punat in the period from the beginning of 2009 to the end of 2018. Significant correlations are bolded

	Temp.	pH	Conduct.
Spring – Surface			
pH	**−0.369452**	1.000000	
Conduct.	0.146241	**0.354587**	1.000000
DO	−0.236887	**0.435290**	**0.393885**
Spring – Bottom			
pH	**−0.384090**	1.000000	
Conduct.	0.259543	**0.358525**	1.000000
DO	**−0.384695**	**0.455652**	0.328742
Summer – Surface			
pH	−0.139891	1.000000	
Conduct.	**0.347365**	−0.222920	1.000000
DO	−0.203513	**0.435689**	**−0.308707**
Summer – Bottom			
pH	−0.200675	1.000000	
Conduct.	**0.294543**	**−0.387368**	1.000000
DO	−0.105717	**0.342987**	**−0.386848**
Autumn – Surface			
pH	−0.249155	1.000000	
Conduct.	0.002392	0.289077	1.000000
DO	**−0.581464**	**0.442288**	0.187509
Autumn – Bottom			
pH	**−0.335751**	1.000000	
Conduct.	0.077872	0.162840	1.000000
DO	**−0.359951**	**0.437376**	**0.375569**

bioproduction. Unfortunately, to our best knowledge, the measurements of N and P or phytoplankton production in the seawater column were not conducted in Punat Bay. Since the effect starts to manifest in spring, before the main tourist season in Marina Punat or nearby settlements, it cannot be ascribed to marina activities or an increased number of tourists in the area. Thus, the explanation of the increased bioproduction in Punat Bay over the last 10 years remains to be investigated in future studies. However, it is worthwhile to note that during the summer season over the last 2 years, a significant decrease in DO values has been observed within the marina, especially at the bottom layer of the seawater column. In the year 2018, the DO values below 6 mg/L (Category III) were registered for the first time. If adverse effects with DO decreasing continue, dredging of the Punat Bay sill to deepen the entrance into the bay might improve the situation, allowing greater exchange of the bay seawater with the open sea.

Results regarding the conductivity values show no trend in spring, however, there was a slightly decreasing trend in summer and a steep decrease in autumn (Fig. 2), which might be an indication of an increasing amount of freshwater discharge in Punat Bay during summer and autumn. There was no statistically significant correlation with other parameters measured in the seawater column.

No particular trends were observed with respect to microbiological indicators. The number of total coliforms and faecal coliforms was mostly within Category II, occasionally Category III (especially during the summer season). The number of faecal streptococci was mostly below 20, rarely exceeding 50. The situation concerning mineral oil has been significantly improving from 2015 onwards, after installation of the additional wastewater plant in 2014 to treat the polluted waters collected from the marina's service area #2 and dry docks. Only 2 measurements resulted in values within Category III and 2 resulted in values within Category II (out of 64 measurements in total). Results of correlations, microbiological parameters, and mineral oils are presented in Fig. 3.

3.2 Sediments

Sediments accumulate contaminants from the seawater column over a long period and they are one of the best indicators for determining the quality of the marine environment. They can be used to assess the present exposure to contamination, as well as to gather evidence on past contamination events and to reconstruct a historical record of pollutant discharges.

It is well established that sediments in marinas have elevated concentrations of biocide metals such as Cu and Zn which are used in AFPs for boat protection [9–11, 28]. Before the 1980s, the tin organic substances, such as tributyltin (TBT), were major biocides used in AFPs. The prohibition of TBT by International Convention on the Control of Harmful Antifouling Systems on Ships (the AFS Convention) [29], which entered into force in 2008, has caused an increase in the use of AFPs containing different Cu compounds as active ingredients [28]. In addition to Cu, the so-called booster biocides, e.g. zinc pyrithione ($C_{10}H_8N_2O_2S_2Zn$ or $ZnPT_2$), zineb ($C_4H_6N_2S_4Zn$), irgarol ($C_{11}H_{19}N_5S$), and diuron ($C_9H_{10}Cl_2N_2O$) might be added to AFPs to enhance the prevention of fouling by attacking a wider range of fouling pests [9, 28, 30]. The highest input of AFPs biocides in the Adriatic Sea could be found in marinas [10, 31], where the traffic of vessels is frequent and the sea currents are usually weak. In marinas Cu easily deposits in the sediment (in principle very close to boats) staying there for a long time. Many studies have shown that a smaller number of species, also a smaller diversity, could be found in an area where the concentration of Cu is high [32]. Zn, Pb, and other elements, which role is to improve the quality of the AFP matrix, are released at a much slower rate from coatings than Cu [33].

In our first studies during the 1990s in Punat Bay, it has been found that concentrations of potentially toxic elements are 10 to 20 times increased in the area with anthropogenic influence (marine area, shipyard) in comparison to areas without it [34]. Since 2000s the Marina Punat was continuously investing in

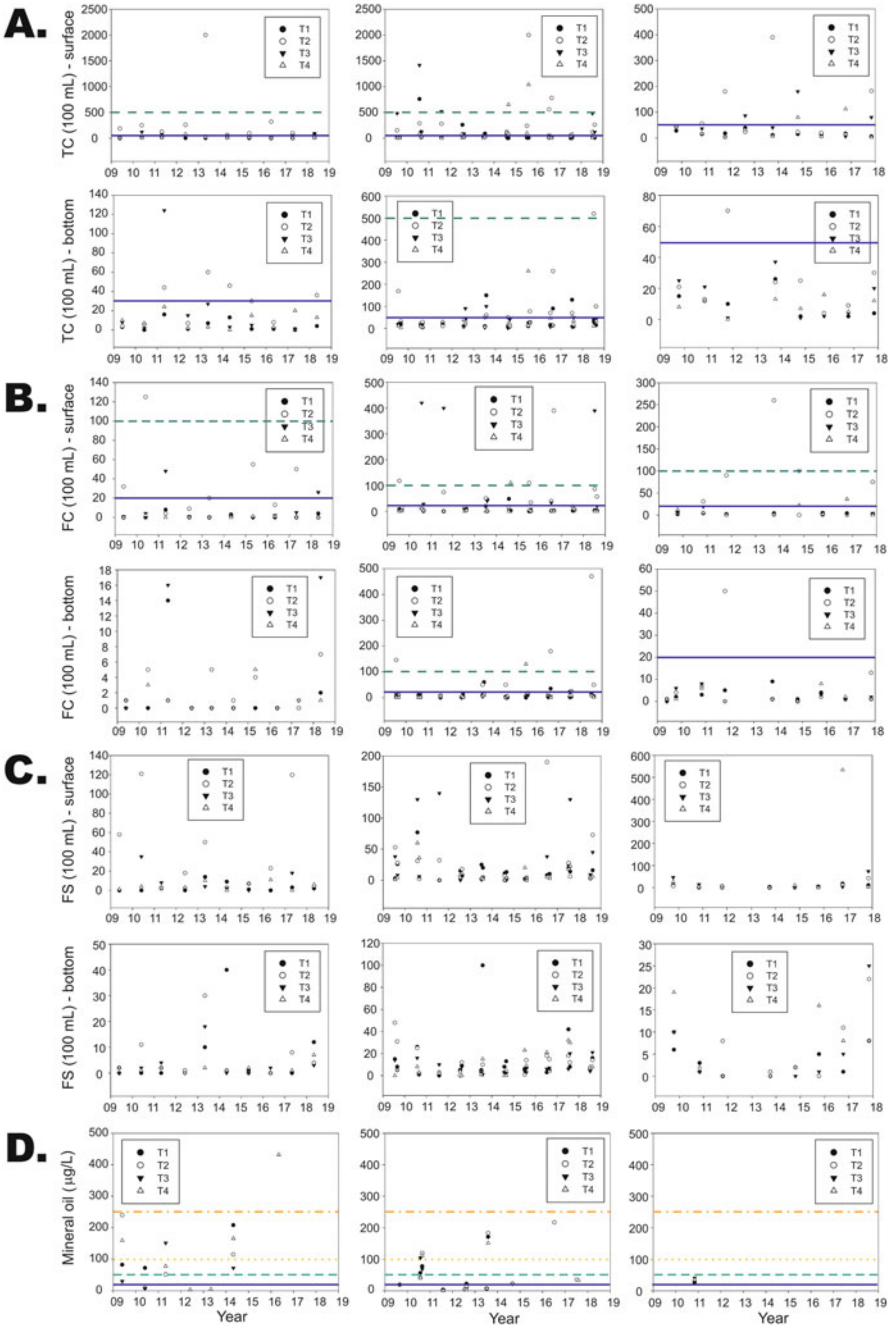

Fig. 3 Seasonal trends in (**a**) total coliforms (TC) bacteria; (**b**) faecal coliforms (FC); (**c**) faecal streptococci (FS) (intestinal enterococci); and (**d**) mineral oil measured in seawater column in spring (May, 1st column), summer (July and August, 2nd column), and autumn (October, 3rd column) at T1-T4 locations in the period from the beginning of 2009 to the end 2018. The solid blue line marks

wastewater treatment infrastructure. The first testing wastewater treatment plant for removal of metals was installed in the Marina Punat service area in 2000 and was in operation until 2010. In 2010 a new device of larger capacity and with the possibility of working in continuous mode has been installed in the shipyard Punat, which is located next to the Marina Punat. Since 2014 another device has been installed on the north of the marina to treat the wastewaters from boat washing collected from service area#2 and from marina's dry docks. The impact of these measures has been seen as an improvement in sediment quality evident from decrease in concentration of Cu from 10,030 mg/kg to 770 mg/kg in surface sediments at the vicinity of the boat lift where boat' hulls are washed from AFP (locations #91 and MP5 in Fig. 1) in the period from 2005 to 2013 [35, 36]. The effect has been observable also at the pier area in the wider surroundings of the service area, where the concentration of Cu in 2005 at location #92 (Fig. 1) was 2,761 mg/kg [35], while values measured presently within marina area do not exceed 300 mg/kg.

The natural precipitation of the fresh sediment from the seawater column and slow replacement of sediments by the sea currents greatly improved the sediment quality of Marina Punat in comparison to 2005.The improvement in the sediment quality has been observed in the close surrounding of the marina's service area#1 and in the outer monitoring point T4. However, the monitoring conducted in the period 2009–2018 has shown a slow but steady increase in concentrations of V, Fe, Cu, Zn, As, and Pb at locations within the marina's area (monitoring points T1, T2, and T3). Table 3 shows the descriptive statistics for concentrations of elements measured in Marina Punat surface sediments, while Fig. 4 shows the temporal trends of V, Fe, Cu, Zn, As, and Pb concentrations measured in sediments at all 4 monitoring locations. From diagrams presented in Fig. 4, it can be observed that Cu, Zn, As, and Pb concentrations measured in surface sediment at T1, T2, and T3 monitoring locations within Marina Punat in the period 2009–2018 have mainly stayed within Category II. On the other hand, concentrations measured at the control point T4 have decreased, reaching the Category I for Zn, As, and Pb, while Cu concentrations remained at a steady level since 2015 (Category II). Vanadium is the only element whose concentrations were increasing at T4, presumably because of the fuel consumption. Cu concentrations at locations T1 and T3 in the last few years have been close to or within the Category III. Considering the increase of Fe, Zn, As, Pb, and especially Cu concentrations within marina and a decrease of these concentrations at the control monitoring point, it could be concluded that passive leaching from AFPs applied to boats is likely the major source of Fe, Cu, Zn, As, and Pb input, while the source of V input is probably the fuel used by boats. Run-off water due to stormy weather might be considered as an additional source of these elements.

Fig. 3 (continued) limit value for Category I/II, dashed green line marks limit value for Category II/III, dotted yellow line marks Category III/IV limit, and orange dash-dotted lines mark values above Category IV

Table 3 Descriptive statistics for concentrations of elements in mg/kg measured in surface sediment. The values under MDL have not been taken into account

	Valid N	Mean	Median	Min.	Max.	Lower quartile	Upper quartile	St.D.	Skew.	Kurt.
K	76	12,900	12,500	6,100	19,300	11,500	14,200	2,400	0.37	0.85
Ca	76	143,600	145,700	50,400	226,000	115,400	172,400	38,800	−0.17	−0.34
Ti	76	1,520	1,556	744	2,133	1,300	1,696	276.59	−0.35	0.04
V	76	40.9	40.8	13.7	80.0	30.7	49.6	14.0	0.25	−0.16
Cr	70	36.3	32.9	5.3	85.2	25.0	45.2	18.26	0.73	0.27
Mn	76	201.3	101.7	41.3	1654.1	74.6	169.1	271.6	3.32	12.65
Fe	76	14,000	12,480	6,910	68,740	10,900	15,370	7,190	6.09	45.67
Ni	76	27.3	26.4	8.6	60.0	22.8	31.4	8.6	0.62	2.19
Cu	76	107	95	40	300	68	138	48	1.16	2.25
Zn	76	197	192	20	596	151	237	86	1.89	7.20
Ga	66	6.4	6.0	2.0	15.6	5.0	7.7	2.5	0.94	1.94
As	76	24.8	23.2	12.2	53.6	18.0	29.8	8.5	1.03	1.02
Br	76	325	289	128	687	206	414	148	0.86	−0.11
Rb	76	65.6	64.5	35.1	101.6	56.5	73.0	13.7	0.35	0.13
Sr	76	1,313	1,408	227	2,326	1,024	1,602	518	−0.35	−0.24
Y	76	30.1	30.7	17.2	43.0	26.5	34.3	5.7	−0.16	−0.36
Zr	67	153	141	28	462	101	193	78	1.50	4.15
Sn	14	57.2	49.2	15.1	211.9	33.0	64.3	48.0	2.85	9.48
Hg	20	1.678	1.534	0.761	3.859	1.060	1.902	0.787	1.37	2.24
Pb	74	47.6	43.4	13.4	150.8	33.3	54.0	22.0	2.11	7.07

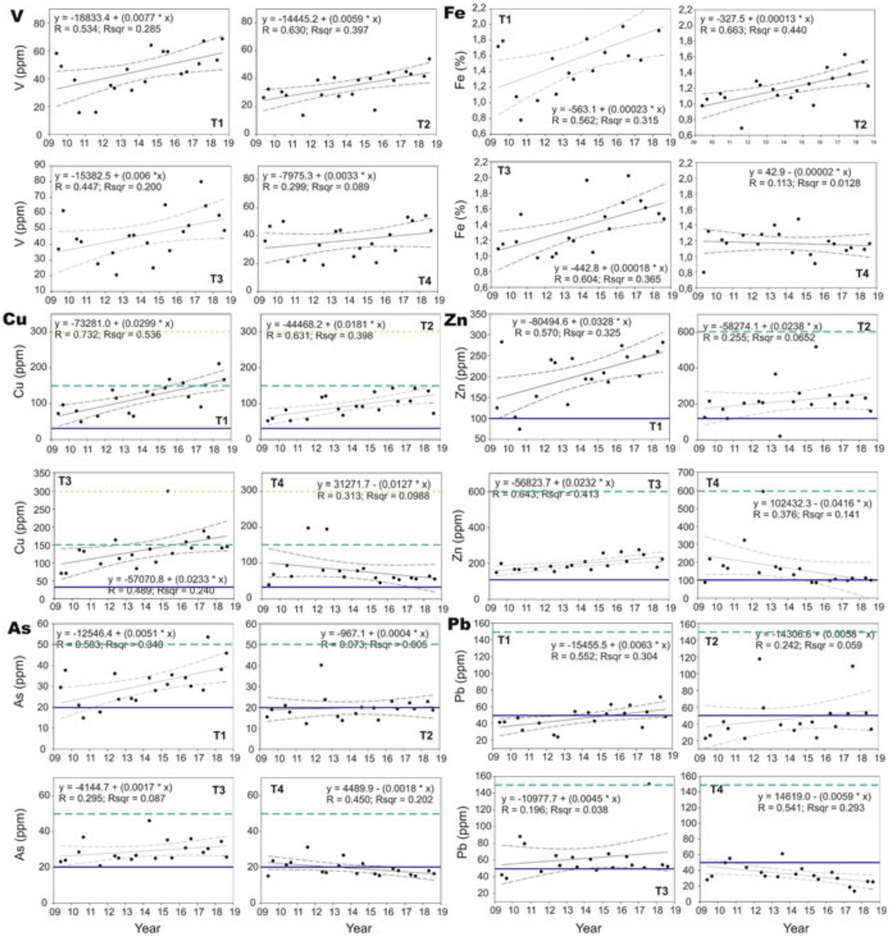

Fig. 4 Seasonal trends in concentrations of V, Fe, Cu, Zn, As, and Pb measured in surface sediments at monitoring locations (T1-T4) in Marina Punat in the period 2009–2018. The solid blue line marks the limit value for Category I/II, dashed green line marks the limit between Category II/III, and dotted yellow line marks Category III/IV determined according to Caeiro et al. [18] for elements Cu, Zn, As, and Pb

Although neither of the measured data imposes an immediate or significant risk for the marine environment of the Punat Bay, these data need to be put into the future perspective of environmental protection. The highest risk represents the increase of Cu concentrations in surface sediments. Since AFPs coating should be replaced once a year, the improvement within a reasonable time with respect to Cu in sediments could be achieved by advising boat owners to use Zn based instead of Cu based AFPs. Currently, there is a product on the market containing a sole Zn biocide – $ZnPT_2$ (trade name Zinc Omadine®) [28]. Irgarol (or Cybutryne) based AFPs products are also an alternative to Cu based AFPs. However, these are quite new products and presently it is not clear what ecological impacts might be expected from exposure to these biocides, thus the future evaluation is necessary.

3.3 Marinas in Montenegro

There are 6 main marinas in Montenegro: Lazure Marina in Herceg Novi (160 berths, up to 20 m length yachts); Portonovi Montenegro in Herceg Novi (238 berths, up to 120 m length yachts); Porto Montenegro in Tivat (430 berths, up to 250 m length yachts); Luštica Bay in Radovići (176 berths, up to 45 m length yachts); Dukley Marina Budva in Budva (300 berths, up to 70 m length yachts); and AD Marina Bar in Bar (900 berths, 300 dry berths, up to 40 m length yachts). According to the Joksimović et al. [31], who reviewed concentrations of potentially toxic elements in surface sediments of the Montenegro coast for the period from 2005 to 2016, some of the highest concentrations of Cu, Zn, As, and Pb are found in sediments close to marinas service areas. Specifically, they have sampled Marina Porto Montenegro, Lazure Marina, and AD Marina Bar. The concentrations above 500 mg/kg, up to 1,600 mg/kg, up to 40 mg/kg, and above 700 mg/kg were found for Cu, Zn, As, and Pb, respectively (the highest concentrations have been found in the years 2010 and 2011). According to criteria applied to Croatian marinas, this would represent Category IV (contaminated material) considering Zn and Pb, and Category V considering Cu (very contaminated material). These sediments would be prohibited for disposal in the sea in case of the marina dredging.

