The Relevance of the Implementation of AZA According to the Principles and Standards of GFCM Guidelines in the Site Selection Process for Sustainable Development of Aquaculture: Montenegro Case Study

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Abstract Marine aquaculture is one of the fastest growing industries in the world, with a long-term growing trend and wide opportunities for the development and dissemination of production. It is clear that seafood production is the future of the marine fisheries sector, especially in terms of preserving existing fish resources, repopulation and conservation of endangered species, developing innovations in breeding technologies, and supplying the market with quality farmed food throughout the year.

In order to define the new mariculture zones that can be used for the production process, it is necessary to meet special conditions, among which the most important are the environmental, administrative, and socio-economic. There are numerous papers dealing with the issue of determining suitable zones for aquaculture, but certainly one of the most important principles to be followed in the selection of zones is the concept of AZA (Allocated Zones for Aquaculture) which was adopted as a specific resolution of the General Fisheries Commission of the Mediterranean (GFCM) of the Food and Agriculture Organization of the United Nations (FAO). Montenegro has accepted these recommendations and started a detailed analysis of new, potentially suitable areas for the development of marine aquaculture in the zone of the Boka Kotorska Bay which is under the influence of the waters of the open sea.

In order to comply with the rules and recommendations implied by the AZA principle, detailed research of environmental parameters was conducted in accordance with the selected indicators implemented within the project on "Indicators for Sustainable Development of Aquaculture and Guidelines for their use in the Mediterranean" (InDAM project). As a precondition for the application of the AZA principle, a pilot study was conducted during 2013 on the identification of indicators for sustainable aquaculture in Montenegro (Indicators and AZA identification) with the participation of researchers, decision-makers, and professionals involved in the aquaculture sector in Montenegro, during which consideration was also made on the economic and social aspects.

This paper aims to (1) present the process of work and application of AZA principles in Montenegro (2) present the results of numerous environmental analyses conducted on the open sea of the Montenegrin coast, and (3) be an example of good practice in knowledge transfer in the field of aquaculture at the Mediterranean level.

Keywords Adriatic Sea, Aquaculture, AZA, Indicators, Montenegro, Site selection

1 Introduction

The identification of aquaculture zones is one of the crucial factors for the successful and long-term operation of the farm, the sustainability of the sector, and proper spatial planning. Within the numerous analyses that need to be conducted in order to define with certainty a zone suitable for aquaculture, the precondition is the ecological, ecosystem and holistic approach, but also to apply as many tools and methodologies as possible. The latter is especially important for overcoming the potential risks and conflicts posed by fish farming, ensuring quality and safe production, and for the sustainability of the sector and ensuring investment.

An Allocated Zone for Aquaculture (AZA) is defined as a "marine area where the development of aquaculture has priority over other uses, and therefore will be primarily dedicated to aquaculture" [1]. There are several aspects that are crucial for the quality implementation of the AZA principles – these are the legislation, the existence of spatial plans for marine area, the social and economic component as well as the interaction with the other activities along the coastal zone, the availability and evaluation of environmental data, and the established monitoring system. In 2012 the GFCM adopted a specific resolution (i.e., Res. GFCM/36/2012/1) that provides guidelines on the AZA implementation and create the basic framework (FAO 2012) to guide the countries in its establishment [2].

According to the FAO global aquaculture fish production in 2018 was about 82.1 million tons, dominated by 54.3 million tons of finfish; mollusk production about 17.7 million tons, and crustacean production about 9.4 million tons [3]. Total production decreased compared to the period up to 2000, so it is estimated that production growth in the 2001–2018 period was around 5.3% [3]. However, although reduced, the production is constantly growing. The role of farming and the demand for farmed fish is most clearly seen when compared to the production of certain types of meat. For example, the global production of veal and beef in 2019 was about 70.4 million tons (source: statista.com), which is about 20% higher than the amount of fish produced, but the consumption of these types of meat per capita is significantly higher than fish consumption.

Meat and fish are the main source of high-quality protein, and the consumption of fish is especially recommended due to its positive effects on human health. Fish is a food of exceptional nutritional value, providing high quality protein and a wide variety of microelements. Fish is the major source of the LC n-3 PUFA eicosapentaenoic acid (EPA, C20: 5 n-3) and docosahexaenoic acid (DHA, C22: 6 n-3), to which many health effects are attributed [4, 5]. In addition to being the major source of n-3 LC PUFA, fish and other seafood also have a well-balanced amino acid composition, contain high proportions of taurine and choline, vitamins D3 and B12, and the minerals calcium, phosphorus, iodine, and selenium [6]. Due to these facts, but also very favorable geographical and environmental conditions, one of the strategic goals of the fisheries development is the development of a fish farming sector in the open sea [7].

One of the basic preconditions for defining aquaculture zones is the existence of documents and spatial plans that cover the topic of Marine Spatial Planning (MSP). MSP is a place-based, multi-sectoral decision-making approach that is being widely promoted for reducing the conflicts and impacts commonly encountered in conventional sector-by-sector planning [8]. This is especially important in countries that have developed tourism or for which tourism is a priority activity, as is the case with Montenegro. The coastal area is under increasing pressure from different sources – pollution, intensive and/or illegal construction, and other anthropogenic activities leading to conflicts between different sectors competing for the same area. Given that the coastal area is limited and finite in physical and spatial terms, long-term planning is extremely important both for the development of the sector and for the conservation of resources.