Since 2014 the team of the SUST-MARINA international project (Applying and Promoting the Concept of Sustainable Development to AD Marina Bar) has started to monitor the water column parameters (temperature, salinity, conductivity, total dissolved solids, DO, pH) in AD Marina Bar [36]. Thus, the capacity for the monitoring of Montenegro's marinas in terms of expertise and infrastructure exists and baseline data are accessible [31, 36]. However, according to our experience, the marinas' managers and their employees appreciate environmental monitoring, but if it is not legally obliged they will look on it as an extra cost which they will not be willing to finance. Therefore, it is perhaps useful to describe in more detail the Croatian national legislation on environmental monitoring in marinas, which is in force since 1998. The national legislation has complied with the EU policy since 2012 when Croatia has become an EU member. Marinas are obliged to monitor the water column parameters and concentrations of elements in the surface sediments (usually seasonally, i.e. during spring, summer, and autumn), as well as changes in the ecosystem (usually once in 10 years). The parameters and frequency of monitoring are evaluated within the Environmental Monitoring Study which must be conducted before the certain interventions in the marina's environment (e.g. extension in a number of berths), or before planning of the new marina. If the service area is planned within such an investment than the installation of the wastewater treatment plant for the cleaning of wastewater collected from marinas service areas, which is loaded with potentially toxic elements and hydrocarbons, is an integral part of the investment. The drawback of such policy is the omission of older marinas (i.e. those built before the 1990s) which do not have the Environmental Monitoring Study conducted; hence they are not obliged to conduct environmental monitoring. In addition, these marinas usually have no wastewater plant for the treatment of wastewaters collected from the marina's service area. This problem remains to be dealt with in the future.

In the view of the forecasted global climate change, the monitoring of the environment heavily consumed with human activities such as marinas will become even more important. Since the Adriatic Sea is a closed sea, the changes in the next 50 years might be even more rapid than in the oceans and seas globally. Probably the most significant change, except for the sea temperature and salinity, could be expected in the primary bioproduction and consequently in the oxygen regime. Since marinas are usually built at locations with very weak sea currents, the effects can be even more pronounced and marinas should be prepared to adapt to these new scenarios. Except for the parameters evaluated in the previous chapters (listed in Table 1), we recommend to marinas to monitor the nutrient concentrations (PO_4^{-3}, NH_4^+, NO_2^{-1}, NO_3^{-2}) and phytoplankton communities. The measurements should be performed approximately at the same time of the year in the pre-season (spring), season (summer), and post-season (autumn). The larger marinas (e.g. those with more than 400 berths) should conduct more frequent measurements (e.g. twice measurements in the summer). For small to medium size marinas, up to four locations (including the control point) should be sufficient. Larger marinas should be covered by more monitoring locations. If marina does not possess the wastewater treatment plant, additional monitoring point should be included within the area of the travel lift where the boat washing is performed. Long-term evaluation of the collected scientific data (e.g. every 10 years) is very important and should be done with the purpose to assess trends of the measured parameters and to undertake the appropriate corrective measures, if necessary.

4 Conclusion

To our knowledge, this study presents the first attempt to validate undertaken environmental measures with respect to seawater and sediment quality within a marina. For this purpose, the decade long measurements of several environmental parameters in seawater column and surface sediments (pH, DO, and conductivity in seawater, the content of elements in sediments) have been assessed. It has been shown that changes in pH and DO values in Punat Bay are governed by an increase in primary production over the last 10 years which is unlikely to be related to marinas' activities. Dredging of the Punat Bay sill to deepen the entrance into the bay is recommended to prevent worsening of the oxygen regime by allowing the faster exchange of the bay seawater with the open sea.

The evaluation of the marine environment quality in the Marina Punat can be summarized as follows. The environmental quality has been improved compared to the situation in 2005 with respect to sediments in the closer surrounding of the service area and at the control monitoring point due to a decrease in the total AFPs load. In addition, the discernible improvement has been noted with respect to decreased input of mineral oils (petroleum hydrocarbons). However, the attention has to be kept to future increasing trends of Cu, Zn, As, and Pb concentrations in sediments due to passive leaching from AFPs applied to the boat hulls, and due to increasing trends of V concentrations (presumably because of the fuel used by boats). Since the highest environmental risk currently presents the Cu input from AFPs, the transitional solution might be a rapid introduction of Cu free AFPs, while the lasting solution would be the introduction of biocide-free antifouling practices. The Marina Punat has undertaken environmental measures against pollution recommended by the environmental experts so far and demonstrated that it is possible to improve and maintain a reasonably good seawater quality, and to slow down the accumulation of biocide metals in sediments.

The achievement of high environmental standards is becoming more important for marinas in Croatia and Montenegro, as this is one of the most recognized components of the marinas' quality among its users. Therefore, environmental monitoring is becoming a priority issue for marinas in Croatia and Montenegro. This study shows how long-term scientific data are used to develop corrective measures for the improvement of environmental management. This is useful to marinas managers as well as to domestic people who might live of and with these activities in their neighbourhood.

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Pollution from Fish Farming Activities in the Adriatic Sea

Slavica Matijević

Contents

Abstract Fish farming (sea bream and sea bass, as well as bluefin tuna) production in Croatia exhibited a large increment from <1,500 t per year in 1997 to >14,000 t per year in 2018. This expansion has led to enhanced concern for the environmental integrity of the coastal areas from the public and the scientific community, particularly regarding ecological impact of fish farming. To reduce pollution caused by these activities in Croatia, monitoring of physical, chemical and biological parameters in the water column and sediments was introduced. According to Croatian legislative, monitoring activities are based on Environmental Impact Assessment studies (EIAs) for particular fish farm facility. These monitoring programs are not unified considering the parameters to be monitored as well as criteria or standards applied. Similar situation of different monitoring practice of environmental impact of fish farming based on EIAs can be found on European and Mediterranean level.

In this chapter an overview of physicochemical parameters monitored at Croatian fish farms is given. On the example of one sea bass and sea bream farm, methodology of sampling and analysis of the water column and sediments is presented as

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well as the obtained results. Analysed parameters from the water column were: oxygen concentration, pH value, dissolved phosphorus (inorganic and organic), inorganic nitrogen (sum of nitrates, nitrites and ammonia), organic nitrogen concentrations. Parameters determined in sediments were : phosphorus, organic carbon, total nitrogen content and sediment redox potential. According to the presented results parameters in sediments such as phosphorus concentration and redox potential proved as very good indicators of fish farm generated pollution, while from the water column, dissolved inorganic nitrogen form ammonia and organic phosphorus indicated changes caused by farming activities. Parameters proposed to be monitored in sediment represent the organic matter content (carbon, nitrogen and phosphorus) and the degree of its degradation (redox potential). Their analyses are not expensive and they are feasible to obtain. Majority of parameters monitored in the water column are already included in the water quality analysis that are monitored for the commitments of European directives (WFD, MSFD) or Mediterranean plans (IMAP), and their interpretation can be obtained in accordance with the existing threshold values.

Brief overview of Montenegrin mariculture activities, legislation, monitoring and perspectives is also given to compare with Croatian experiences. It can be summarized that presented Croatian monitoring design of physicochemical parameters in water column and particularly in sediments can be applicable example of future monitoring practice on the Montenegrin fish farm facilities.

Keywords Adriatic Sea, Fish farming, Nutrients, Pollution, Sediment, Water column

1 Introduction

Aquaculture in Croatia is very important economic activity with long tradition. It is playing an important role in Croatian fisheries with the share of aquaculture in the total fishery in Croatia of 18.6% (in 2017) that is close to the EU average of 20.4% (http://www.fao.org/fishery/countrysector/naso_croatia).

Farming of aquatic organisms in Republic of Croatia includes marine and freshwater aquaculture. In 2018 total aquaculture production was 18,067 t and the marine fish production had the largest share (84% in total) (Fig. 1).

Marine aquaculture includes farming of finfish, pelagic fish and shellfish (Fig. 2). Marine finfish farming in Croatia is dominated by European seabass (*Dicentrarchus labrax*), gilthead seabream (*Sparus aurata*) with the production of these two species exceeding 11,000 t in 2018, and Atlantic bluefin tuna (*Thunnus thynnus*) with >3,220 t) (http://www.fao.org/fishery/countrysector/naso_croatia). Shellfish farming comprises farming of Mediterranean mussel (*Mytilus galloprovincialis*) and European flat oyster (*Ostrea edulis*) whose production in 2018 was 900 t, i.e. 5% in total marine production (https://ribarstvo.mps.hr/default.aspx?id=14). According

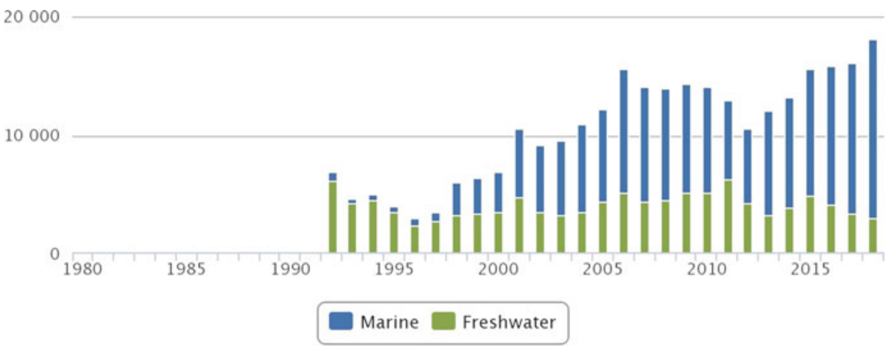

Fig. 1 Aquaculture production by the culture environment in the Republic of Croatia (Source: https.www.fao.org/fishery/countrysector/naso_croatia)

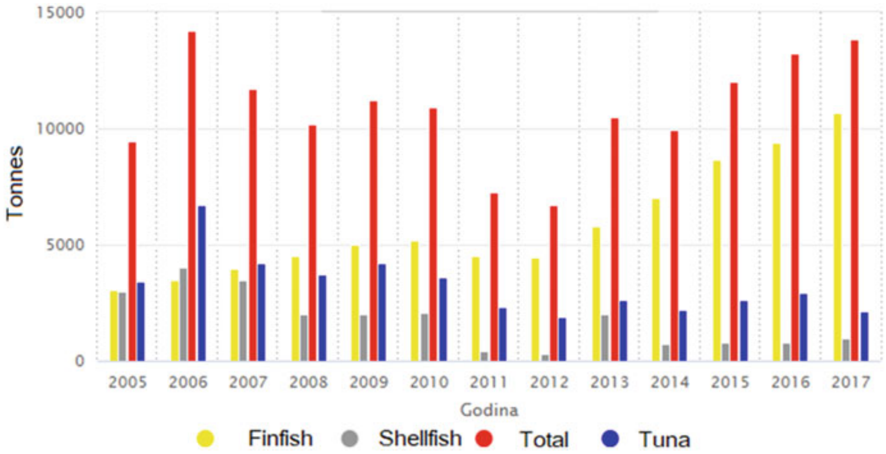

Fig. 2 The production of finfish (gilthead sea bream and sea bass), shellfish and tuna in Croatia for the 2005–2017 period (http://baltazar.izor.hr/azopub/bindex)

to National Strategic Plan for Aquaculture Development of Republic of Croatia (NSPA) in strategic objectives and priorities it was planned to reach the number of 10,000 t of marine fish (excluding tuna, until 2020, and for tunas 3,000 t) [1].

Croatia pioneered commercial marine aquaculture with one of the first and largest hatcheries for European sea bass in the early 1980s. During the 1990s war activities interrupted its development and it took a long time to consolidate. Marine aquaculture has completely recovered and now represents the fastest growing part of total aquaculture sector in Croatia. Production involves a closed farming cycle, where the first phases take place in a hatchery and then in the floating cages at sea.

Farming of Atlantic bluefin tuna (*Thunnus thynnus*) in Croatia has started in the 1990s. Production is based on capture of wild tunas (8–10 kg in size) and their subsequent farming to the market size (30 kg and larger). If the captured tuna have acceptable size at capture, the cage farming may last only a few months, but if this is not the case, these smaller captured fish may be kept in cages for up to 2 years. Tuna is fed with small pelagic ("blue") fish, which is rich in fat content. Due to the low utilization rate of this feed, large quantities of food is needed, which may sometimes lead to unwanted impact on environment.

Annual production of Atlantic bluefin tuna has been stagnating in the last few years due to the restriction measures in tuna fishery managed by ICCAT (International Commission for the Conservation of Atlantic Bluefin tuna). Atlantic bluefin tuna represent on average nearly 25% of the volume of marine aquaculture production. Almost the entire tuna production is placed on the Japanese market.

Shellfish farming has the longest tradition in Croatia. There are written evidences about oysters farming in the sixteenth century in Mali Ston Bay. Farming includes Mediterranean mussel (*Mytilus galloprovincialis*) and European flat oyster (*Ostrea edulis*), using traditional farming technology of floating parks. All shellfish production areas are continuously monitored by the State (Monitoring of water quality).

According to the Ministry of Agriculture, Directorate of Fisheries, in 2017, the total number of aquaculture production centres was 204, including both marine (158 farms) and freshwater (46 farms).

The farms are mostly microscale enterprises, particularly family-owned farms. There are 35 companies registered for finfish farming on a total of 63 locations at sea, while 9 locations are licensed for polyculture (farming of fish and shellfish). There are also 4 land-based hatcheries. Tuna farming takes place in floating cages at sea, in Split-Dalmatia County and dominantly in Zadar County. There are 4 companies registered for tuna farming on a total of 10 locations. Oysters are in general farmed in the area of Malostonski Bay and Malo More, while mussels are mostly farmed in the area of western coast of Istria, area of the river Krka estuary, and in Novigrad Sea. There are 124 registered shellfish farmers on a total of 280 locations (http://www.fao.org/fishery/countrysector/naso_croatia).

The public awareness of the aquaculture in Croatia has experienced significant transformation; from acceptable "eco-production" activity, at the beginning, to activity with negative anthropogenic impact on the marine environment, nowadays. The sources of possible negative impact are: generated waste (especially caused by feeding), the appearance of pests and diseases, genetic pollution caused by the escape of cultivated fish and their interbreeding with wild fish populations, visual "pollution" of the area, unwanted odours, etc. The intensity of negative impact depends on the farm size, the type and the efficiency of feeding; the substrate (bottom) type, the sea depth, the intensity and volume of water mass exchange.

2 State of Knowledge About Environmental Impact of Fish Farming

Since mariculture production becomes more intensive, it requires new sites for cultivation and this consequently results in conflict with other users of the coast. Therefore, targeted research with the aim to assess the impact of fish farming on the marine environment is necessary [2].

Great expansion of fish farm activities in Croatia has led to enhanced concern for the environmental integrity of the Croatian coastal areas from the public and the scientific community, particularly regarding its ecological influences.

Fish farming releases a variety of waste into the marine environment including nutrients, organic matter as well as pharmaceutical products, which can have undesirable impacts [3]. According to Karakassis et al. (2005), there is a small risk of hypernutrification at large spatial scales in the Mediterranean, while potential changes in the water column occur at short spatial scales [4]. The effects of fish farming, monitored in the immediate vicinity of the fish cages (small spatial scales), on the nutrients and chlorophyll-a concentrations in the water column in most cases were not significant [5–7].

On the contrary, degradation of the seabed beneath and around the fish cages is the most widely documented effect of fish farming. These changes were demonstrated through disturbances of different parameters such as a negative sediment redox-potential [8, 9], accumulation of organic carbon, phosphorus and nitrogen compounds [10–15] and accordingly changed or reduced benthic communities [16–22].

Targeted researches of fish farm impacts were also focused on the efficiency of feeding and food composition in order to improve the growth of cultured organisms and reduce the negative environmental impact [23, 24]. The impact of farms on the nearby seagrass communities in the Mediterranean was also researched [18, 25]. Slišković et al. (2010) described the populations of bio-fouling communities on farming installations in the eastern Adriatic [26]. The fate of the organic matter accumulated under farming installations [27, 28], the regeneration of bottom system after the removal of cages [29, 30] and genetic comparisons of wild and cultured populations of fish [31, 32] were the objects of numerous research studies.

3 Legislative Regulation of Fish Farming Activities

The greatest number of regulations that directly impact how the activity of aquaculture is performed at EU level comes from the field of environmental protection. The key regulations include the Water Framework Directive (WFD), (2000/60/EC), the Directive on the Conservation of Natural Habitats and Wild Flora and Fauna (Council Directive 92/43/EEC), the Directive on Conservation of Wild Birds (Directive 2009/147/EC 15) (together creating framework of establishing Natura 2000

Network), the Environmental Impact Assessment Directive (EIA Directive 2014/52/EU), the Marine Strategy Framework Directive (MSFD), (2008/56/EC), the Directive on Alien and Locally Absent Species in Aquaculture (EC) No 708/2007 and the Strategic Environmental Assessment Directive (SEA) (2001/42/EC).

From the point of view of aquaculture, the WFD and MSFD refer primarily to issues of water quality. The objective of the MSFD is to safeguard the ecological standards in the maritime environment. The EIA and SEA directives regulate the issues of size and shape of spatial interventions that require impact assessments, that is, create the framework for performing environmental impact assessments when preparing strategic plans for development of a specific activity.

3.1 Monitoring of the Impact of Mariculture on the Environment

Republic of Croatia implements the Plan for Monitoring sea and shellfish quality in production areas and areas of reintroduction of live shellfish, which is in accordance with the Regulation (EC) (No 854/2004) determining specific rules for the organization of official controls on products of animal origin intended for human consumption.

Monitoring the impact of fish farming on the environment is regulated by the Croatian Law on Protection of the Environment (OG 82/94 and OG 128/99) [33, 34] and the Ordinance amending the Ordinance on assessment environmental impact (OG 59/00 and OG 136/04) [35, 36]. All marine fish and shellfish farms of annual production more than 50 tons, and all marine hatcheries with an annual production of more than 500,000 fish juveniles, are obliged to prepare an EIA study, which prescribes the monitoring of the impact of farming on the environment for specific area.

Unfortunately, this monitoring plan is not unified, nor are the indicators defined follow, neither the criteria nor the required standards. Consequently, monitoring of marine fish farms is inconsistent considering the physical, chemical and biological parameters to be monitored. Similar experiences of monitoring of environmental impact of fish farming based on EIAs can be found on European and Mediterranean level.

Aquaculture is according to Land Based Protocol (LBS) included in the list of sectors of activity which are to be primarily considered when setting priorities for the preparation of action plans, programmes and measures for the elimination of the pollution from land-based sources and activities. (Both the HELCOM and OSPAR as well as relevant FAO and GFCM Decisions and Guidelines provide measures to address pollution from aquaculture.) However, there are no relevant provisions in the existing Mediterranean Regional Plans. Developing of technical guidelines and management standards to tackle inputs of nutrients and contaminants from aquaculture is taken into consideration during preparing new UNEP Mediterranean Regional Plans (https://wedocs.unep.org/handle/20.500.11822/26540?show=ful).

As a part of Possible Elements of the UNEP/MAP Regional Plan on Aquaculture Management the objective of the Regional Plan is "to minimize water pollution caused or induced by aquaculture sector". Inside the Proposed measures to be taken, one of the proposed measures is to *Control discharges through monitoring of:*

– Sediments: phosphorus, carbon and nitrogen content, redox potential.
– Water column: oxygen, nutrients (inorganic nitrogen and phosphorus), total nitrogen and phosphorus, chlorophyll-a, TRIX index, etc.

Except for the above-mentioned discrepancy in monitoring of fish farms in Croatia, monitoring of fish farms on Croatian farms that are prescribed with EIAs mostly matches with the proposed Control of discharges and monitored parameters of future UNEP/MAP's Regional Plan on Aquaculture Management to minimize water pollution by aquaculture sector.

So, this chapter will give an overview of physicochemical parameters monitored at Croatian fish farms with the emphasis on parameters that proved as good indicators of fish farming impact. Methodology of sampling and analysis will be presented as well as interpretation of results obtained for one sea bass and sea bream farm in the Adriatic Sea area.

Presented design of the monitoring can also be applicable and useful example of monitoring practice on the Montenegrin fish farm facilities.

4 Overview of the Physicochemical Parameters Monitored in the Water Column and Sediment at Fish Farm

4.1 Sampling and Analysis

Republic of Croatia implements the Monitoring Plan to estimate fish farm impact on physical and chemical parameters through analysis of seawater and sediment at the fish farm area as well as on the area of similar hydro morphologic characteristics without fish farm (control site). (Parallel with these investigations, at the same sites the composition of benthic communities and the physical impact of fish farming on the seabed as well as changes in the composition of fish communities around the fish farm were examined.)

Sampling was obtained at the Adriatic seabass and sea bream farm located in the bay on 3 sites inside it, approximately 200 m distanced away: K1 – cage (44°37.977'N and 14°27.174′E), 12 m depth; K2 (44°38.004'N and 14°26.981′E, 38 m depth; and K3 (44°38.003'N and 14°26.823′E), 39 m depth. Neighbouring bay without fish farm inside was chosen for control location with site K-REF (44°37.349'N and 14°27.890′E), 21 m deep.

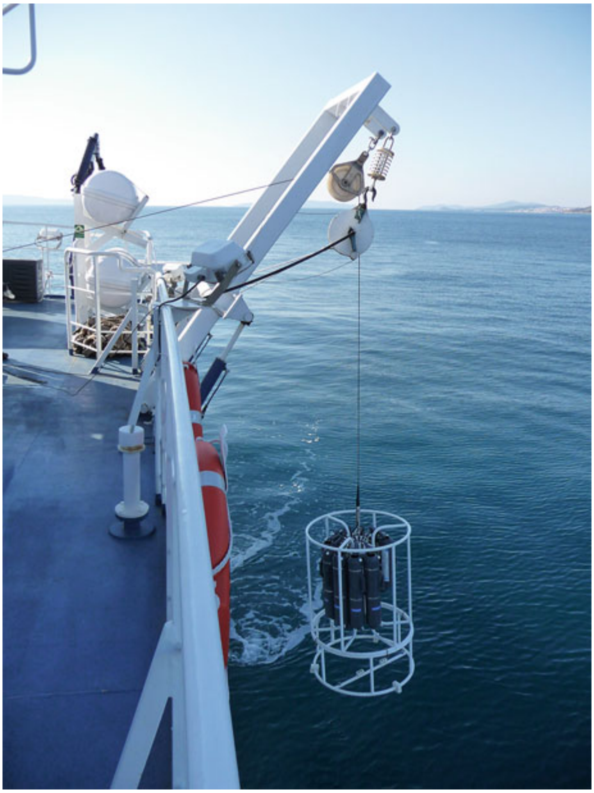

Fig. 3 Seawater samplers – carousel of Niskin bottles (Photo by S. Muslim)

Sampling of seawater and sediments at investigated sites was obtained from oceanographic research vessel „BIOS DVA“ from the Institute of Oceanography and Fisheries (IOF) in Split, Croatia. Seawater was sampled using a carousel of Niskin bottles, which can be triggered to close at selected depth for water collections (Fig. 3). Sampling was obtained at standard oceanographic levels (0, 5, 10, 20, 30, 50 m), depending on the depth of the water column at the site.

Measured parameters in seawater samples were: oxygen saturation, pH value, concentrations of dissolved inorganic nitrogen species (nitrates NO_3^-, nitrites NO_2^-, ammonia NH_4^+), orthophosphates (HPO_4^{2-}) and orthosilicates (SiO_4^{4-}) as well as dissolved organic phosphorus and nitrogen concentration. (Dissolved inorganic nitrogen, total dissolved phosphorus, oxygen and chl-a concentrations are included in the calculation of TRIX index [37].

Most of these parameters are included in the water quality analysis that is monitored according to the Water Framework Directive 2000/60/EU demands, or they are incorporated into monitoring for the MSFD (2008/56/EU) (Descriptor 5, Eutrophication), or IMAP’s Ecological objective 5 (Eutrophication).

Determination of oxygen saturation in seawater samples were obtained by using standard oceanographic Winkler method according to Grasshof (1976) [38]. pH value was measured with combined glass electrode on pH-meter Sartorius PB-11.

Concentrations of nutrients (ammonia and orthophosphates) were determined immediately after the collection of samples without freezing on board laboratory according to Grasshof (1976) [38] on spectrophotometer Shimadzu UV Mini 1240. For analysis of other nutrients (nitrates, nitrites, orthosilicates, organic phosphorus and organic nitrogen), seawater samples were frozen (on $-18°C$) and brought to Laboratory of Chemical Oceanography and Sedimentology at the IOF, Split. Analysis of nutrient concentrations was obtained colorimetrically on Auto Analyzer Seal Analytical according to Grasshof (1976) [38] and Operating Manuel of the instrument.

In order to estimate fish farm impact on geochemical characteristics of sediment, phosphorus, organic carbon and total nitrogen content in sampled sediments were determined. According to previous investigations of sediments under the fish farms, ratio of phosphorus, carbon and nitrogen was largely changed in relation to reference sites undisturbed by the mariculture [39, 40]. Phosphorus proved as good indicator of fish farm impact through elevated concentrations in most of the investigated sediments of European and world fish farms [6, 12, 29, 41–43].

Investigations of „cage sediments "in the Adriatic indicated increased concentrations of certain inorganic phosphorus forms that were attributed to remains of uneaten fish food as a direct influence of fish farming [14, 42].

Sampling of marine sediment was obtained by gravity corer from the deck of research vessel „BIOS DVA", while sediment core was divided on subsamples each 1 cm thick.

At the sampling site below the cage, sediment was sampled by autonomic diver who took the sample by inserting the plastic tube of corer into the seafloor. Immediately after the sampling, diver emerged the sample at the surface in the vertical position to preserve the undisturbed sediment core (Fig. 4).

Sediment was divided into subsamples 1 cm thick, frozen ($-18°C$) and brought to Laboratory of Chemical Oceanography and Sedimentology of IOF – Split, Croatia for further analysis. For analysis of phosphorus concentration in sediment, samples were freeze-dried, grounded and sieved on the sieve ($\Phi < 250$ μm). Extraction of inorganic and total phosphorus was obtained according to Aspila et al. (1976) [44]. Orthophosphate concentration in extracts was determined on spectrophotometer UV MINI 1240 Shimadzu according to Grasshoff (1976) [38]. Standard marine sediment reference material PACS-2 (NRC-CNRC) was used for method evaluation.

Redox-potential in undisturbed sediment cores (Fig. 5) was measured „in situ" by vertical penetration of Pt electrode with Ag/AgCl reference electrode, with quinhydrone buffer solutions in $pH = 4$ and $pH = 7$ prepared according to Metrohm (Ag Herisau, Switzerland).

For determination of organic carbon and total nitrogen in sediments, freeze-dried sample was treated with hydrochloric acid to remove carbonates [45]. Analysis of element contents in sediments was obtained on CHNS-O analyzer (Perkin Elmer 2,400 Series II).

Fig. 4 Sediment sampling by autonomic divers with plastic tubes of corer (Photo by S. Matijević)

4.2 Results of Monitoring in the Water Column and Sediment

4.2.1 Oxygen in the Water Column

Oxygen solubility in the natural waters runs according to Henry's law, like other atmospheric gasses. In the state of equilibrium oxygen concentration is proportional to its partial pressure in the atmosphere. The main processes that can disturb this balance are primary production of organic matter (photosynthesis) that increases oxygen content and respiration or heterotrophic degradation (oxidation) of organic matter that decreases oxygen content. Oxygen is very sensitive indicator of intensity of bio-chemical processes and besides temperature and salinity is the most common chemical constituent determined in the water column. According to ecological definition, oxygen concentration (in mL/L), that is considered as critical for the life of benthic organisms is 0.7–2 mL/L and presents hypoxic conditions, while values $\leq$0.7 mL/L implicate anoxia.

Oxygen concentration in the water column at fish farm sites and reference site ranged from 5.10 to 6.21 mL/L (Table 1) with the lowest value determined in surface layer under the cage, and highest value in the bottom layer at K3 site located at the exit of the bay with farm inside.

Average values of O_2 concentrations indicate no significant differences between sites (Table 1). All determined O_2 concentrations are significantly higher than 2 mL/L (the value that could potentially have negative impact on the life of organisms in the marine environment), so obtained results implicate good state of oxygen at all investigated sites.

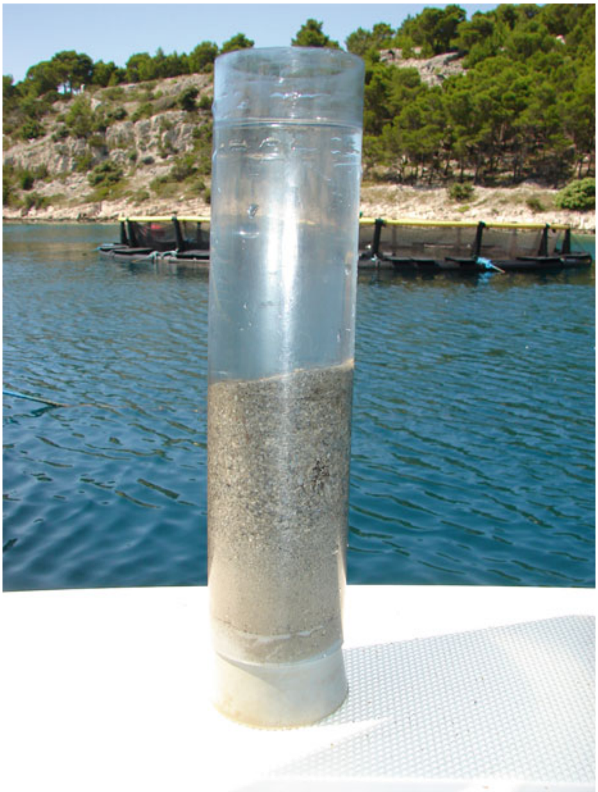

Fig. 5 Undisturbed sediment core sampled by autonomic divers. (Photo by S. Matijević)

Vertical distribution of oxygen concentrations was characterized with higher values in the middle and bottom layer. That is in accordance with distribution of temperature in the water column and the solubility – temperature dependence of gasses solubility in water (solubility of gas increase with temperature decrease in the deeper layer of the water column at investigated sites). Additionally, this distribution pattern of vertical of oxygen concentrations is in accordance with usual oxygen profiles in the Adriatic during spring season that indicates stratification of the water column (http://baltazar.izor.hr/azopub/bindex).

4.2.2 pH Value in Seawater

Seawater pH is slightly alkali due to excess of dissolved anions that is mainly influenced by marine carbon cycle. Namely, during the processes of production and degradation of organic matter in marine ecosystem CO_2 is produced (respiration) or it is removed (photosynthesis). Usual pH value for Adriatic Sea is $pH = 8.2 \pm 0.1$. During intensive photosynthesis pH can increase up to 0.2 units, while degradation of organic matter can decrease it under the $pH = 8$. Despite these

Table 1 Basic statistic parameters (range, average value and standard deviation) for all parameters investigated in the water column and sediments at investigated sites

Parameter		K1	K2	K3	REF
Water column					
O_2 (mL/L)	AV ± STD	5.36 ± 0.31	5.65 ± 0.34	5.78 ± 0.33	5.61 ± 0.33
	Range	5.10–5.70	5.30–6.14	5.42–6.21	5.31–5.99
pH		8.20 ± 0.01	8.2 ± 0.01	8.19 ± 0.01	8.19 ± 0.01
		8.19–8.21	8.18–8.21	8.18–8.19	8.18–8.19
TIN (μmol/L)		4.9 ± 3.9	0.84 ± 0.29	0.56 ± 0.24	0.69 ± 0.31
		1.12–8.96	0.64–1.34	0.28–0.94	0.40–1.07
NH_4^+ (μmol/L)		4.51 ± 3.85	0.41 ± 0.29	0.26 ± 0.27	0.41 ± 0.19
		1.12–8.96	0.23–0.93	0.05–0.72	0.28–0.68
NO_3^- (μmol/L)		0.31 ± 0.10	0.31 ± 0.06	0.22 ± 0.11	0.18 ± 0.19
		0.23–0.42	0.26–0.38	0.12–0.39	0–0.40
NO_2^- (μmol/L)		0.09 ± 0.05	0.12 ± 0.06	0.08 ± 0.01	0.09 ± 0.01
		0.05–0.15	0.01–0.16	0.07–0.11	0.09–0.10
HPO_4^{2-} (μmol/L)		0.07 ± 0.01	0.05 ± 0.01	0.058 ± 0.060	0.06 ± 0.01
		0.05–0.08	0.04–0.06	0.00–0.135	0.05–0.07
SiO_4^{4-} (μmol/L)		1.36 ± 0.07	1.51 ± 0.08	1.39 ± 0.05	1.45 ± 0.08
		1.31–1.44	1.43–1.64	1.35–1.46	1.36–1.54
N-ORG (μmol/L)		6.9 ± 0.9	8.24 ± 0.66	8.10 ± 0.89	7.99 ± 0.93
		6.35–7.89	7.36–9.19	6.79–9.06	6.63–8.68
P-ORG (μmol/L)		0.43 ± 0.32	0.06 ± 0.08	0.15 ± 0.15	0.27 ± 2.59
		0.11–0.76	0.01–0.21	0.02–0.40	0.05–0.59
Sediment					
TP (μmol/g)		17.7 ± 29.9	9.8	5.3	3.0 ± 0.4
		4.2–106.4			2.2–3.4
IP (μmol/g)		16.0 ± 30.2	6.4	1.7	0.9 ± 0.4
		2.9–106.4			0.1–1.4
OP (μmol/g)		2.6 ± 2.3	6.4	1.7	0.9 ± 0.4
		0.14–4.2			0.1–1.4
C-ORG (%)		3.27–3.44	2.62–2.94	2.57–2.71	2.32–2.92
		3.35 ± 0.08	2.80 ± 0.16	2.65 ± 0.07	2.70 ± 0.5
EH (mV)	Range	−(322) to 59	−(88) to 120	(−30) to 100	(−59) to 65

two natural processes, pH value is also impacted with industrial and effluent waters inputs as well as with freshwater sources. Due to buffering of carbonate system in seawater, these impacts are locally restricted.

pH values determined in the water column at investigated sites ranged between 8.18 and 8.21, that is in accordance with values determined for the Adriatic. From average values, no existence of significant differences between sites is obvious (Table 1). Vertical distribution of pH values indicated negative gradient from surface to bottom layer that can be a consequence of respiration in deeper layers that releases the CO_2.

4.2.3 Concentrations of Nutrients in the Water Column

Dissolved nitrogen and phosphorus salts (nutrients), with sunlight, carbon dioxide, some trace elements and vitamins are necessary for photosynthesis in the marine environment. Primary producers by photosynthesis generate amino acids, proteins and nucleic acids that are incorporated in marine food chains. After the death of organisms and organic matter sedimentation, heterotrophic degradation and remineralization occur. Products of organic matter degradation are dissolved inorganic nutrients (nitrates, nitrites, ammonia and orthophosphates) that return into the water column. Some phytoplankton species (diatoms, silicoflagellates) can also use dissolved silicate for their skeletons formation. Regeneration of silicate is taking part by chemical dissolution of settled biogenic silica (opal). These processes do not present complete biogeochemical cycles of nitrogen, phosphorus and silica. Part of these elements is permanently removed from the cycles (by sediment burial, mineral adsorption or gasification), but they can also be input by freshwater, groundwater or from the atmosphere.

Total dissolved inorganic nitrogen in natural waters exists in oxidized (nitrates, nitrites) or in reduced forms (ammonia). Due to very fast oxidation and reduction processes, here we present sum of all inorganic nitrogen forms (TIN = sum of nitrates, nitrites and ammonia). Basic statistic parameters for TIN in the water column of investigated sites in farm location (K1, K2 and K3) and nearby site (K-REF) are given in Table 1.

Concentration of total inorganic nitrogen ranged from 0.28 μmol/L (at K3 site) to 8.96 μmol/L at site K1. From average values of TIN concentrations significantly higher value in the water column at site K1 under the cage regarding other sites is evident. Average TIN concentration determined at sites K2, K3 and –K-REF (0.65–0.89 μmol/L) in relation to values established for the coastal Adriatic area belongs to group of low values. According to defined threshold values determined in accordance with WFD (2000/60/EU), for TIN in Croatian part of the Adriatic, mentioned cage values belong to "very good state" category (OG 73/2013) [46].