There are numerous papers that have dealt with the topic of spatial planning and zoning in aquaculture. Particularly important are those that have dealt with the importance of maritime spatial planning and integrated coastal zone management, the efficiency of spatial planning and the possibility of cohesion and "multi-use maritime spatial planning" [1, 8–10], as well as sustainable management in aquaculture [11–14]. In addition to respecting the principles and indicators for the development of sustainable aquaculture, special attention should be paid to the impact of farming on the marine ecosystem. As marine aquaculture can have significant positive and negative impact on the ecosystem and human health [15], in order to preserve good environmental status, it is necessary to overcome all possible conflicts in the coastal zone and the use of the sea, but also to give suggestions on production capacity, farmed species, and measures for the preservation and improvement of the marine ecosystem.

As a precondition for the application of AZA according to the FAO-GFCM principles in the selection of new locations for aquaculture in Montenegro, within the frame of the AdriaMed and InDAM[1] projects implemented by FAO-GFCM in 2013 a case study was implemented with the aim of identifying and pre-selecting indicators to be used at the farm, on a local and national scale through a methodology adapted to the Montenegrin context. In particular, this case study also provided an opportunity to identify criteria that could be applied in the identification of allocated zones for aquaculture (AZAs) [16].

After the realization of the pilot project case study in Montenegro in 2013, the development of the *Special Purpose Spatial Plan* for the *Coastal Zone* of Montenegro [17] was worked on over the next 2 years, in which potentially suitable locations for mariculture on the open sea of the Montenegrin coast were defined.

On just over 300 km of coastline, 10 potentially suitable localities have been defined, which are summarized in 4 zones (Zones I-IV), and which are still the subject of detailed research into the possibilities of mariculture development. This

[1]InDAM FAO-GFCM project (*Indicators for the sustainable development of aquaculture and guidelines for their use in the Mediterranean)* was supported by the European Union under Grant Agreements SI2.514971, SI2.577103, SI2.636975, and SI2.695832.

Fig. 1 Investigated locations for the application of AZA principles (yellow marks) (Source: Google Earth)

paper will present the results of research activities in Zone I, which includes 3 suitable locations for mariculture development in the zone of the Boka Kotorska Bay which is under the influence of the waters of the open sea (Fig. 1).

2 Material and Methods

2.1 Study Area

The research was conducted at three locations in the contact zone between the exit from the Boka Kotorska Bay area and the open waters of the Montenegrin coast (Fig. 1, Table 1). The locations are defined in the *Special Purpose Spatial Plan* for the *Coastal Zone* of Montenegro as zones suitable for mariculture.

Table 1 Geographical coordinates of investigated locations (in WGS system)

Station	Longitude	Latitude	Maximum depth [m]
Rose	18° 32′ 55,6″E	42° 25′ 29,30″N	30
Dobreč	18° 33′ 24,67″E	42° 24′ 43,75″N	35
Mirišta	18° 34′ 31,04″E	42° 23′ 39,57″N	26

2.2 Methodology

The methodology that was used in this work refers to the application of Allocated Zones for aquaculture [18] following the ecosystem approach principles applied to aquaculture.

The procedure of the work was as follows:

1. Ecological–baseline study ("zero state") at three locations which are defined in the *Special Purpose Spatial Plan* for the *Coastal Zone* of Montenegro.
2. Comparative analysis of all obtained results and the definition of a suitable zone in accordance with AZA principles.
3. Identification of the AZA.

In order to prepare the detailed baseline study, several ecological and hydrological parameters of the sea were analyzed:

– Basic physico-chemical parameters were analyzed by monthly dynamics (temperature, salinity, dissolved oxygen content, total suspended matter).
– The microbiological (sanitary) quality of sea water was analyzed on a monthly basis.
– The qualitative and quantitative composition of phytoplankton and ichthyoplankton was analyzed by monthly dynamics.
– Characteristics and specifics of the seabed: benthic research (phytobenthos and zoobenthos), heavy metal content in sediment and sediment granulometry were analyzed twice a year.
– Oceanographic research (direction of sea currents, wave height, dynamics of water masses.

For the needs of these analyses, a comparative research and compilation of all existing data was done, as well as an analysis of basic and administrative data, which included:

– Basic data on maritime transport, coastal infrastructure or accessibility of the zone (connection with roads, ports, airports, possibility of transport, availability of water and electricity).
– Analysis of conflict with other sectors.
– Protected areas (natural parks, RAMSAR areas, areas of special importance),
– Underwater archeological sites,
– Traditional fishing zones.

Due to the large amount of data obtained during the research, this paper will summarize some of the data that are most important biologically and ecologically for defining new locations and development of the mariculture sector in the zone of the Boka Kotorska Bay which is under the influence of the waters of the open sea.

3 Results

3.1 Environmental Study

Analyses of basic physico-chemical parameters of the sea (oxygen concentration, oxygen saturation, total suspended matter), as well as determination of nutrient content (nitrites – NO_2^-, nitrates – NO_3^-, ammonium ion – NH_4^+ and phosphates – PO_4^{3-}) showed that throughout the research period (January–December 2019) the water quality corresponded to a very good ecological status. The categorization was done in accordance with the Rulebook on the manner and time constraints for determining the status of surface waters [19].

3.1.1 Microbiological Analyses

Analyses of fecal coliform bacteria, *E. coli* were performed according to MEST EN ISO: 9308-1: 2015 standard and intestinal enterococci according to MEST EN ISO: 7899-2: 2011 standard by membrane filtration method. The results were analyzed in accordance with the Regulation on Classification and Categorization of Surface and Groundwater [20], and according to Article 8 on the quality of water that can be used for shellfish farming. At all three locations, the number of sanitary pollution indicators was very low or below the limit of detection for the method during the entire research period (January–December 2019).

3.1.2 Phytoplankton

Analyses of phytoplankton organisms were performed according to MEST EN 15204: 2014 standard. The analysis of phytoplankton showed characteristics of the mesotrophic area [21, 22]. The increased density of phytoplankton cells was present at the Rose location, probably as a consequence of the environment of the Bay. At the other two locations the dynamics of water masses is stronger, which led to a lower density of phytoplankton. Most of the dominant species (*Chaetoceros affinis, Pseudo-nitzschia* spp. and *Thalassionema nitzschioides*) are characteristic of nutrient-rich areas [23–25]. Of the toxic species, *Lingulodinium polyedra, Phalacroma rotundatum* and *Prorocentrum cordatum* were reported, but in small numbers (up to 160 cells/l). The recorded numbers of phytoplankton organisms, as well as the number of toxic species indicate lower productivity of algae in the study area, and thus the absence of any danger of excessive growth of algae, or the appearance of their blooming.

3.1.3 Diversity of Benthic Communities (Phyto and Zoobenthos)

The research of phytobenthos was performed by autonomous diving at three locations shown in Fig. 2. At all three locations: Rose, Dobreč, and Mirište, two transects 100 m long and 5 m wide were investigated. Some of the taxa were identified in situ and some specimens were sampled and determined in the laboratory.

3.1.4 Rose Location

In the mediolittoral zone, a solid rocky substrate was present that turns into large stones in the upper infralittoral zone. A total of 12 algal taxa and one seagrass (*Posidonia oceanica*) were found. Of the algae, it is important to note the presence of two protected species according to the Barcelona Convention (*Cystoseira amentacea* – Fig. 3 and *Cystoseira corniculata* f. *Laxior* – Fig. 4), although both were present in small numbers.

According to the [26] classification, the measured densities of *Posidonia oceanica* were 144, 160, 160, and 128 shoots/m^2, which represents a low density, while the total conservation index (CI) was good at 0.73 [27, 28].

The rocky substrate was inhabited by sea urchins *P. lividus*, while the sandy substrate was characterized by the shells of dead mollusks and echinoderms. Analysis of the content of animal species present in benthic communities showed the