Vertical distribution of TIN concentrations indicated relatively unique distribution at K2, K3 and KR1 sites, except at 10 m depth layer at K2. At site K1, TIN concentrations were up to 10 times higher related to other sites at the bay with farm, as well as to reference site K-REF. Significantly elevated concentrations were in surface layer and at 5 m depth.

Vertical distribution of each nitrogen species inside TIN (nitrates, nitrites and ammonia) indicates that obtained differences in TIN are consequence of increased or decreased ammonia concentrations. High ammonia concentrations determined in the water column at K1 site belong to group of extremely high values determined for the middle Adriatic. Similar high ammonia concentrations were also obtained for the water column below the tuna cages monitored in the middle Adriatic area. Increase in NH_4^+ concentrations can be assigned to fish farm impact as potential source of ammonia salts. Similar was obtained for middle Adriatic fish farm where urea concentrations were enhanced in the upper part of the water column (0–20 m) compared to the reference sites [15]. Considering the urea's role as an intermediate species in the oxidation of compounds from organic nitrogen to ammonia, the increase was attributed to fish excretions and degradation of their metabolic products.

Concentrations of nitrates were twice higher than nitrite concentrations (Table 1), that is also in accordance with the results obtained for the water column of the Adriatic areas. Vertical distribution of NO_3^- concentrations was in accordance with its usual distribution pattern during spring season (with elevated concentrations in the bottom layer of deeper sites); while NO_2^- concentrations in the water column of all investigated sites were relatively uniform.

According to abundance of certain nitrogen species at "cage site" K1, ammonia was the most predominant species (85%), while at K2, K3 and K-REF sites its portion ranged between 45 and 62%. The abundance of nitrates at site below the cage was the lowest (12%), while at other sites it ranged from 40 to 44% (at K2 and K3), and 21% at K-REF site. Nitrate portion was 3% (at K1) and 14–18% on other investigated sites. Similar portions of inorganic nitrogen species determined for June 2015 at investigated sites are generally in agreement with natural seasonal oscillations of ratios of certain species for the coastal Adriatic area [47] with the exception of site K1.

Besides the inorganic nitrogen forms, concentrations of organic forms were also determined (Table 1). The highest average value was calculated for K2 site (8.24 ± 0.66 μmol/L).

Average values of N-ORG concentrations indicated lower values for the water column at site K1 related to other investigated sites. These results obtained for fish farm investigation belong to group of low N-ORG concentrations determined during long-term investigations of coastal Adriatic areas (range:4.8–13.8 μmol/L) [47]. N-ORG portions in total dissolved nitrogen generally exceed TIN portions (from 62% at K1 site to 93% at K3), that is in accordance with usual distribution of nitrogen forms in the Adriatic water column. Due to unknown portions of autochthonous and allochthonous fractions in organic forms of N (more complex analytical determination is needed), detailed analysis of their input or output from this marine environment is not possible.

Orthophosphate concentrations ranged between 0 and 0.135 μmol/L (in the middle and bottom layer at K3 site). HPO_4^{2-} range of concentrations is inside ranges determined during 2011/2012 period for Adriatic [47]. The obviously highest concentrations were at K3 site, while for other sites, as well as for reference site K-REF, average values were lower. These differences can be assigned to impact of circulation in the bay rather than to fish farm impact. According to defined threshold values determined in accordance with WFD (2000/60/EU), for HPO_4^{2-} in Croatian part of the Adriatic, most of these values belong to "very good state" category (OG 73/2013) [46].

Vertical profiles of orthophosphate concentrations at investigated sites indicated relatively unequal distribution. The highest values were obtained in surface and the bottom layer for deepest K3 site. Relatively unequal vertical distribution marked at other sites is in accordance with vertical profiles of HPO_4^{2-} for most of the coastal middle Adriatic locations, except for estuaries or city harbours where increased input of HPO_4^{2-} was obvious in surface layer.

Calculated portions of orthophosphates and organic phosphorus forms in total phosphorus indicated prevailing of organic form at K1 and KR1 sites (80 and 69%), while inorganic phosphorus prevailed at other sites (55 and 57%). Relatively low orthophosphates portions in total dissolved phosphorus is in accordance with average portions obtained for the middle Adriatic water column (26 ± 14%) [47].

P-ORG concentrations indicated higher values for the water column at site K1 related to other investigated sites. Similar results were obtained for tuna farms at the middle Adriatic area. According to defined threshold values determined in accordance with WFD (2000/60/EU), for P-TOT (sum of P-ORG and orthophosphate) in Croatian part of the Adriatic, most of these values belong to "very good state" category (OG 73/2013) [46], P-TOT concentrations at K1 site belong to "good state" category.

Orthosilicate concentrations (SiO_4^{4-}) were in narrow range (1.31–1.64 μmol/L) determined at K1 and K2, respectively (Table 1). These values are inside wider range of orthosilicate concentrations determined for Adriatic (0–67 μmol/L) [47]. Average values of SiO_4^{4-} indicated no significant differences between investigated sites. Vertical distribution of orthosilicate concentrations was relatively equal inside the investigated bays, with no expressed maximum in surface or bottom layer that can be a consequence of seasonal oscillations.

4.2.4 Concentrations of Phosphorus in Sediment

Dissolved phosphorus (P) from water column arrives into the sediment in organic (photosynthetically produced) forms and inorganic forms (mineral origin). During diagenesis in sediment, total phosphorus content varies and its distribution into different fractions takes part. Phosphorus in sediments can exist in several forms: phosphorus adsorbed on mineral surfaces, phosphorus in mineral precipitates (iron bound P, apatite P) and detrital P as well as P incorporated in organic matter [42]. Phosphorus in sediment proved as good indicator of fish farm impact where concentrations obtained in sediments under the cages were up to 10 times elevated regarding the reference sites with no fish farm inside [15, 42]. Methods for phosphorus determination in sediments applied in this investigation divide only two phosphorus fractions; organic P and total P that presents sum of listed inorganic P forms and organic P (TP).

Total phosphorus concentration (TP) ranged between 2.2 and 106.4 μmol g^{-1} at K3 and K1 sites, respectively (Table 1). These values are inside the range determined for sediments under the anthropogenic influence such as eutrophicated bays and fish farms in the Adriatic (19–135 μmol g^{-1}) [42]. Extremely elevated concentrations in surface layer at K1 site can be assigned to input of phosphorus compounds probably originated from settled remains of fish food and excretes.

Average TP values indicated significant differences between site under the cage and other investigated sites in the farm location with obvious negative gradient in TP concentrations from inside to the exit of the bay. This result is implication of fish farm impact on the very tight area under the cage that was also found during previous investigations of fish farm influence on the environmental parameters in the water column and sediments.

Inorganic phosphorus concentrations ranged between 1.9 and 106.4 μmol g^{-1}, which belong to group of extremely high values compared to values obtained in sediments at the middle Adriatic. Organic phosphorus range was from 0.1 to 5.8 μmol g^{-1} and was in accordance with values previously determined for the Adriatic sediments. Vertical profiles of total and inorganic phosphorus indicated extremely high concentrations in surface sediment layer (0–1 cm). However, lower values obtained for depths higher than 3 cm layer can be attributed to group of TP and IP concentrations usual for sediments that are under the anthropogenic impact. Vertical distribution also indicated that almost all phosphorus was in inorganic form, while organic P was not detected in surface layers.

In sediments at KR1 site vertical distribution of IP was relatively unique, and concentrations of organic phosphorus (OP) were significantly lower. According to previous investigations extremely high IP portion in total phosphorus (89%) was obtained only for sandy sediments under the cages of sea bass and sea bream farms in the north and middle Adriatic. Investigations of different fractions inside the sediment inorganic phosphorus pool at sea bass and sea bream farms in the middle Adriatic [14, 48] by using SEDEX analysis proved that the highest portion was for P bound to iron oxides and hydroxides. Extremely high portion of "fish debris phosphorus" fraction (that includes P bound in biogenic apatite originated from remains of fish bones and tooth settled in sediment) was obtained and it was assigned to fish farm activity. Method applied for the samples from this fish farm location enables only organic and total inorganic phosphorus concentrations, so it is not possible to determine what P fraction is responsible for disturbed ratio between IP and OP fraction in surface sediment at fish farm site.

4.2.5 Sediment Redox Potential

Sediment redox potential measurements obtained at site below cage and REF site showed wider range of values (−322 to 59 mV) (Table 1). Redox-cline was determined at K1 below the cage even in the first centimetre of depth, while at other and reference site, redox cline was deeper. These negative values of redox potential belong to lowest E_H recorded for the fish farm sites at the middle Adriatic area [14]. Extremely negative potentials indicate high concentrations of sulphide ions (S^{2-}) as well as degradation of organic matter in the absence of oxygen [48]. Additionally, visual monitoring of below-cage sediments indicated appearance of filamentous sulphur Beggiatoa bacteria that confirmed the measurement results.

4.2.6 Organic Carbon Content in Sediment

Organic carbon content in sediment (C-ORG) at investigated sites was between 2.57 and 3.44% at K-REF and K1 site, respectively. These values were in the range of values found in sediments under the fish farming impact in the Adriatic Sea (0.7–10.13%) as published according to Najdek et al. (2007) [22] and Matijević et al. (2006) [14]. Giles (2008) suggested sediment enrichment state considering C-ORG and N-TOT values (low, moderate, high and very high) [40], and within that, presented results fall into the category of sediments moderately enriched by fish farming impact.

5 Conclusions

An overview of physicochemical parameters from the water column and sediments monitored at Croatian fish farms is presented through investigations at one sea bass and sea bream farm. Examined parameters from the water column were: oxygen concentration, pH value, dissolved phosphorus (inorganic and organic), inorganic nitrogen (sum of nitrates, nitrites and ammonia) and organic nitrogen concentrations. Parameters determined in sediments were phosphorus, organic carbon, total nitrogen content and sediment redox potential.

According to results from the water column the key observations arose. Analysis of nutrients indicated the increased concentrations of dissolved nitrogen and organic phosphorus in the water column due to the increase of ammonia or urea (from the fish excretion and degradation of their metabolic products) and the increase of the input of organic matter (food, excreta and metabolic products).

In the sediments the extremely increase in phosphorus concentration was found, which was directly connected to the input of organic material from the farm area. Extremely negative redox potentials were detected that indicate high concentrations of sulphide ions as well as degradation of organic matter in the absence of oxygen. Additionally, the appearance of sulphur bacteria genus Beggiatoa confirmed the consumption of oxygen for the organic matter degradation in the sediment and anoxic conditions.

It is very important to highlight that all mentioned consequences of the fish farming impact were mainly localized in the area under the fish cages and decreased in value with the increasing distance from the cages.

Taking into account presented results, it can be concluded that parameters in sediments such as phosphorus concentration and redox potential proved as very good indicators of fish farm generated pollution, while from the water column, dissolved inorganic nitrogen form ammonia and organic phosphorus indicated changes caused by farming activities.

Parameters proposed to be monitored in sediment represent the organic matter content (carbon, nitrogen and phosphorus) and the degree of its degradation (redox potential). Their analyses are not expensive and they are feasible to obtain. Majority of parameters monitored in the water column are already included in the water quality analysis that are monitored for the commitments of European directives (WFD, MSFD) or Mediterranean plans (IMAP), and their interpretation can be obtained in accordance with the existing threshold values.

Furthermore, it is also very important to monitor "control site" with similar hydrographic conditions as farm location but with no farm inside, that is very useful in the interpretation of obtained monitoring results.

To compare with Croatian presented experiences, brief overview of Montenegrin mariculture activities, legislation, monitoring and perspectives is as follows.

Marine aquaculture in Montenegro comprises gilthead seabream and European seabass and shellfish farming that includes Mediterranean mussel and European flat oyster. All mariculture activities are concentrated in the Boka Kotorska Bay. There are 20 mussel farms, all using floating park systems (long-lines). Sea bream and sea bass farming started in the late nineties, and currently there are two farms using the floating cage system breeding method whose first phase taking place in the hatchery and then in floating cages in the sea [49]. The multitrophic integrated mariculture farming of mussels and fish is implemented on both farms. The annual production at fish farms was 121 t in 2015 (http://www.fao.org/fishery/countrysector/naso_montenegro/en). Although it shows a mild growth over the past few years, it is still at very low level, in comparison with Croatia and other Mediterranean countries with relatively small production.

Similar to presented Croatian overview of legislative issues regarding mariculture, all the relevant issues in Montenegro are regulated by the National Laws. The Law on Marine Fishery and Mariculture [50] lays down the conditions for farming of fish and other marine organisms in locations planned in line with the Spatial Plan of Special Purpose Costal Zone [51], the Law on Environmental Impact Assessment [52], Law on Environmental Protection [53] and in line with the other laws that apply on the basis of the Laws above mentioned.

For each new fish farm it is obligatory to make assessment on the environmental impact, and based on the zero state of the site to estimate the minimum distance between locations for mariculture. To ensure proper and final site selection, additional studies with analysis of the sediment (granulometry, organic matter) benthic fauna, water quality (salinity, dissolved oxygen, temperature, chlorophyll-a, suspended solids, nutrients), oceanographic conditions, sanitary control and monitoring of biotoxins were recommended [54].

Programme of water quality monitoring and biomonitoring on the farms and around the farms is regulated by the Law on Marine Fishery and Mariculture [50]. The aim is to give farm owners timely information about the appearance of pollution and natural phenomena, if any, which may have a negative impact on the mariculture zone and on mariculture products. According to the Law the monitoring should be carried out on the basis of the Water Quality Monitoring and Biomonitoring Program in the fishing sea, adopted by the Ministry at the proposal of the competent institution (Institute of Marine Biology in Kotor). Monitoring is conducted by the Institute or an accredited laboratory [50].

Monitoring of mussel farms conducted in Boka Kotorska Bay included mostly analysis in the water column such as nutrient composition, microbiological parameters, and qualitative and quantitative data on phytoplankton [55]. For fish farm monitoring there are no specified parameters to be analysed.

To expand mariculture in the draft of the Special Purpose Spatial Plan for the Coastal zone of Montenegro, as potential new locations, nine new sites have been included in the open sea area (http://www.fao.org/fishery/countrysector/naso_montenegro/en). Fisheries Strategy of Montenegro 2015–2020 with an Action Plan [56] recognized aquaculture as one of the development activities of fisheries sector. Strategy predicts development of sustainable aquaculture through modernization of existing capacities in order to increase the production as well as to strengthen the efficiency of this sector, while respecting high environmental, animal health and welfare standards (http://www.fao.org/fishery/countrysector/naso_montenegro/en).

Considering the brief overview on Montenegrin state of mariculture activities and its perspective it is obvious that number of fish farm sites will increase in the future as well as the need for the protection of the marine environment regarding ecological impact of fish farming. According to the given information there are no specified parameters to be monitored at fish farms in Montenegro, so presented Croatian monitoring design of physicochemical parameters in water column, and particularly in sediments, can be applicable in future monitoring practice on the Montenegrin fish farm facilities.

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The Priority Areas of Innovations in Maritime Industry: An Application to the Adriatic Marine Environment

Senka Šekularac Ivošević

Contents

Abstract The aim of this paper is to identify the areas of current and future innovations in maritime industry, especially in the field of the Adriatic marine environment. The topic is investigated from the perspective of academic professionals from maritime faculties in the Adriatic region, including Slovenia, Croatia, Montenegro, and Albania. The paper relies on a qualitative analysis of the data gathered through a questionnaire containing questions about the priority areas of innovation and recommendations for the specific area of the Adriatic marine environment. The data analysis was conducted by means on the Atlas.ti software. The research discovered that the academic professionals from the Adriatic region frequently research and do innovation projects on the maritime environment. Based on the attitudes of the participants in the research, the paper proposes the solutions for the Adriatic region concerning its future research, innovations and vision for development. The paper contributes to the identification of the areas which could be the focus of various innovation projects and the specific projects concerning the

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innovations in marine environment. Likewise, the paper provides an insight into the profile of the academic professionals and scientific potential of the region. The unprecedented idea of the paper is an overview of the scientific potentials of the maritime professionals from the Adriatic region, which should support the development of the Adriatic region as an eco-friendly zone and a cluster of key stakeholders promoting sustainable development and the valorization of maritime resources.

Keywords Academic professionals, Innovation, Marine environment, The Adriatic region

1 Introduction

Based on the research by relevant maritime institutions, shipping enables around 90% of the global trade and represents the main means of the transport and supply of raw materials, consumer goods, essential foodstuff and energy for the world population. Similarly, the vast majority of products are transported exclusively by ships, so shipping is the main facilitator of the global commercial and economic growth [1].

The maritime industry is dominantly affected by economic and technological factors, and the innovations in this industry gain an increasing importance. Autonomous ships, smart port operations, and new environmental and safety considerations are just a few of the innovative areas in maritime sector that will affect all maritime stakeholders and their relationships [2]. Ecological sustainability is the most obvious structural challenge for all maritime sectors since maritime activities affect the sustainability of the air and water [3]. Compared to land-based industries and marine pollution caused by human activities, shipping is a relatively minor polluter. This is a consequence of a continuous rise in environmental awareness, concern and joint efforts of the International Maritime Organization (the IMO) and maritime community [1].

However, a negative impact of maritime transportation on the marine environment is still notable. The pollution of the marine environment is defined as "the introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities" [4]. The global shipping industry is responsible for 2.6% of the total energy-related CO_2 emissions and ocean pollution by 5.25 million plastic particles whose weight is 268,940 tons [5].

Marine transportation has multiple environmental effects such as air pollution, greenhouse gas emissions, releases of ballast water containing aquatic invasive species, the traditional use of antifoulants, oil and chemical spills, dry bulk cargo releases, garbage, underwater noise pollution; ship strikes, grounding and sinking risks, and widespread sediment contamination of ports during transshipment or ship-breaking activities, etc. [6]. The solutions for the problems listed are the rise in environmental awareness, rewards for responsible behavior, the implementation of legal regulations, technological innovations, regional and international programs (e.g. programs for the protection of the environment).

The EU Strategy for the Adriatic and Ionian Region (EUSAIR), which was in 2014 defined as a macro-regional strategy adopted by the European Commission, served as a motivation for this research. The Strategy was jointly developed by the Commission and the countries and stakeholders from the Adriatic-Ionian region based on four principles – blue growth, regional connections, environmental quality, and sustainable tourism [7]. Namely, maritime industry needs more projects on innovations that would define a set of priority innovations that would ensure the attainment of ecological goals and emphasize the importance of environmental protection and the collaboration of key stakeholders.