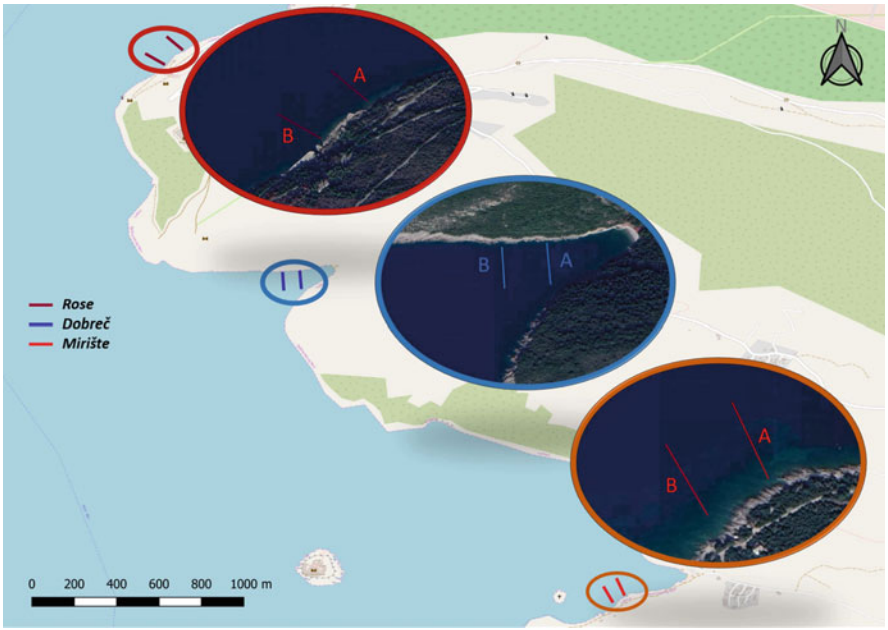

Fig. 2 Transects of investigation of benthic communities

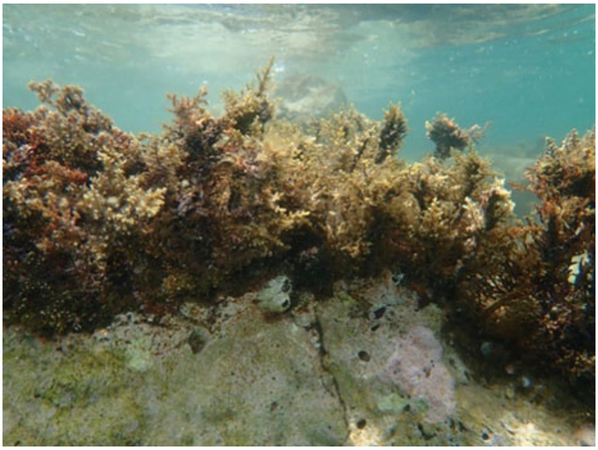

Fig. 3 *Cystoseira amentacea* (Photo by V. Mačić)

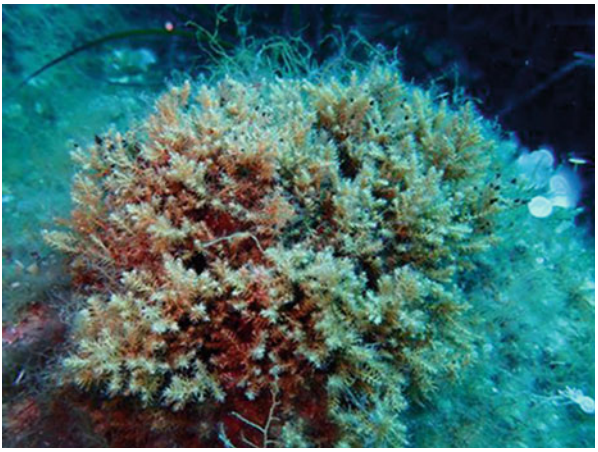

Fig. 4 *Cystoseira corniculata* (Photo by V. Mačić)

presence of all major macrozoobenthic groups. A total of 52 species were identified from the groups Porifera 13, Cnidaria 4, Mollusca 16, Annelida 5, Arthropoda 1, Bryozoa 3, Echinodermata 7, and Tunicata 3 species (Figs. 5 and 6).

Among the protected species in the Rose locality were found: *Aplysina aerophoba, Spongia (Spongia) officinalis, Cladocora caespitosa, Lithophaga lithophaga,* and *Paracentrotus lividus.*

3.1.5 Dobreč Location

In the coastal part of the investigated transects there were a rocky substrate and larger stones, while in the deeper parts there was a sandy substrate.

Out of the three investigated locations, at the Dobreč location, the largest diversity of phytobenthos species was found, more precisely 26 species of algae and two

Fig. 5 *Thuridilla hopei* (Photo by S. Petović)

Fig. 6 *Ova canalifera* (Photo by Photo by S. Petović)

seagrasses. Of the protected species at this site, 4 species of Cystosira were found: *Cystoseira amentacea*, *C. corniculata, C. foeniculacea* (Fig. 7), and *C. spinosa* (Fig. 8). In addition to these protected species, two invasive algae were found: *Caulerpa cylindracea* (Fig. 9) and *Womersleyella setacea* (Fig. 10), which were present in some places, mainly in the deeper parts of the investigated transects.

On both investigated transects, only patches of seagrass *Posidonia oceanica* were present, in parts from 12 to 25 m depth.

Analysis of the composition of animal species present in benthic communities showed the presence of all major macrozoobenthic groups. A total of 53 species were identified, of which 14 were from the group of Porifera, Cnidaria 5, Mollusca 14, Annelida 4, Arthropoda 1, Bryozoa 3, Echinodermata 9, and Tunicata 3 species. Of the protected species, the following were found: *Pinna nobilis, Axinella damicornis, Ophidiaster ophidianus, Cladocora caespitosa, Balanophyllia europaea, Madracis pharensis, Tonna galea,* and *Lithophaga lithophaga*.

Fig. 7 *Cystoseira foeniculacea* (Photo by V. Mačić)

Fig. 8 *Cystoseira spinosa* (Photo by V. Mačić)

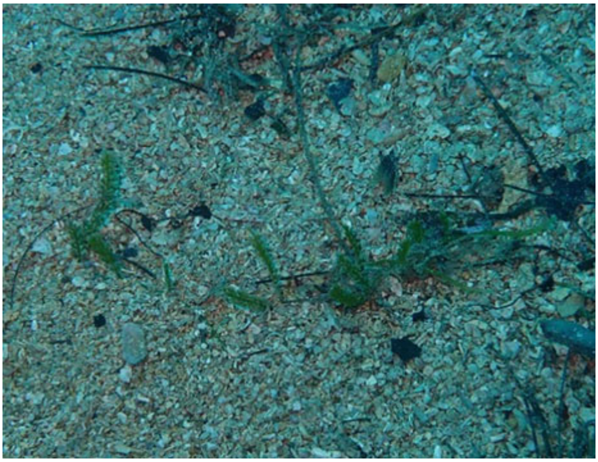

Fig. 9 *Caulerpa cylindracea* (Photo by V. Mačić)

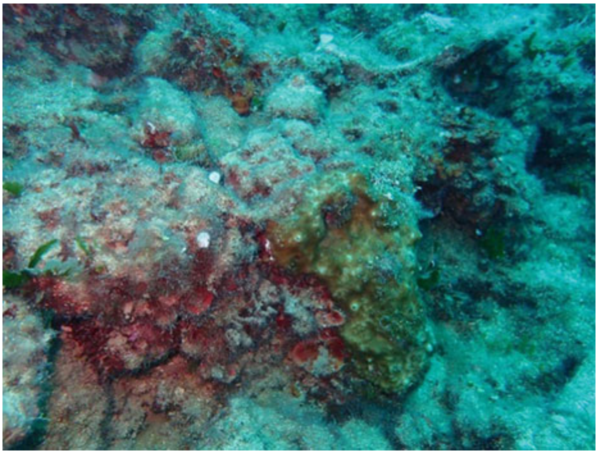

Fig. 10 *Womersleyella setacea* (Photo by V. Mačić)

3.1.6 Mirišta Locality

Only ten species of phytobenthos were found at this location, of which two were seagrasses. The narrow coastal part of the investigated transects is represented by a rocky substrate, followed by a sandy substrate with mosaic posidonia meadow. In this part of the investigated transect, small settlements of the invasive alga *Caulerpa cylindracea* were also found. The density of posidonia was measured at a depth of 9 m and was: 336, 288, 304, and 320 shoots/m^2, which represents a low density of settlements. The conservation index shows that the condition is good, but the research showed significant degradation of settlements in the shallower parts of the investigated transects.

The identification of the animal species showed that this area is inhabited by representatives of all major invertebrate phylums. Systematic affiliation was determined for a total of 36 species. Of this number, Porifera was present with 7 species, Cnidaria 1, Mollusca 15, Annelida 2, Arthropoda 1, Bryozoa 1, Echinodermata 8, and Tunicata 1. Among the protected species the following were found: *Spongia (Spongia) officinalis, Lithophaga lithophaga, Pinna nobilis, Holothuria (Roweothuria) poly,* and *Ophidiaster ophidianus*.

3.2 Hydrodynamics of Water Masses

3.2.1 Analysis of the Movement of Surface Sea Currents

From the geographical and oceanographic point of view, the Boka Kotorska Bay represents a semi-enclosed basin with specific hydrographic and dynamic characteristics. Communication with the open Adriatic takes place through the passage of Cape Oštra–Cape Mirište, which is only 2,794 m wide. The entire bay is characterized by relatively large depths in the bay area, and communication straits between individual bays. The exceptions are the marginal parts of Herceg Novi Bay (Topljanski Bay) and Tivat Bay (Krtoli and Podpolja bays), which are characterized by shallow depths and limited water circulation.

Compared to the open Montenegrin Sea, this basin shows its specifics in certain climatological, hydrological, and hydrographic elements. This conditions large annual, seasonal, monthly, and daily variations of physical and oceanographic characteristics of the sea, which is why determining some changes and processes is very complex.

The main source of data on currents and most other oceanographic parameters for the Boka Kotorska Bay are still measurements and studies done during the eighth decade of the last century for the purpose of Montenegrin coastal sewerage solution project, as well as measurements and studies done independently of this project at the Hydrographic Institute of the Yugoslav Navy (HIJRM) in the second half of the last century.

The exception is the measurement of sea surface currents by drifters performed in 2016 and 2017 by the Institute of Marine Biology, which was conducted within the project BIO-ICT – Center of Excellence in Bioinformatics.

The results of water mass dynamics in the southern part of Herceg Novi Bay were derived based on the analysis of the general flow of currents in February and November (Figs. 11 and 12), which was obtained on the basis of individual depth