The IMO as an agency of the UN is seen as a major institution that supports numerous projects in the field of environmental protection and has a duty to provide the mechanisms for the cooperation among governments on the prevention and control of the pollution of the marine environment that is caused by vessels [4]. The IMO is in charge of environmental protection and the development and adoption of the global regulations on safety, security, and efficiency of vessels. Over the past few years, the IMO has implemented numerous projects in the field of the marine environment such as:

- The ratification and effective implementation of the IMO instruments for the protection of the marine environment;
- The prevention of the pollution caused by vessels;
- The improvement of the cooperation mechanisms on marine pollution preparedness and response in certain regions;
- The control of harmful antifoulants;
- Safe and environmentally sound recycling of vessels;
- The introduction of zero and low-emission solutions for shipping in developing countries;
- The reduction of greenhouse gas emissions from vessels, etc. [8].

The IMO played an important role in the promotion of green shipping by establishing the following goals: the reduction in sulfur emissions from motor vessels to 0.5% by 2020, the reduction in greenhouse gas emissions by at least 50% by 2050, and the reduction in the average carbon intensity in the sector by at least 40% by 2030, and 70% by 2050 [5].

The European Commission invests 15.1 million euros in new, sustainable blue projects in maritime sector in order to encourage the development of sustainable blue economy. The projects are focused on innovations, marine environment (marine debris prevention and the restoration of ecosystems), and the cooperation promoting sustainable blue economy and better ocean governance in the basin of the Mediterranean Sea [9]. The goals for the Mediterranean marine environment for the period

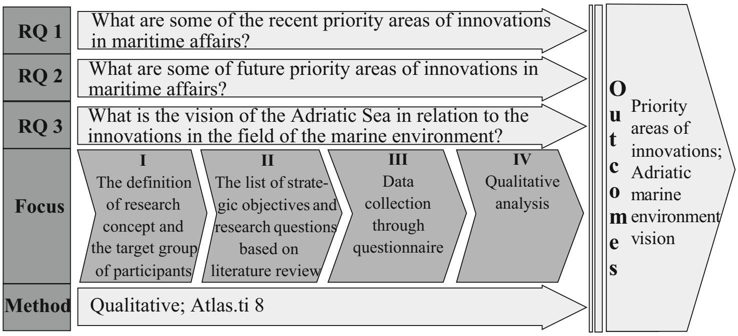

Fig. 1 The framework of the paper (Source: According to [13])

between 2016 and 2021 are: the minimal transfer of aquatic invasive species, the monitoring and supervision of illegal discharges, the enforcement and prosecution of discharge offenders, the establishment of ship routing systems, the identification of particularly sensitive sea areas (PSSA), the reduction of the marine noise caused by vessels, places of refuge which would prevent the spreading of pollution, a development of contingency plans that would strengthen the capacity of specific coastal states to respond effectively to marine pollution incidents [10].

When it comes to the Adriatic region, it is confirmed that most of the global marine economic sectors in the Adriatic will significantly grow in the next 15 years, with the exception of fishery and military sectors. New maritime sectors, such as off-shore renewable energy, will gain an increasing importance in the future. Additionally, it is expected that three biggest sectors – maritime transport, tourism and off-shore oil and gas industry – will evidence a dramatic increase in the next years [11]. It is also observed that there is an urgent need for better cooperation and coordination of all institutions involved in the prevention of oil pollution in the Adriatic region [12].

In that sense, the paper promotes the vision of the Adriatic as a region with a huge potential for the development of maritime (ports, yachting, etc.) and other activities while the resources of the region should be exploited in accordance with the principles of protection and conservation. The aims of the paper are the detection of the priority areas of innovation development in maritime industry, and recommendations for the innovations in the specific environment in the region of the Adriatic Sea. The framework of the paper is presented in Fig. 1.

Figure 1 indicates that the paper relies on the set of five logically related steps – from the formulation of ideas, over defining of research objectives up to the results and specific implications. The research is based on a qualitative method and the Atlas.ti program. The attitudes of the participants from 20 scientific fields in maritime industry were subjected to a qualitative analysis [14]. The paper identifies the areas of current and future innovations and proposes the measures for the Adriatic region in terms of the research of the marine environment.

2 Literature Review

Innovation management has triggered considerable attention in recent years. Innovation management is one of the branches of strategic management and represents a top-level activity of company management. The aim of innovation management is the identification of the main directions of scientific, technical, and production activities of a company in the areas such as the elaboration of gaps and the introduction of new products (innovation), the modernization and improvement of products, further development of the production of traditional products, and the removal of outdated products [15]. Innovations ensure competitive advantages and managerial innovations are therefore seen as crucial for the success on the global market [16].

According to a multidisciplinary definition, an innovation is "a multistage process within which organizations transform their ideas into new, improved products, services or processes, in order to advance, compete and excel on the market" [17]. Nowadays, one of the principal qualities of an innovation is the tendency to surpass the boundaries of a single organization or foundation, to emerge across sectors, industries, and countries and produce surges of information that flow quickly from confined zones to the worldwide field. In that sense, innovations are especially important for maritime industry considering the multidisciplinary nature and the relationship between the activities of this industry.

Based on the data about the year 2020, the countries of northern Europe are innovation leaders as their performance is high above the EU average innovation performance. Austria, Belgium, Estonia, France, Germany, Ireland, and Portugal are strong innovators as their performance is above or close to the EU average innovation performance. Croatia, Cyprus, Czech, Greece, Hungary, Italy, Latvia, Lithuania, Malta, Poland, Slovakia, Slovenia, and Spain have performance below the EU average innovation performance and are considered moderate innovators. Bulgaria and Romania are modest innovators with performance significantly below the EU average innovation performance. As shown in Fig. 2, the south of the Adriatic region lacks official studies on innovation and is surrounded by the countries that are considered moderate innovators (Croatia, Slovenia, Italy, and Greece). The south of the Adriatic should therefore be the focus of future analysis.

The previous decades witnessed a change in business relations between companies as they started to collaborate more on mutual innovation projects. The relevant terms are thus "open innovation" [19] and "innovation through cooperation" [20]. The model of collaborative innovation management has three steps:

1. Preparation – which is the most important and often neglected step. Preparation refers to the definition of objectives, identification of the right partners, cultural preparation of all partners, incentives that encourage collaboration, and the establishment of connections with good potential partners;
2. Partnership – implies negotiations with partners and tailoring of the projects in order to ensure an adequate definition of benefits, risks and governance aspects; and

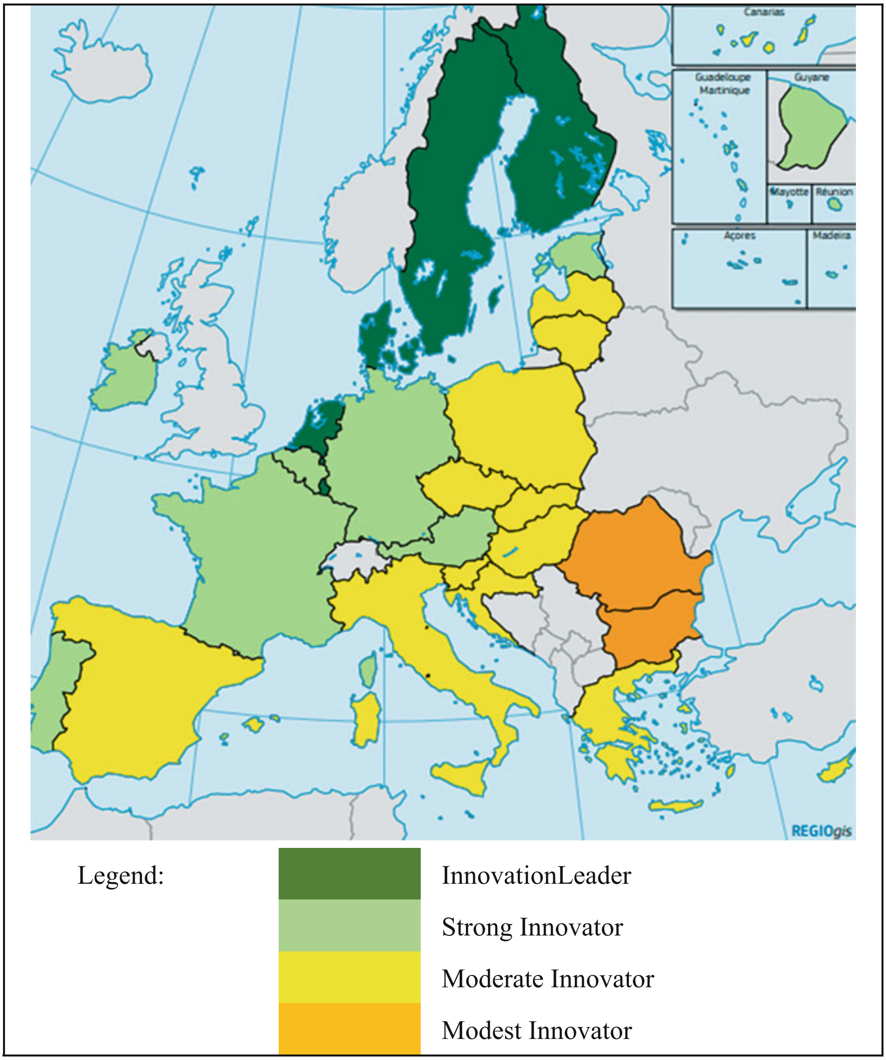

Fig. 2 The map of innovation systems in the member countries of EU (Source: [18])

3. Pioneer – implies the adaptation and progress of the partnership in terms of mutual and lasting benefits [21].

This collaboration model is now combined with helix models (triple, quadruple, and quintuple) that were investigated in maritime sector so far. Many governments have the strategies for the development of maritime sector based on the application of quintuple helix model which relies on the collaboration of all key stakeholders – universities, industry, government, civil society, and the environment [22].

The principles of triple helix can efficiently overcome four structural challenges in maritime sector – the discrepancy between supply and demand on shipping market, the guarantee of safety and security in digitalized world, ecological sustainability, and an outdated decision-making process.

In that regard, governments and maritime private sector are now willing to support applied research which would result in improvements in the field of the marine environment (e.g. lower emissions in ports and the sea, reduced greenhouse effect and black carbon, energy efficiency, green technological innovations, etc.). The studies on green shipping are another example of collaboration which focuses on the cleaner practices of emission control, port management, and equipment lifecycles, i.e. circular economy. The collaboration among industry, regulators, port authorities, and communities is necessary for the practical application of green shipping [5].

As impartial stakeholders, governments hold a pivotal position within triple helix models for the initiation of collaboration in maritime sector. Government programs including third-party partners like shipowner associations, clusters, and consulting organizations should actively encourage triple helix collaboration. The literature recommends top-down approach that is based on governmental recognition and support of potential value-added initiatives of industries, while universities provide maritime sector with theoretical framework [3] [2]. Maritime industry should follow several principles in order to successfully apply the suggested approach and create an industry that actively contributes to a triple helix [23]:

(a) The assessment of own capacities and the identification of the problems that should be solved through the collaboration with governments and universities;
(b) The shift in the focus from short-term towards long-term results that are also the aim of other partners within a helix, which enables a more fruitful collaboration;
(c) Practical activities, e.g. experiments and pilot studies;
(d) The extension of collaboration scopes through clusters and increase in the concern for public interests. Maritime industry should act as a partner within collaboration and not as a client or supplier.

Scientific research on innovation management in maritime industry is limited. The literature analyzes innovation management from different angles. Most studies focus on the understanding of potential changes of climate in the future, the distribution and evolution of marine ecosystems, and corresponding economic interests and conflicts [24].

When it comes to maritime education, the studies focused on educational topics and approaches that could train the students and maritime professionals for the participation in innovations. The results confirmed that the students are not fully competent for innovation processes while their interests are primarily related to better education about new trends in maritime sector. The success of a course on maritime innovation management signaled a need for a corresponding transnational course such as online learning approach based on triple helix collaboration between academic and industry professionals [2].

From the perspective of innovation management, the research concerning seaports investigated the issues of environmental sustainability in ports and the lack of legislative framework and research. According to innovation management approach, the authors proposed two solutions for the problem of environmental sustainability in seaports. The first solution is the introduction of management accounting instruments for the assessment, monitoring, measurement, and control of the performance of all stakeholders in seaports in terms of the impact on environmental sustainability. The other solution is training and the development of environmentally sustainable behavior among maritime professionals [25].

Innovations which could solve the problem of environmental protection are not always supported. The research from 2014, following the InnoSuTra EU FP7 project, investigated the range of successful innovations that enhanced environmental sustainability in the seaports of Antwerp, Genoa, Hamburg, Los Angeles/Long Beach, Rijeka, Singapore, and Zeebrugge. The research proved that green goals that are prioritized in policy actions are not always related to successful innovations. This means that the green innovation success is achieved incidentally and in areas that were not prioritized in the policy actions [26]. Many innovations that were considered successful were subsequently attributed to the managers of ports [26], which is particularly relevant for the Adriatic region.

In regard to shipping companies, the literature confirmed that innovations, especially the innovations in production processes, positively affect financial results, market positions, and the bargaining power of companies [27]. Namely, the research identified factors that promote innovations in Norwegian shipping companies, whereby the explicit strategies that promote innovations influence the actual innovation levels in companies. In that sense, it is highly important that managers make precise decisions in order to promote innovations [28].

The projects about innovation management are conducted in the Adriatic-Ionian region. The SHIPmEnTT is one of the projects that was designed to improve the innovation capacities of small and medium enterprises in the Adriatic-Ionian area (ADRION) through specially designed technology transfers and measures supporting innovation management. The project should benefit the enterprises in maritime sector in terms of blue growth and green sea mobility and is aimed at the sectors of energy, logistics, safety, and environmentally sound technologies [29]. Additionally, the project confirmed that small and medium enterprises need significant support of scientific institutions and legislative bodies in order to generate, protect (patent), and commercialize innovations.

Generally, authors emphasize costs and risks as the main obstacles to innovations. The obstacles also include the lack of qualified workers/partners, financial access, the lack of information, easy imitation, cooperation percentage and legal protection index per sector, etc. [30].

Universities, research centers, and academic professionals have a highly important role. Based on the European Educational Association, the role of modern universities is based on the integral collaboration with stakeholders or, more precisely, "the university's new centrality is inextricably intertwined with its role of orchestrating multi-actor innovation networks" [31]. In that sense, there are four roles that universities nowadays can assume: (1) education – the provision of "human capital" for innovations, (2) research – knowledge (co)production for the creation of private and public values, (3) knowledge exchange for innovation systems, (4) strategic information – innovation embedding [31].

The role of universities is nowadays notable when it comes to the realization of the projects on sustainable development and environmental protection. In that regard, the collaboration in terms of green economy refers to the group of the related initiatives that were undertaken in order to encourage the development of environmental management in maritime affairs. For example, there are groups of initiatives in shipping industry [32]: (a) research and innovation (the reduction or alleviation of harmful emissions in the environment, technological design of safer and more sustainable ships), (b) Corporate Social Responsibility (CSR) and marketing (a voluntary integration of corporate social and environmental concerns in business operations and interactions with stakeholders), and (c) awareness raising/environmental education.

The results of previous studies should assist future research and the establishment of clusters for the development of green economy in the Adriatic region. A cluster represents collaboration among different partners – maritime industry (seaports, shipping companies, shipyards, marinas), governments (protection, regulations), universities or research centers, civil society, and the marine environment. The research on the promotion of eco-innovations analyzes similar concepts and emphasizes academic support of industry–government partnerships that should achieve sustainability in the Panama Canal Watershed [33].

Eco-innovations have been popularized in the past years due to rapid changes in maritime industry and environmental concerns associated with vessels and maritime transportation. Eco-innovation is defined as a specific kind of innovation that is beneficial to the environment – "any form of innovation or innovation process promoting sustainable development and innovations that benefit the environment and lead to sustainability"[34]. An example of eco-innovation is retrofitting of old ships, which is performed in the industry of maritime equipment and supplies.

Similarly, future research should investigate the Adriatic region as "a green maritime route" in proximity to science parks and with a potential for the creation of a green cluster that would promote eco-innovations. This vision of the region should also be explored in a broader context of clustering in blue economy [35].

3 Methodology

The paper relies on a qualitative analysis by means of the Atlas.ti 8 program and a statistical analysis of the data gathered though a questionnaire. An initial research questionnaire described the purpose of the paper, specific questions and instructions and was electronically delivered to the participants. The research sample includes 45 participants from maritime faculties in Slovenia, Croatia, Montenegro, and Albania.

The questionnaire contains three segments with the total of nine questions – general information about the participants (5 questions), multiple-choice questions about innovations (3 questions), and an open-ended question about the marine environment of the Adriatic region (1 question) (see the Appendix). The selection of the questions is aimed to increase the participants' general understanding and interest in the issue.

The Atlas.ti program enabled the formation of codes based on broadly defined responses to the questions. Coding is an interpretive process meant to capture the essence or the central theme of a part of the data, i.e. the answers collected. The main code in this research is called Adriatic Marine Environment. The quotations of the participants' attitudes on the vision of the Adriatic region in regard to innovations are added to the code. Likewise, there is a graphical illustration of the code with qualitative explanations and analysis.

4 Results and Discussion

4.1 The Profile of the Participants

The participants in the research were academic professionals from the Adriatic region and their characteristics are presented in Table 1. Initially, the participants had to select their research areas among 20 maritime areas listed in the questionnaire. Some of the participants selected more than one area, so the total number of the responses obtained was 94. Most of the participants investigate the area of the marine environment (17.02%). The second most researched area includes technical sciences (marine engineering, navigation, marine automation and electronics, transportation & modes of transport, safety and security, etc.) while the least investigated was the area of humanities.

After the selection of the research areas, the participants were identified on the basis of their academic rank. The academic professionals that participated in the research include assistant professors, associate professors, teaching assistants, full-time professors, and lecturers. More than a half of the participants (assistant and associate professors who constitute 58.78% out of the total number of participants) are actively progressing in their academic careers as they are conducting research, publishing results, and establishing the network of contacts during the creation and implementation of new projects.

In that sense, the analysis of innovations will continue in the future along with career development of young and experienced assistant and associate professors from the Adriatic region. Similarly, teaching assistants (who constitute 17.78% out of the total number of participants) also showed a considerable potential. Lecturers were the least numerous among the participants.

Besides the research field and academic rank, the participants were also identified based on the length of their work experience in the R&D teams:

Table 1 The characteristics of the participants

Characteristics	Frequency	(%)
The area of research		
Marine environment	16	17.02
Marine engineering	15	15.96
Navigation	7	7.45
Hydrography	1	1.06
Marine automation & electronics	6	6.38
Transportation and modes of transport	5	5.32
Marine information systems	4	4.26
Maritime law	2	2.13
The management of marine systems	4	4.26
Maritime health	2	2.13
Marine finance	1	1.06
Modern technologies	2	2.13
Safety and security	8	8.51
Intelligent transport systems	3	3.19
Human resources in transport	5	5.32
Education in transport	8	8.51
Marine defense	2	2.13
Applied mathematics	1	1.06
Language for specific purposes	2	2.13
Others	–	–
Total	94	100.00
Academic rank		
Full-time professor	7	15.56
Associate professor	12	26.67
Assistant professor	14	31.11
Lecturer	4	8.89
Teaching assistant	8	17.78
Others	–	–
Total	45	100.00
Years of experience in the R&D projects		
No experience	5	11.36
<5	7	15.91
6–10	10	22.73
11–15	10	22.73
16–20	3	6.82
>20	9	20.45
Total	44	100.00

1. 10 participants had between 6 and 10 years and 10 participants had between 11 and 15 years of experience;
2. 9 participants had more than 20 years of experience;

3. 7 participants had less than 5 years of experience;
4. 5 participants did not have previous experience; and
5. 3 participants had between 16 and 20 years of experience.

The fact that the two most numerous groups (1 and 2) constitute 65.91% out of the total number of participants indicates that the Adriatic region has qualified researchers who are competent for the creation of innovations.

4.2 *The Priority Areas of Innovations*

The paper focuses on the quintuple helix perspectives of the Adriatic region. Likewise, the participants were inquired about the priority areas of maritime cluster development that would be based on green economy principles and studies about the most developed clusters in the European Union [36]. The main economic activities include seaports, shipping, logistics and transport, shipbuilding, maritime tourism, fisheries and bio-products, off-shore industry, navy, marine engineering, maritime services, maritime education and training, maritime health, and marine environment. Among the activities listed, the participants were required to select those that are already innovated and those that should be innovated in the future. The field "others" was offered in case the participants wanted to add their own ideas. The participants have already introduced innovations in the maritime areas that are exhibited in Table 2.

It should be noted that most innovations were introduced in the area of maritime education (20%), marine engineering (16.92%), and shipping (12.31%). Six participants selected the answer "others" and indicated the areas of maritime informational systems, e-learning, maritime law, maritime safety, hydrography, and marine

Table 2 The maritime areas that the participants have innovated so far

The area of research	Frequency	Percentage (%)
Seaports	4	6.15
Shipping	8	12.31
Logistic and transport	4	6.15
Shipbuilding	4	6.15
Maritime tourism	1	1.54
Fisheries	1	1.54
Off-shore industry	1	1.54
Navy	2	3.08
Marine engineering	11	16.92
Maritime service	5	7.69
Maritime Educ. & train.	13	20.00
Maritime health	2	3.08
Marine environment	3	4.62
Others	6	9.23
Total	65	100.00

Table 3 The priority areas of future research

The area of research	Frequency	Percentage (%)
Seaports	11	16.92
Shipping	13	20.00
Logistic	9	13.85
Shipbuilding	8	12.31
Maritime tourism	6	9.23
Fisheries	8	12.31
Off-shore industry	8	12.31
Navy	8	12.31
Marine engineering	17	26.15
Maritime services	11	16.92
Maritime education	13	20.00
Maritime health	4	6.15
Marine environment	6	9.23
Others	2	3.08
Total	124	100.00

materials. Additionally, the participants expressed their attitudes about the areas that should be innovated in the future (Table 3).

Future innovations are mostly expected in the areas of marine engineering (26.15%), shipping (20%), maritime education (20%), seaports (16.92%) and maritime services (16.92%). Two participants added their ideas to the field regarded as "others," so innovations could also be expected in two areas – energy and ship administration and digitalization – which shows the emergence of the new areas of innovations.

The attitudes of the participants about innovation through collaboration were investigated by means of the question "Will future innovations be dominantly created at universities/R&D centers, or based on the cooperation between different industrial and other stakeholders in maritime affairs i.e. maritime clusters?". All the participants replied to the question, nine participants (20%) reported that innovations will be created at universities/R&D centers while 36 participants (80%) opted for innovation through collaboration between industrial and other stakeholders in maritime affairs, i.e. maritime clusters. These results indicate that academic professionals have strong awareness of the necessity of innovations and collaboration on the creation and implementation of innovations.

5 The Vision of the Adriatic Marine Environment

According to Fig. 3, the key responses in relation to the Adriatic marine environment concern shipping, the quality of seawater and protection of ecosystems, IT technology, regulatory measures, marinas, cruise ports, energy, economy, etc.

In terms of innovations, the participants claim that an adequate patent and the protection of intellectual property are crucial, both of which were neglected in the

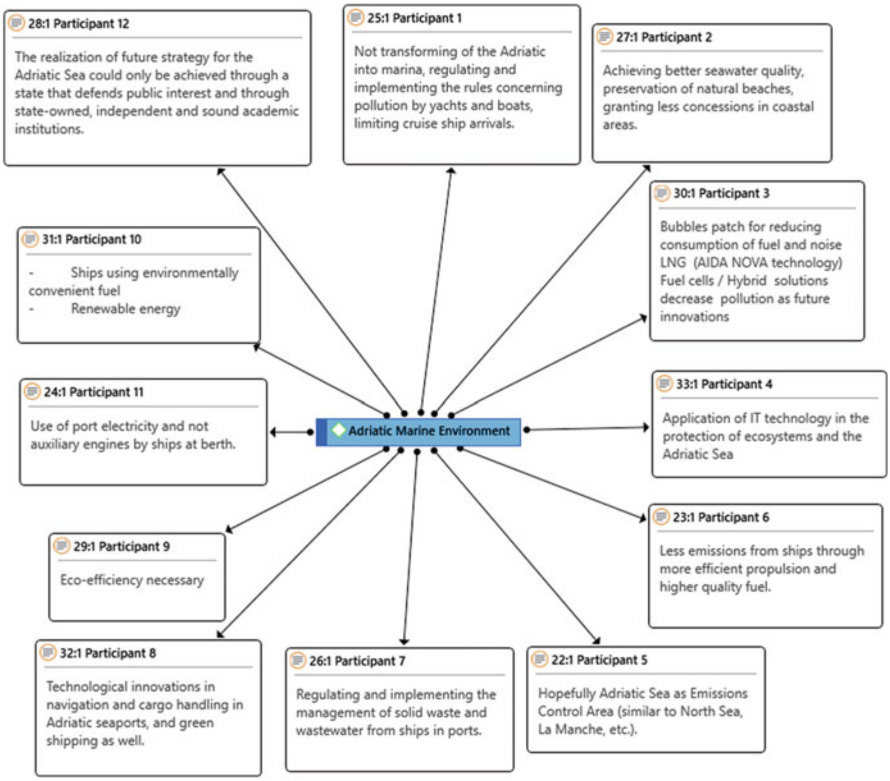

Fig. 3 The participants' recommendations for the Adriatic marine environment

Adriatic region so far. The participants agreed that a mutual platform for innovative solutions is necessary for the joint actions of the key stakeholders (maritime industry, research centers, and regulatory bodies). In the future, the key stakeholders in the Adriatic region should collaborate more than they did in the past.

The innovations in the area of shipping are related to the use of environmentally sound fuel, lower emissions and more efficient propulsion, solid waste and wastewater management in ports, hull maintenance technologies, green shipping, etc.

When it comes to the role of IT in the protection of the Adriatic ecosystems and seawater, the participants suggested "smart buoys" that would gather data about seawater, e.g. salinity, temperature, density, etc. By means of the GPRS systems, the data collected would be visible on the monitors in hotels, port terminals, and similar tourist places. In that way, the tourists in the Adriatic region would be informed about the conditions of the sea upon their arrival, which would enable efficient vacation planning, e.g. going to the beaches if the sea temperature is adequate or the use of other tourist services. Similarly, smart buoys would also measure pollution levels, so the authorities could timely react in case of incidents and prevent severe pollution and harmful consequences. Therefore, the focus of future innovations should be on the development of fast monitoring systems, e.g. in case of oil spills in the sea.

Regarding rules and regulations, the participants emphasized the introduction of innovative approaches to sea control, which implies the creation and concern for the rule book that defines poaching. The exploitation of the marine resources should be monitored by means of drones and similar devices. In that sense, the state and state research institutions would play a key role and their impartiality and strength are essential.

The regulation and implementation of the rules on the pollution from yachts and boats are necessary in the area of marina operations. In relation to cruising, the number of allowed entries should be limited. The potential economic losses caused by the limitation of the entries should be mitigated by innovated economic measures, e.g. the increase in the quality and price of tourist services.

Concerning economic measures and production, the participants suggested innovations in fishery, e.g. an increase in the catch of small oily fish and the formation of small and medium enterprises that would process the fish and sell the products that would be competent on the local market and available to tourists, as well. The area of fish processing and breeding is also a fruitful ground for innovations.

Ultimately, the participants emphasized the importance of innovations in relation to the positioning of the Adriatic region as a tourist destination with clear seawater and beaches whose residents and stakeholders understand the importance of the conservation and sustainability of the resources.

6 Conclusion

Despite the fact that many projects investigated the mitigation of the negative influences of maritime activities on the marine environment, there is still a considerable uninvestigated area which is becoming the focus of scientific and academic research. In relation to the Adriatic region, it was confirmed that most of the global economic sectors will grow in the future, which would require the introduction of the timely measures for protection and conservation of the region.

As a suggestion for the Adriatic solution, the paper emphasizes the projects based on contemporary concept of open innovation and innovation through collaboration along with helix model that comprise five elements – universities, industry, governments, civil society, and the environment.

The Adriatic region investigated in the paper is still not a part of the European innovation scoreboard. However, the paper confirms that there is a considerable scientific potential of academic professionals and institutions that could participate in innovation projects and their implementation. Marine engineering, shipping, and maritime education were identified as the areas of the current and future innovation projects. The potential for innovation is also detected in the area of the marine environment. The innovations in the area of the marine environment are expected in relation to shipping, the quality of water and protection of ecosystems, IT technology, regulation measures, marinas, cruise ports, energy, and economy.

The protection of the Adriatic region relies primarily on the collaboration of key stakeholders. Investments in the environment should be seen as the investments in the bright and sustainable future, which is highly profitable in the long run. However, the timely realization of green ideas is a significant and challenging task that could be completed by means of an integrated approach. The paper confirmed that the region abounds in scientific institutions, capacities, projects, and foundations that fund the research on the marine environment.

The paper could not encompass all topics related to maritime innovation management, which is the key limitation of the research conducted. The obstacles that researchers face during the creation of innovation projects as well as the roles of universities and researchers will be the focus of future studies, while the sample should include the participants from other countries of the Adriatic region, as well.

Appendix

Questionnaire

1. Working Institution name and location:						
2. If possible your Name and email address:						
3. Field of research (please make strike or write your field)						
Marine engineering	Maritime law			Intelligent transport systems		
Navigation	Management of Marine Systems			Human resources in transport		
Marine environment	Maritime health			Education in transport		
Hydrography	Marine finance			Marine defense		
Marine Automation & Electronics	Modern technologies			Applied mathematics in maritime		
Transportation & Modes of transport	Safety and Security			Language for specific purposes		
Marine information systems				Other: ___________________________		
4. Academic rank	Full-time professor	Associate professor	Assistant professor	Lecturer	_________________________ (please write)	
5. Experiences in R&D projects in years	No experience	<5	6–10	11–15	16–20	>20
6. Which maritime area(s) was/were the focus of your recent innovation projects?	Seaports, shipping, logistics and transport, shipbuilding, maritime tourism, fisheries and bio-products, off-shore, navy, marine engineering, maritime services, maritime education and training, maritime health, marine environment Others_______________________________________					

(continued)

7 which maritime are(s) will, in your opinion, be the most innovated in the future?	Seaports, shipping, logistics and transport, shipbuilding, maritime tourism, fisheries and bio-products, off-shore, navy, marine engineering, maritime services, maritime education and training, maritime health, marine environment Others____	
8. Will future innovations be dominantly created at universities/R&D centers, or based on the cooperation between different industrial and other stakeholders in maritime affairs, i.e. maritime clusters?	1-Dominantly R&D centers	2-innovations through cooperation between different stakeholders – Maritime clusters
9. Could you give recommendations for the improvement of maritime operations in terms of the increased efficiency, productivity, and sustainability in the Adriatic region? Explain your vision of the Adriatic marine environment.		

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Harmonization Requirements for MSFD and EcAp (Contaminants) in the ADRION Region: From Sampling to Data Visualization

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Contents

Abstract The overall increase in maritime activities along the Montenegrin coast, and in the Adriatic–Ionian (ADRION) Region in general, may pose serious risks of pollution from hazardous substances for several coastal areas. In order to promote the sustainable use of the seas and, at the same time, preserve Good Environmental Status (GES), Montenegro, as well as most countries of the Mediterranean region, ratified the Mediterranean Action Plan of United Nations Environment Program (UNEP-MAP), aiming to reach and maintain GES in the framework of the Ecosystem Approach (EcAp), by implementing an Integrated Monitoring and Assessment Programme (IMAP) coherent and consistent with the Marine Strategy Framework Directive (MSFD), the overarching European Union legal instrument for the marine environment.

Countries that share a marine region or sub-region should cooperate to assure a coherent approach to environmental monitoring and the definition and assessment of Good Environmental Status. However, in the ADRION Region, bordered by EU and non-EU countries, the level of coherence is still low and efforts are needed to improve a harmonized and coordinated approach to face environmental problems, with particular regard to marine pollution.

Thanks to the cooperation among research institutions and environmental agencies of most countries bordering the Adriatic and Ionian Seas, supported by European Union Interreg ADRION Programme, a comparison of monitoring, analytical protocols, data management, and visualization approaches was carried out to evaluate the level of coherence of information of marine chemical contaminants in the ADRION Region. The results of the comparison allowed to identify and prioritize methodological aspects to improve a harmonized approach to monitoring chemical contaminants and managing marine data in the Adriatic–Ionian Region.

Keywords ADRION region, Data visualization, Environmental assessment, Harmonized protocols, Marine contaminants, Monitoring, The Adriatic Sea

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1 Introduction

The Adriatic and Ionian (ADRION) Seas are crucial for the blue growth of both EU and non-EU coastal states. However, increased human use of the marine and coastal space may threaten marine ecosystems through several kinds of physical, chemical, and biological disturbances and through contamination by hazardous substances. In particular, the general increase in maritime traffic, the increasing coastal urbanization, and the expected growth of offshore oil and gas production in the ADRION Region pose serious risks of pollution from hazardous substances for several coastal countries. Several relevant and growing economic maritime activities, such as coastal and maritime tourism, fishery, and aquaculture, depend on maintaining ecosystem services and reducing pollution. Besides, the region hosts natural protected areas and sites of conservation interest of global importance (National Marine Protected Areas, NATURA 2000 sites). In order to promote sustainable use of the seas, the Protocols for the Protection of the Mediterranean Sea against Pollution of the Barcelona Convention and the Marine Strategy Framework Directive of the European Union (MSFD) [1] commit all UNEP/MAP Contracting Parties as well as EU Member States to take measures to maintain or achieve Good Environmental and Ecological Status (GES) in the European seas by 2020 [1]. Countries that share a marine region or sub-region should cooperate to assure a coherent approach to environmental monitoring and the definition and assessment of Good Environmental Status. A consistent number of EU regulations and technical reports have aimed, in the last years, to provide technical specifications to achieve a common approach among EU Member States for monitoring water status according to the Water Framework Directive (WFD) and MSFD [2–5] and similar approaches have been proposed in the Mediterranean Sea by the Barcelona Convention [6–8]. Nevertheless, the in-depth evaluation of EU member states submission for the MSFD as well as other independent reviews and the latest review carried out by UNEP/MAP Mediterranean Quality Status Report have highlighted that the degree of coherence in Mediterranean Sea in terms of implementation of EU environmental policies and the MEDPOL protocols, as well as the comparability of data and their suitability for regional and sub-regional assessment, is considered low, particularly in the case of chemical pollution [9–12].

The comparability and interoperability of data depend not only on sampling and analytical protocols, but also on how data and metadata are archived. Interoperability is guaranteed by using common sets of metadata, common formats for data and metadata, and the adoption of standard vocabularies to assure a homogeneous syntax and semantics, as detailed in EU INSPIRE Directive [13, 14]. Visualization is a useful tool for collecting datasets and creating practical and understandable information for many stakeholders and decision-makers. The effective transfer of data is as important as monitoring and data management. The visualization of contaminant levels in the marine environment can be a useful instrument to facilitate the evaluation of the environmental status.

Thanks to the cooperation among research institutions, National Oceanographic Data Centers (NODCs), and national environmental agencies of most countries bordering the Adriatic and Ionian Seas (Italy, Slovenia, Croatia, Montenegro, Albania, and Greece) (in the framework of HarmoNIA project, funded by the European Union Interreg ADRION Programme, https://harmonia.adrioninterreg.eu/), a comparison of monitored substances and matrices, sampling and analytical protocols, Quality Assurance and Quality Control (QA/QC) procedures, data management, and visualization approaches was carried out to evaluate the level of coherence of information of marine chemical contaminants in the ADRION Region. The comparison allowed to identify and prioritize the need for harmonization of measured parameters and matrices, monitoring approaches, data and metadata management, and visualization protocols and to propose guiding principles to improve a harmonized approach to monitoring chemical contaminants in seawater, sediment, and biota and data management in the Adriatic–Ionian sub-region.