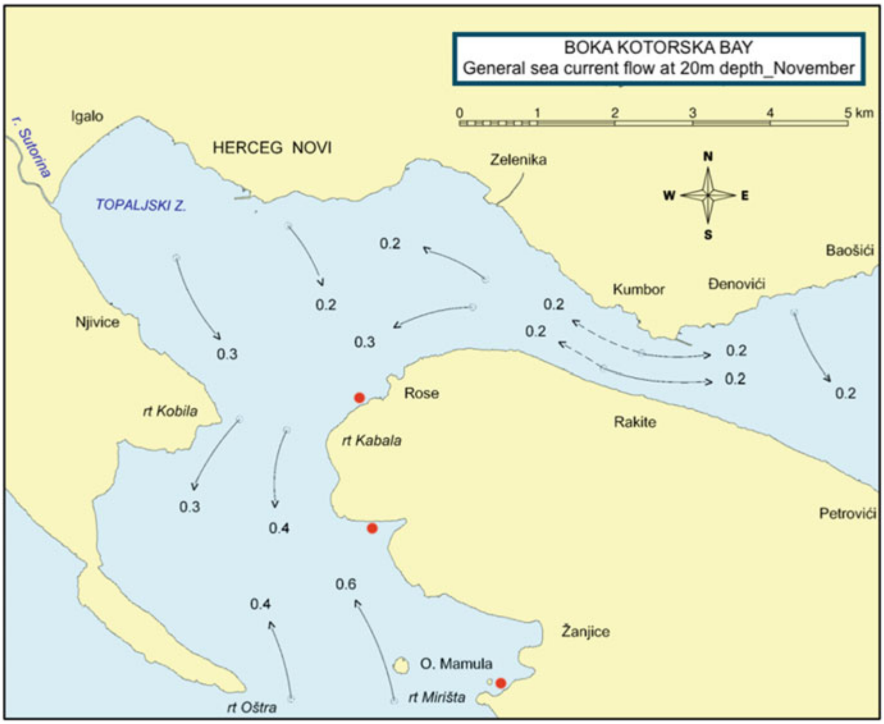

Fig. 11 General sea current flow at a depth of 20 m for the month of November (velocities in knots) with marked potential aquaculture sites (red dots), modified from [29]

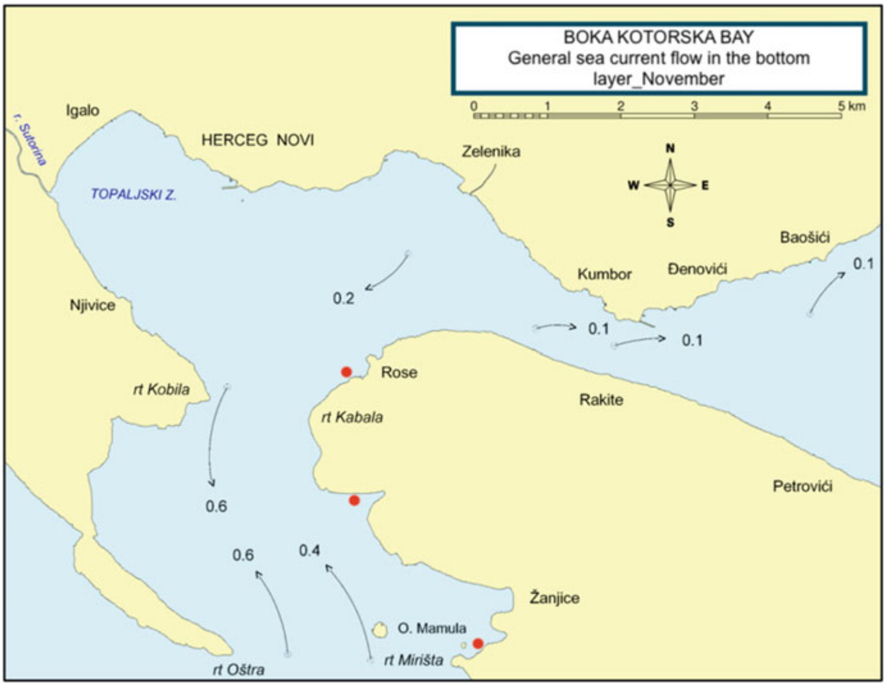

Fig. 12 General sea current flow at a bottom layer for the month of November (velocities in knots) with marked potential aquaculture sites (red dots), modified from [29]

measurements at 35 stations; a 24-h series of measurements in February at the southern entrance to the bay and two 24-h series of measurements in July at the junction of Cape Kobila–Cape Kabala (these two 24-h measurements were performed with current meters hung on an oceanographic buoy with registrations every 5 min).

The general flow of water in the Bay of Herceg Novi, both in February and in November, shows a great dependence on the influence from the open sea, and especially on the influence of tidal currents. While in the surface layer and in the layer of 5 m depth there is an intense output current of 0.6 to 0.8 knots (31 to 41 cm/s), in the bottom and depth layer there are input–output currents of 0.3 to 0.6 knots (16 to 31 cm/s).

During February, the influence of the winter input current is evident. In the surface layer, the average value of the input direction speed is 0.34 (18 cm/s) and the output value is 0.5 knots (26 cm/s). These values decrease with depth to 0.15–0.28 knots (8 to 15 cm/s) and change direction at approximately equal intervals. In the deep bottom layer, the input direction with medium speeds predominates, as in the middle layer.

The maximum speed was measured in the surface layer and is 0.7 knots (36 cm/s) and in the deeper layers it does not exceed 0.4 knots (21 cm/s).

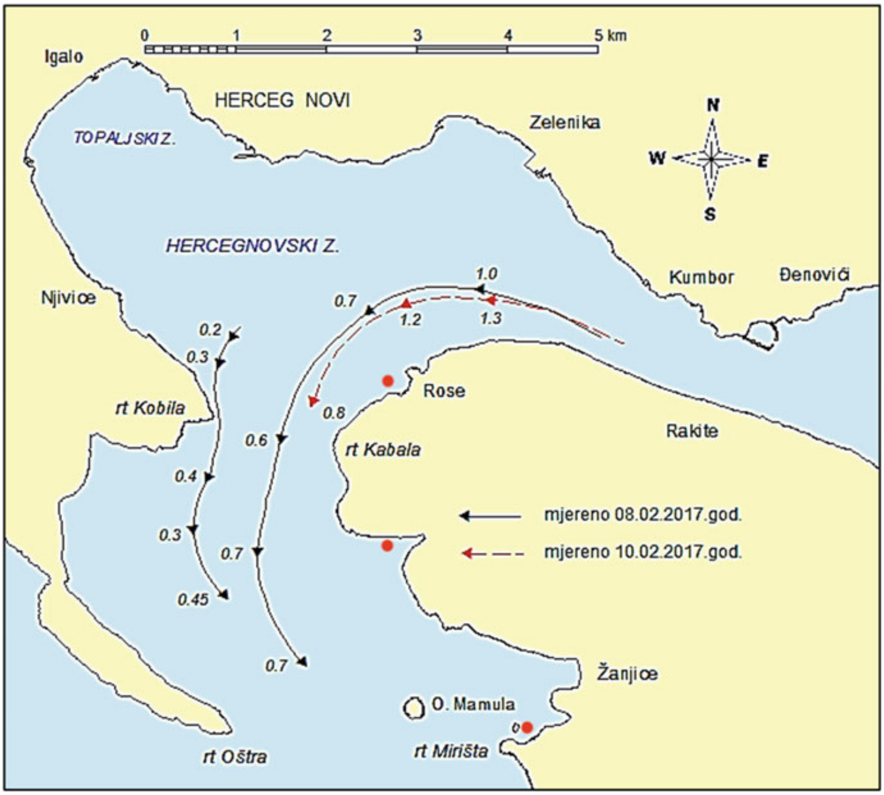

Fig. 13 Surface sea currents measured by drifters in February 2017 (velocities in knots) with marked potential aquaculture sites (red dots)

Measurements of sea surface currents by drifters performed in February 2017. (Fig. 13) confirmed the fact that, in the winter, in the surface layer, there is a strong outflow current as denivelation current caused by large inflows of fresh water through heavy rainfall and underwater springs which are present in the bay.

In Fig. 13, it can be seen that measurements from February eighth showed that the current along the western coast of the entrance in the bay has lower intensity in the range of 0.2 to 0.45 knots (10 to 22 cm/s). Along the eastern coast, a higher surface current speed in the range of 0.7 to 1.0 knots was registered (36 to 47 cm/s).

Measurements performed on February tenth registered a significantly stronger surface output current in the area of the Rose location with speed ranging from 0.8 to 1.3 knots (40 to 70 cm/s).

In both cases, the speed of the current is highest at the exit from the Kumbor Strait and then decreases slightly towards the exit from the bay.

The measured directions and velocities of sea surface currents in this area confirm the advantage of the proposed locations for mariculture in terms of the positive effect of currents on reducing the effect of pollution caused by farms.

Analyses of 24-h measurements from stations at the Cape Kabala–Cape Kobila junction also show intensive dynamics in all water layers.

3.2.2 Bathymetry

An important characteristic of the whole bay is the approach of isobaths of greater depths at small distances from the shoreline. For example, the 20-m isobath follows the configuration of the coastline at a distance of 200 to 300 m, except in the southeastern part of Tivat Bay and the northwestern part of Herceg Novi Bay. This bathymetric characteristic enables the stratification of certain oceanographic parameters and the creation of a thermocline and a pycnocline in certain seasons during the year.

The bathymetry at the Rose location (Fig. 14) is characterized by a relatively large depths in front of the coast: the 20 m isobath is only 45 m away from the shoreline, and the 30 m isobath approaches the shoreline at only 82 m. At such depths in certain periods of the year there is a stratification of the water mass, i.e., the formation of a thermocline and pycnocline already in the immediate vicinity of the shore, which favorably affects the intensity of diffusion and dilution of waste materials from the cage to the sea before reaching the surface.

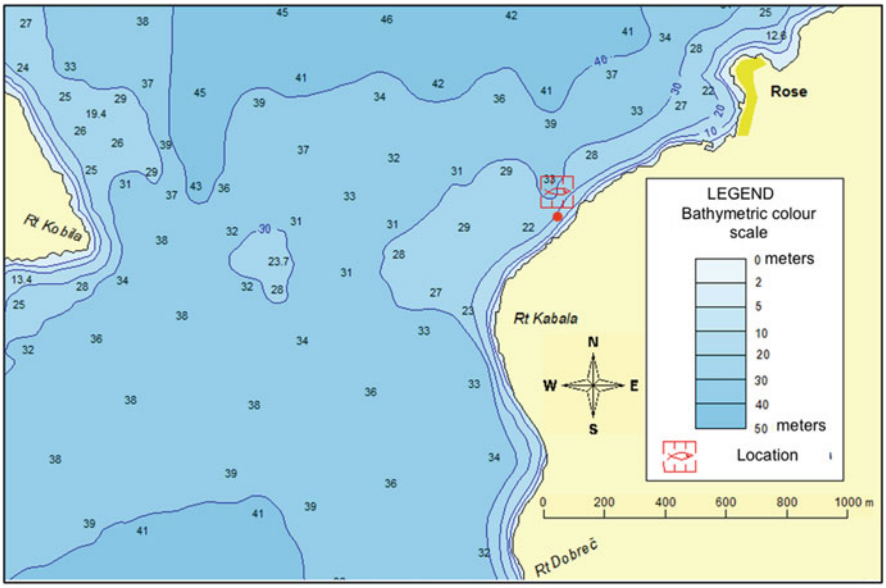

Fig. 14 Bathymetry at Rose location modified from [30]