2 Legal Background

Taking into account the Ecosystem Approach (EcAp) vision agreed within the Contracting Parties of the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention), the Integrated Monitoring and Assessment Programme of the Mediterranean Sea and Coast and related assessment criteria adopted by the Barcelona Convention [15], and the MSFD of the European Union [1], Good Environmental Status (GES) is defined according to 11 qualitative descriptors (according to MSFD) or to, almost overlapping, 11 ecological objectives (EO, according to IMAP):

1. Biodiversity (quality and occurrence of habitats and the distribution and abundance of species) (overlapping with EO1)
2. Non-indigenous species (overlapping with EO2)
3. Populations of all commercially exploited fish and shellfish (overlapping with EO3)
4. Marine food webs and their components (overlapping with EO4)
5. Human-induced eutrophication (overlapping with EO5)
6. Seafloor integrity (overlapping with EO6)
7. Hydrographical conditions (overlapping with EO7)
8. Concentrations of contaminants (overlapping with EO9: contaminants cause no significant impact on coastal and marine ecosystems and human health)
9. Contaminants in fish and other seafood (overlapping with EO9)
10. Marine litter (overlapping with EO10)
11. Energy introduction, including underwater noise (overlapping with EO11).

In addition, UNEP/MAP has defined Ecological Objective EO8 – Coastal ecosystems and landscapes – which proposes that for good environmental status, natural dynamics of coastal areas should be maintained, and coastal ecosystems and landscapes should be preserved.

With regard to monitoring and assessment of contaminants, the Ecosystem-based Approach (EcAp) focuses on the concentration of contaminants in different matrices (seawater, sediment, and biota), but also on biological effects of pollution at various biological levels of organization. Assessment of environmental status is carried out comparing contaminant levels against background thresholds (BACs) [7]. However, accurate environmental assessment criteria (EACs), with the definition of acceptable or unacceptable environmental chemical status in the Mediterranean Sea from an environmental perspective, have not been determined yet for all matrices. Lastly, coherence among substances monitored, quality, and comparability of analytical results should be ensured to allow a joint assessment in areas shared by different countries, such as the Adriatic and Ionian Seas [2, 16].

2.1 State of Implementation in Montenegro

Montenegro, as well as most countries of the Mediterranean region, ratified the Mediterranean Action Plan of United Nations Environment Program (UNEP-MAP) that aims to reach and maintain GES toward the Ecosystem Approach (EcAp) by implementing an Integrated Monitoring and Assessment Programme (IMAP) coherent and consistent with MSFD for EU countries.

The monitoring program of the state of coastal sea ecosystems of Montenegro, in its structure and methodological approach, is based on several national regulations: Law on Environment [17], Law on Waters [18], and Rules on the method and deadlines for determining the status of surface waters [19]; in addition, it takes into account the requirements of relevant EU documents: European Environment Agency Guide on transitional, coastal, and marine waters [20], and related guidelines for reporting [21], as well as requirements of MEDPOL program. Water quality assessment, also in terms of marine chemical contaminants, is based on the criteria prescribed under the rules on the method and deadlines for determining the status of surface waters [19, 22–25].

The definition of the Monitoring Programme of Marine Environment in accordance with the Barcelona Convention and IMAP recommendations is in progress and the transposition of the MSFD in Montenegrin legislation standards resulted in the Law on the Establishment of a Framework for the Protection of the Marine Environment [26].

3 Methodological Approach

Nine institutions[1] from six countries of the ADRION region (Italy, Slovenia, Croatia, Montenegro, Albania, and Greece), most of them involved in the national monitoring activities, have contributed to the comparison of sampling, analytical protocols, and QA/QC procedures, focused on specific chemical substances. The analysis was focused on a set of substances (from: pesticides, biocides, antifoulants, pharmaceuticals, heavy metals, hydrocarbons, brominated compounds, and radionuclides), selected considering contaminants that are routinely monitored for WFD and MSFD assessment objectives. The results from the review were compared with the indications of the main directives (MSFD, WFD, and UNEP/MAP – MEDPOL) in order to propose guidelines to improve coherence and harmonization (Fig. 1).

In addition to monitoring and analytical protocols, experiences gained in the various countries in the area of data management and visualization were also exchanged. The consolidated practices of long-established Pan-European infrastructures (e.g. SeaDataNet, EMODnet Chemistry [27, 28]) were proposed in order to develop a common and coordinated approach for the analysis and visualization of data on marine contaminants, thus to support the practical implementation of harmonized transboundary environmental status assessment [29]. Data visualization is a useful tool to produce synthetic information required by most stakeholders and decision-makers. The approach to develop a harmonized and agreed data visualization methodology, common for the whole ADRION region, involved the following steps:

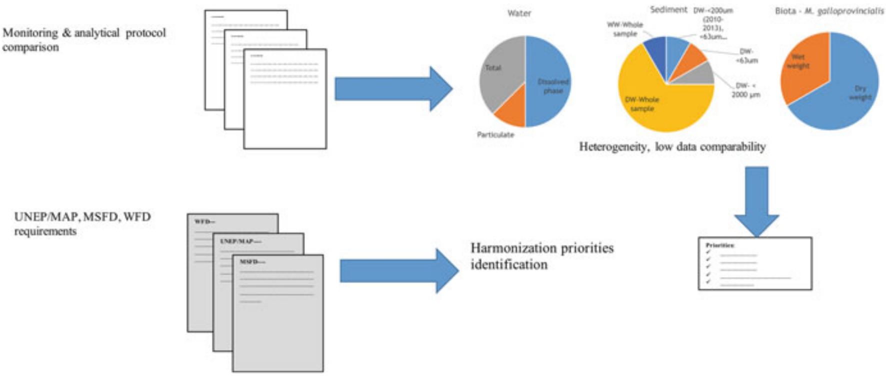

Fig. 1 Approach for the harmonization of monitoring activities

[1]Institute for Environmental Protection and Research (ISPRA, Italy), National Institute of Biology (NIB, Slovenia), Slovenian Environment Agency (ARSO, Slovenia), Institute of Oceanography and Fisheries (IOF, Croatia), Ruder Boskovic Institute (RBI, Croatia), University of Montenegro – Institute of Marine Biology (UoM-IMBK, Montenegro), Center for Eco-Toxicological Research (CETI, Montenegro), Agriculture University of Tirana (AUT, Albania), Hellenic Center for Marine Research (HCMR, Greece).

1. Collection of data and metadata focused on contaminants from institutions from most ADRION countries;
2. Harmonization and quality control of data according to a commonly agreed approach [30];
3. Comparison of data visualization procedures adopted within ADRION countries;
4. Evaluation of the requirements indicated by environmental legislations valid in the ADRION Region (namely EU – MSFD and UNEP/MAP – Barcelona Convention), as well as best practices proposed by OSPAR and HELCOM;
5. Definition of Guidelines on data visualization implementation specific for evaluating contaminants in the marine environment [29].

4 Results and Discussion

4.1 Monitoring and Sampling

The transnational comparison highlighted considerable heterogeneity among substances and matrices measured in the different countries, both in terms of sampling and analytical methods, and in QA/QC procedures, and indicated a clear need for harmonization of the monitoring procedures used for the assessment of environmental status, in order to comply with both European and Mediterranean legislation. The results of the comparison formed the basis to identify the main objectives toward harmonization.

Of the 45 chemical substances or groups of substances considered in this comparison that are most relevant for UNEP/MAP or for EU Legislation, only five are monitored by all countries in water (benzo(a)pyrene, fluoranthene, anthracene, lead, cadmium), three in sediment (benzo(a)pyrene, fluoranthene, anthracene), and two in biota (benzo(a)pyrene and fluoranthene) (Table 1). Conversely, none of the institutions participating in the study is, up to now, monitoring pharmaceuticals or radionuclides.

In the Adriatic–Ionian Region, hydrocarbons, heavy metals, pesticides and biocides, and antifoulants are the most common groups of substances sampled in sediment. Pesticides, heavy metals, and hydrocarbons are most frequently monitored in biota, while in seawater often only hydrocarbons and heavy metals are commonly sampled (Table 1).

With regard to matrix characteristics and sampling methods, an in-depth analysis focused on heavy metals revealed that there is a good degree of harmonization among institutions in the case of water sampling and filtering protocols, and conversely, a high heterogeneity in grain size and thickness of the sampled sediment (Fig. 2) and, with regard to biota, in measurement weight basis (wet or dry, Fig. 3), analyzed tissue and number of replicates [31, 32]. In the case of sediment, heterogeneity among laboratories with regard to the thickness of sediment samples may severely limit a coherent regional or sub-regional assessment of chemical contamination, as, for pollution assessment in the marine environment, only the recently

Table 1 List of substances considered for the comparison of methodological protocols, indications of monitoring activity in the different matrices (X indicates that the substance is monitored by all six countries, x indicates the substance is monitored by five countries, light gray background indicates it is monitored by at least one country), and relevance for UNEP/MAP and for EU Legislation (WFD, MSFD) (dark gray background)

Broad categories	Substances	Water	Sediment	Biota	UNEP /MAP	EU legislation
Antifoulants	Tributyltin cation	x				
Antifoulants	Triphenyltin as cation					
Farmaceuticals	Macrolides					
Farmaceuticals	Other farmaceuticals					
Hydrocarbons	Aliphatic hydrocarbons C10-C40					
Hydrocarbons	Aliphatic hydrocarbons C6-C12					
Hydrocarbons	Acenaphthene					
Hydrocarbons	Acenaphthylene					
Hydrocarbons	Anthracene	X	X			
Hydrocarbons	Benz(a)anthracene					
Hydrocarbons	Benzene					
Hydrocarbons	Benzo(a)pyrene	X	X	X		
Hydrocarbons	Benzo(b)fluoranthene					
Hydrocarbons	Benzo(g,h,i)perylene					
Hydrocarbons	Benzo(k)fluoranthene					
Hydrocarbons	Chrysene					
Hydrocarbons	Dibenzo(a,h)anthracene					
Hydrocarbons	Fluoranthene	X	X	X		
Hydrocarbons	Fluorene					
Hydrocarbons	Naphthalene					
Hydrocarbons	Phenanthrene					
Hydrocarbons	Pyrene					
Hydrocarbons	Total petroleum hydrocarbons					
Hydrocarbons	Ethylbenzene					
Hydrocarbons	Xylene					
Hydrocarbons	Ethylbenzene					
Hydrocarbons	Indeno(1,2,3-cd)pyrene					
Metals	Aluminium					
Metals	Arsenic					
Metals	Barium					
Metals	Cadmium	X		x		
Metals	Chromium		x	x		
Metals	Cobalt					
Metals	Copper		x	x		
Metals	Lead	X	x			
Metals	Nickel					
Metals	Total mercury	x				
Metals	Vanadium					
Metals	Zinc		x	x		
Metals	Total iron					

(continued)

Table 1 (continued)

Pesticides and biocides	DDT	x	x	
Pesticides and biocides	DDD	x	x	
Pesticides and biocides	DDE	x	x	
Pesticides and biocides	Hexachlorobenzene	x	x	
Radionuclides	Cs137/ Pu239			

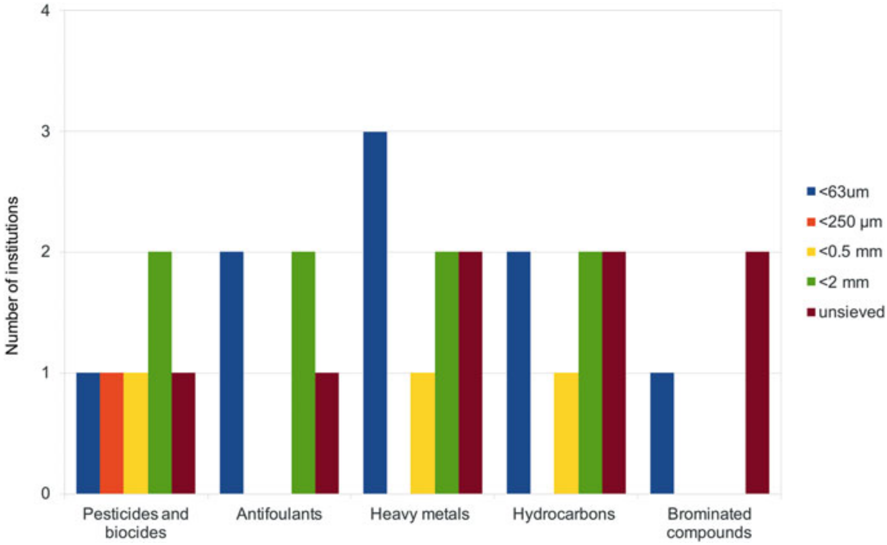

Fig. 2 Sediment grain size per group of substances among institutions

deposited material, which generally corresponds to the top part (approximately 0–2 cm) of the sediment, needs to be collected [33, 34]. This aspect implies the use of appropriate sampling devices that allow the selection of a precise sediment layer, causing the minimal disturbance to the sample (e.g. box corer [32]). With regard to biota, even though *Mytilus galloprovincialis* is the most monitored species, there is more divergence on the choice of the analyzed tissue (muscle vs whole body), though the majority of the substances refer to mussel whole tissue.

Based on the comparative analysis within the ADRION Region, the following harmonization requirements have been identified to improve coherence and comparability of pollution monitoring:

- uniform list of measured chemical substances,
- consistency in grain size fraction of analyzed sediment,

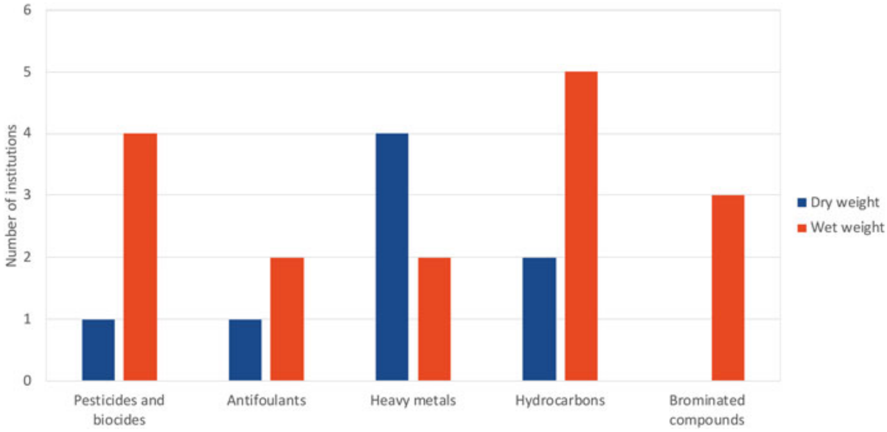

Fig. 3 Measurement weight basis per group of substances among institutions

- unification of thickness of the sampled sediment layer,
- convergence of measurement weight basis for biota (in addition, it is required to have the water content of the soft tissue in order to be able to convert wet weight to dry weight).

Lastly, the importance of providing detailed information on all phases of contaminant monitoring (from sampling, storage, and laboratory analysis) has also been highlighted as a crucial issue to allow data comparability and fitness for use.

4.2 Data Management and Visualization

Besides harmonization of monitoring protocols and analytical methods, coherent data management and quality control are also crucial when environmental status is assessed at regional or sub-regional scale (e.g. for the Mediterranean or the Adriatic Sea), thus requiring data from different sources. Within the framework of HarmoNIA, data of chemical pollutants measured in seawater, sediment, and biota were collected from six countries, enriched with the relevant metadata and managed according to EMODnet Chemistry approach, which involves the use of standard vocabularies (to unambiguously encode parameters, sampling, analytical methods, and measurement units), standard metadata, standard file formats, and processing software [27, 30]. All data were harmonized in terms of parameter names and measurement units, subdivided into three ADRION Region aggregated data collections, one for each matrix (seawater, sediment, and biota), and subjected to a standardized data quality control procedure [35]. The resulting validated and harmonized ADRION Region datasets were used to produce data visualizations for a selection of contaminants measured in seawater, sediment, and biota, according to a commonly agreed approach (Fig. 4).

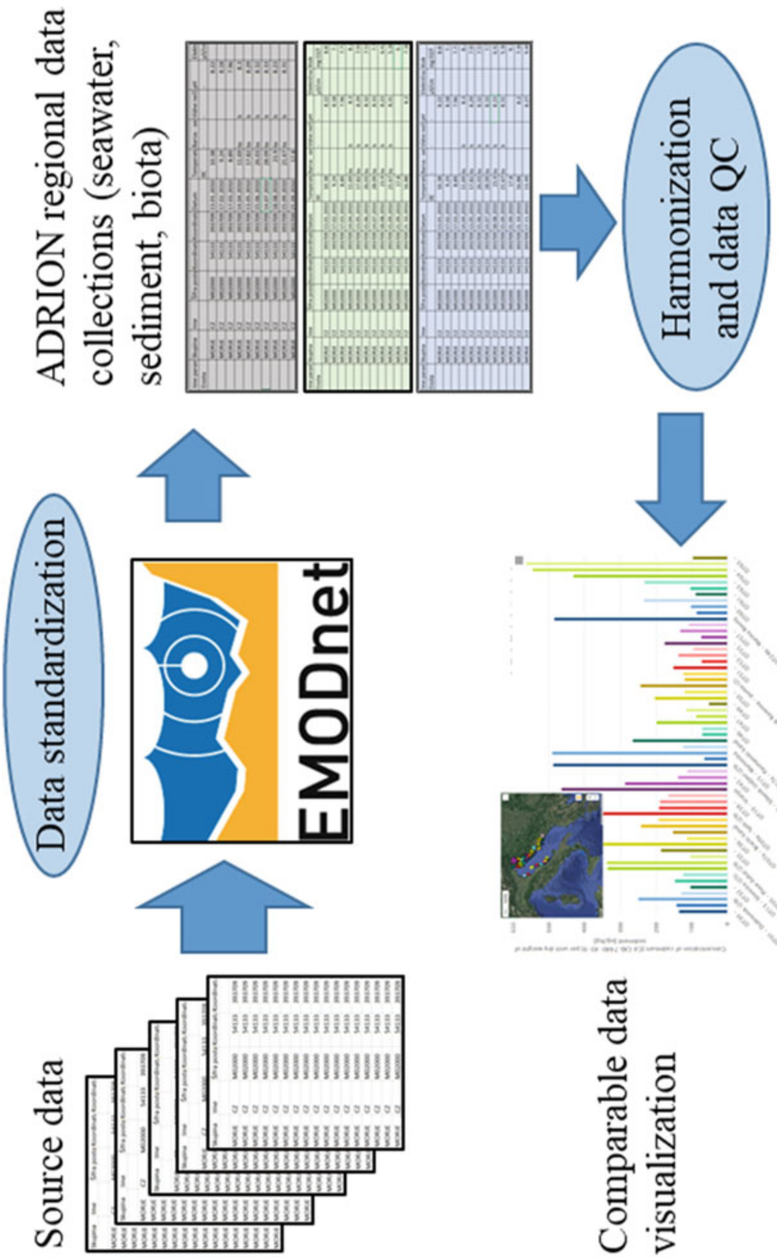

Fig. 4 Approach for harmonization in data management and visualization

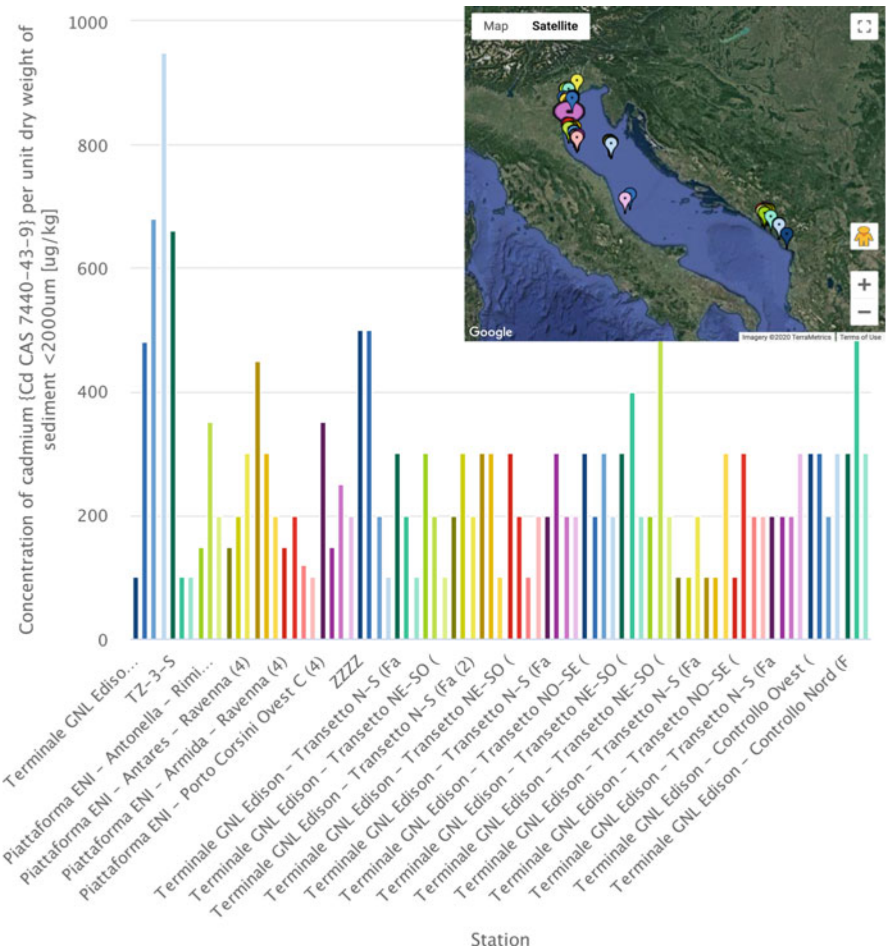

Fig. 5 Example of Cadmium concentration (μg kg^{-1}) per unit dry weight of sediment (<2,000 mm size fraction) in the stations indicated in the map. Bars represent median concentrations if multiple data are available for the same station (from: https://vrtlac.izor.hr/ords/harmonia/H_VIZUAL, last accessed: 18/08/2020)

A dedicated interactive online tool was set up to produce visualization of data of marine contaminants in the ADRION Region (https://vrtlac.izor.hr/ords/harmonia/H_VIZUAL). The harmonized data management system and the standard data visualization approach allow to compare concentrations of contaminants measured by different institutions from different countries (Fig. 5) and, thus, support a harmonized assessment of marine pollution in the ADRION Region.

5 Conclusion

Due to the large heterogeneity in monitoring marine contaminants identified in the ADRION Region, a coherent assessment is yet to be achieved concerning the Good Environmental Status (GES) required by MSFD, IMAP, and the implementation of the EcAp. Nevertheless, this work has allowed us to identify and prioritize issues of harmonization and has proposed a shared approach to improve coherence in monitoring activities and in data management and visualization.

Sharing expertise, information, and marine data and strengthening cooperation between institutions in charge of marine environmental monitoring are crucial aspects to properly manage environmental vulnerability and safeguard ecosystem services in transnational areas such as the ADRION Region.

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Conclusion

Danijela Joksimović, Mirko Đurović, Aleksander V. Semenov, Igor S. Zonn, and Andrey G. Kostianoy

Contents

Abstract Montenegro's coastal area is one of the most valuable national resources. It is characterized by high development potential with an essential importance for the development of Montenegrin society. However, the inextricable relations between man's activities and the natural environment often result in excessive pressure on natural resources. This book presents interdisciplinary studies on the Montenegrin coast 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 hydrographic and oceanographic characteristics, climate change, rivers, forest, agriculture, architecture, shipping, maritime and marine tourism, pollution, and

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protection of the Marine Environment. Montenegro's coastal area, and its narrow coastal zone with its natural and cultural values, in particular, represents the most valuable national resource. Unfortunately, over the last few years, we have witnessed increasing pressure on both natural and cultural values due to accelerated urbanization, industrialization, and tourism development. Although Montenegro and the South Adriatic are among the least polluted areas, the effects of climate change are a serious threat to the sustainable development of the coastal area, as well as natural and anthropogenic effects. One of the main tasks is to preserve the potential of the coastal area of Montenegro and to prevent all pressures from land and sea. Coastal management is a long-term process – it requires a multidisciplinary approach as well as participation and cooperation not only of decision-makers but also of all interested parties such as scientists, lawyers, economists, who will contribute first to the setting and then to the accomplishing of the objectives set.

Keywords Aquatic ecosystem, Coastal zone, Marine pollution, Maritime, Montenegrin coast, South Adriatic Sea

1 Introduction

The diversity of geological substratum, climate, and geographical position of Montenegro on the Balkan Peninsula and the Adriatic Sea has enabled the emergence of a high-value biological diversity. The Adriatic Sea is considered a biodiversity hotspot of the Mediterranean, as a habitat of plant and animal communities with great environmental significance. At the same time, the area is under pressure from intense exploitation of natural wealth and pollution emerges as a key threat and an issue requiring a joint approach regarding its assessment and management. The management and preservation of the coastal area of Montenegro require complementarity and coherence between natural, social, and economic factors. The introduction into this monograph demonstrates why it has been chosen for highlighting the oceanographic characteristics and pollution in Montenegro's coastal area. The South Adriatic is the least polluted area of the Adriatic Sea and at the same time one of the least polluted areas in the Mediterranean. Due to the sudden development of the tourism industry in recent decades, global trends are leading to an increasing number of facilities on the coast. Therefore, it is very important to align the development priorities with the interests of how to protect the resources of the marine ecosystem. To achieve this goal, a scientific approach is essential.

2 The Adriatic Sea

The physical and oceanographic features of the Adriatic Sea provide the basis for describing characteristic area. The area of the whole Adriatic Sea is 138,595 km^2, which is about 5.5% of the total area of the Mediterranean, and its volume is approximately 34,977 km^3. Montenegrin coastline length is about 300 km, of which 105.7 km belongs to Boka Kotorska Bay and 11 km are islands. The area of territorial waters up to 12 n.m. is 2,098.9 km^2, the epicontinental belt area is 3,885 km^2, and the shelf area is $\approx$4,000 km^2.

The Adriatic Sea is mostly shallow. The continental slope or shelf and slope, i.e. the area of seabed to about 200 m in depth, accounts for as much as about 74% of the Adriatic Sea. From northwest to southeast, the depth of the Adriatic Sea increases gradually. Only 7.7% of the Adriatic Sea is characterized by depths over 1,000 m. The highest depth of the Adriatic is in the area of the South Adriatic Sea (1,228 m). The general circulation is cyclonic with a northwest flow along the eastern coast and a return southeast flow along the western coast. There are three principal water masses in the Adriatic Sea: the Adriatic Surface Water (AdSW), the Levantine Intermediate Water (LIW), and the Adriatic Deep Water (AdDW). The climate characteristics are manifested in pronounced extremes of sea temperature, salinity, and other characteristics. Differences in the surface sea temperatures between summer and winter periods are high, as well as differences in salinity during the seasons. Winds which blow in the Adriatic are not of permanent character, therefore they cannot establish certain circulation system, and even they influence the currents, especially in the coastal area. However, the climate change has a great impact on the hydrographic and oceanographic characteristics of the Adriatic Sea.

One of the relief unities in the area of Montenegro that has a clearly defined space is the zone of the Montenegrin coast. Its relief is clearly detached from the neighboring area of the deep karsts, which has a great impact on it. The Montenegrin coastal area is separated by the peaks of the Orijen-Lovcen-Sutorman-Rumija mountain range from the inner part of Montenegro.

The climatic characteristics of the area determine the large amount of precipitation that is excreted during the year. It is important to point out the characteristic that the mentioned barrier stops warm and humid air masses, so the highest precipitation is emitted in this area in relation to the rest of the territory of Montenegro. The amount of precipitation is indicated by the fact that the largest amount of precipitation in Europe (1,938–8,063 mm) was recorded at one point on the Orjen (Crkvice).

The development of forestry in the coastal area must be based on multifunctionality, on professional criteria, and on the principles of the forestry profession, in order to emphasize the general useful functions of forests and ecological balance in space, i.e. on the principle of sustainable development. Existing forest ecosystems need to be more adequately protected, natural regeneration encouraged, their stability and biological diversity maintained, and existing forms of forest vegetation should be translated into a higher form by supporting indigenous species.

3 The Coastal Zone of Montenegro

The coastal zone occupies a narrow strip of Montenegro's territory and it is the most densely populated region in Montenegro. This region comprises six municipalities: Bar, Budva, Herceg Novi, Kotor, Tivat, and Ulcinj. The main characteristic of rural areas in the Coastal region is the negative demographic trends, underdeveloped rural infrastructure, and low degree of commercialization of agricultural holdings. Natural conditions are changing; they are endangered by the development itself, which requires very strict control of land use and protection of all potentials.

In the coastal region, several different types of landscape character can be observed, from the cultural landscape of the settlement through agricultural landscapes (settlements with traditional agriculture in the fields, settlements with traditional agriculture on terraces) to the types of landscapes with natural and semi-natural features, landscapes. Therefore, the focus is on the basic orientation on the development of natural resources of Mediterranean agriculture and mariculture. The complementarity of agriculture and tourism is increasingly important, because a wide range of domestic products enriches the tourist offer, making it unique.

4 Marine Pollution

Environmental pollutants continue to be a worldwide concern and one of the significant challenges faced by the global society. Marine pollution affects the changes in the physical and chemical characteristics of the sea and the ocean, biological communities and the overall health of the marine ecosystem. Due to the rapid development in industrialization and activities on the shore, the discharge of heavy metals in the Montenegrin coastal environment has increased. Even though heavy metals are natural components of the Earth's crust, their current concentrations observed in coastal waters are the consequence of the growth of industrial, agricultural, and urban activities since the 1980s. Metals in traces reach the sea from the atmosphere (rain, dust particles, and other precipitation) or they can be washed away from the land and reach the sea through rivers loaded with both atmospheric and wastewater. Industrial wastewater is also one of the major sources of metals in marine environments. Thus, coastal and industrialized areas are the most endangered when it comes to the high metal contents in the sea compared to the natural levels.

Human activities have led to increased contaminant concentrations in the environment. As a consequence of their circular flow in nature, heavy metals have a great impact on both the environment and human health. Such a situation is observed on the Montenegrin coast as well. Marine organisms adsorb and accumulate these elements from their environments. Since the bioaccumulation is a process that lasts several months or years, the use of living organisms in marine pollution monitoring programs, unlike classical methods of contaminants analysis, allows the determination of biologically available elements in the marine environments, as well as their concentrations over a long period. The Mediterranean mussel (*Mytilus galloprovincialis*) is a sentinel species and a filter-feeding animal, known for the ability to accumulate a wide range of trace elements. Furthermore, their wide geographical distribution, sessile nature, and easy sampling make them valuable bioindicators of marine pollution. Trace elements can be accumulated in mussel tissues to concentrations much higher than those found in the environment, and they can cause long-term harmful effects on marine organisms, but also on humans. The food chain, especially the consumption of seafood, is one of the primary sources of human exposure to trace elements. Besides that, the production and human consumption of shellfish are increasing all over the world. Therefore, in order to minimize the potential adverse health effects, the knowledge about contents of trace elements in mussels planned for consumption and the health risk assessment (HHRA – human health risk assessment) of mussel consumers are of major importance.

It is commonly thought that toxic compounds come only from anthropogenic sources, however toxic compounds can be of natural origin, hence we call them natural toxins. In the marine environment, some molluscs and crabs contain natural toxins produced by symbiotic bacteria. Shellfish in addition to accumulation of natural (biotoxins) toxins may produce toxic secondary metabolites. Some species of phytoplankton are known to produce potent natural toxins, which is also the case with some species of fish, especially pufferfish. Their main feature of such toxins is thermostability, meaning they do not get destroyed through thermal food processing at any temperature and their toxicity remains unchanged. In chapter are presented the results of tetrodotoxin investigations in silver-cheeked toadfish *Lagocephalus sceleratus* (Gmelin, 1789) from the Adriatic Sea. It is a poisonous marine pufferfish that has reached the Mediterranean from the Red Sea through the Suez Canal (Lessepsian migration). This species has also been recorded in the Adriatic Sea, however, its presence is still of periodic nature and currently there is no evidence which would suggest permanent population establishment. Tetrodotoxin is a very potent toxin that has been detected in organs such as skin, muscle, liver, and gonads of the pufferfish specimens collected in the Adriatic Sea.

Marine litter is one of the most widespread problems facing all countries in the world. Beaches, coastal ecosystems, and river basins, which are the basis of tourism development in Montenegro, are negatively impacted by litter, and it is extremely important to reduce the amount and negative impact of marine litter through a collaborative, state and inter-institutional approach that relies on the strengths and resources of local communities, organizations, and state institutions.

Protection of the sea from vessel-sourced pollution is a complex issue which the international community has been facing with for ages. One of the key mechanisms for protection of the marine environment from pollution is an established legal framework which, when obeyed and enforced, can contribute to the preservation and protection of the marine environment. Pollution of the marine environment from vessels, caused directly by the discharge of various substances into the sea, or indirectly through the atmosphere, is a serious global problem. In addition to the international legislative framework for the prevention of pollution from vessels, adopted by the International Maritime Organization (IMO), the obligation of each state is to establish efficient and effective legal mechanisms, which will through their implementation ensure the protection and preservation of the sea and marine environment. Being an ecological state, Montenegro has a clear commitment to protect and preserve the sea from pollution from vessels. In that sense, Montenegro has created its own legal framework which represents a solid basis for further upgrading and improvement of legal solutions on the protection of the sea from vessel-sourced pollution.

The analysis of air pollutant emission inventories from passenger ferries in the Boka Kotorska Bay at the observed period of one year and for analyzed routes represents a first detailed study of the kind, knowing that Kotor and bay are under UNESCO heritage protection. The whole region is recognized by the high level of tourists' visits coming to a destination by cruise ships or by another landside transport mode. Besides the evident maritime activities in the bay, the domicile population is exposed to air pollution from ships, including passenger ferries that are transporting tourists from March to October each year in inner bay zones.

Assessment of environmental quality within marinas is essential to validate implemented environmental protection measures and to adopt appropriate action plans. In the view of the forecasted global climate change, the monitoring of the environment heavily consumed with human activities such as marinas will become even more important. Since the Adriatic Sea is a closed sea, the changes in the next 50 years might be even more rapid than in the oceans and seas globally. Probably the most significant change, except for the sea temperature and salinity, could be expected in the primary bioproduction and consequently in the oxygen regime. Since marinas are usually built at locations with very weak sea currents, the effects can be even more pronounced and marinas should be prepared to adapt to these new scenarios. Also, this study provides support data for further improvement of management practices in marinas.

5 Discussion

The general increase in maritime activities along the Montenegrin coast and in the Adriatic Region in general may pose serious risks of pollution from hazardous substances for several coastal areas. In order to promote the sustainable use of the seas and, at the same time, preserve good ecosystem status (GES), Montenegro, as well as most countries of the Mediterranean region, ratified the Mediterranean Action Plan of United Nations Environment Program (UNEP-MAP), aiming to reach and maintain GES in the framework of the Ecosystem Approach (EcAp), by implementing an Integrated Monitoring and Assessment Programme (IMAP) coherent and consistent with the Marine Strategy Framework Directive (MSFD), the overarching European Union legal instrument for the marine environment. For those countries that have not defined criteria and standards for achieving good environmental status by 2020, they must do so during the initial environmental assessment; identify objectives, monitoring programs and proposed measures for each area defined through MSFD.

Countries that share a marine region or subregion should cooperate to assure a coherent approach to environmental monitoring and the definition and assessment of good environmental status. However, in the ADRION Region, bordered by EU and non-EU countries, the level of coherence is still low and efforts are needed to improve a harmonized and coordinated approach to face environmental problems, with particular regard to marine pollution.

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 environmental issues. After publishing a series of books on studies of ecology and the protection of the northern seas, the Black Sea, some parts of the Mediterranean, the scientists and collaborators of the Marine Biology Institute (Kotor), together with colleagues from the region, have prepared the present book on research and analysis of the marine ecology, biology and chemistry of Montenegro's coast, addressing, in particular, the aspect of the protection and preservation of the marine ecosystem. We would like to remind here that "The Montenegrin Adriatic Coast" is published in two volumes: "Marine Chemistry Pollution" (present volume) and "Marine Biology" [1], and these are follow-on volumes after our previous book "The Boka Kotorska Bay Environment" (one of the most beautiful bays of the Adriatic Sea) published in Springer in 2017 [2].

"The Montenegrin Adriatic Coast: Marine Chemistry Pollution" will be very interesting, above all, to young researchers, but also experts and professionals in various fields dealing with the protection of marine ecosystems, its preservation, and management, all interested parties as well as readers and sea enthusiasts. Volume Editors of this book are authors of the reference monograph "The Adriatic Sea Encyclopedia" [3], which is based on the Russian version of the Encyclopedia published in 2014 [4] and the Second edition in 2017 [5]. This updated English version was published in Springer at the end of 2020. Besides, we would like to recommend two more books on Montenegro: "The Skadar/Shkodra Lake Environment" [6] and "The Rivers of Montenegro" [7] published in Springer in 2018 and 2020, respectively.

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