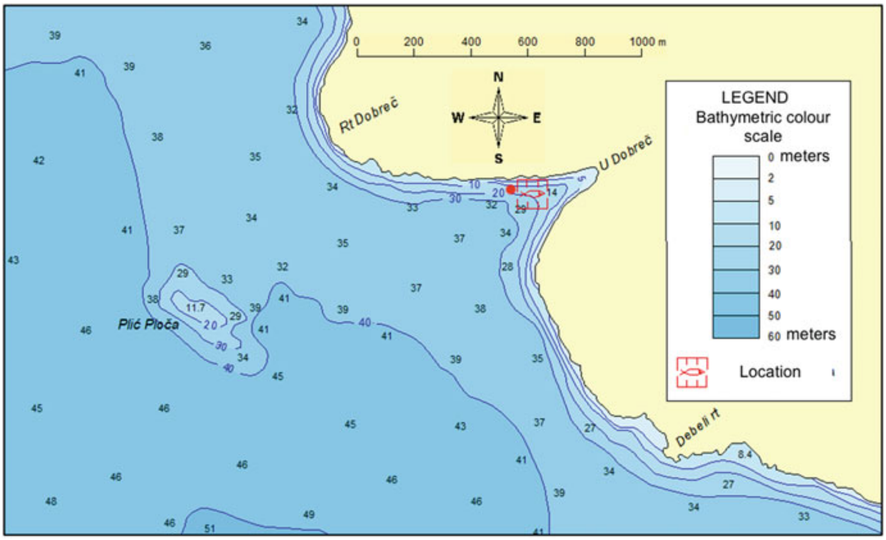

Fig. 15 Bathymetry at Dobreč location modified from [30]

The bathymetry at the Dobreč location (Fig. 15) has similar characteristics to the Rose location: the 20 m isobath is 52 m from the shoreline. In these waters, in certain periods of the year, the water mass will be stratified, i.e., the formation of a thermocline and pycnocline, which will favorably affect the intensity of the process of diffusion and dilution of waste materials that reach the sea from the cage.

The bathymetry at the Mirišta location (Fig. 16) is also characterized by relatively large depths in front of the coast: the 20 m isobath is 70 m away from the shoreline.

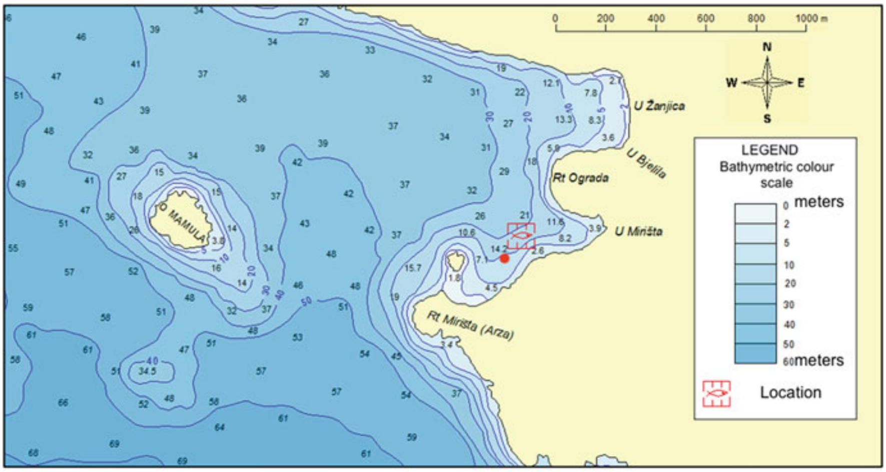

Fig. 16 Bathymetry at location Mirišta modified from [30]

At such depths in certain periods of the year there is a stratification of the water mass, i.e., the formation of a thermocline and pycnocline already in the immediate vicinity of the coast, which favorably affects the intensity of diffusion and dilution of waste materials from the cage into the sea.

It is important to emphasize that the temperature stratification occurs during the warmer period of the year, during the greatest pressure on the marine ecosystem in the bay due to the multiplied number of inhabitants during the tourist season.

A general characteristic of the entrance to the Boka Kotorska Bay, where potential aquaculture sites are located, is the openness to the southern wind from the direction of the open sea. The fetch for waves from these directions is very long and stretches across the entire Adriatic all the way from the Italian coast. Therefore, the destructive waves from the southern directions towards this area will advance directly from the open sea, undisturbed by any obstacles (Fig. 17).

Such a situation with southern winds can be expected only in the winter months, when strong winds are possible, which blow continuously for longer periods of time. The bora in this area blows strongly and in gusts, but the waves of the bora have limited space for development, so heights of no more than 1 m under conditions of stronger wind gusts should be expected, and only in front of the Rose location. The bora waves in this area are short, steep, and with a pronounced crest.

Fig. 17 Illustration of exposure of suitable mariculture sites to waves from the open sea (Source: modified from Google Earth)

Mistral waves are very frequent, especially in the summer months. However, since the short fetch for their development is not favorable, they do not pose a problem for navigation and other activities in this area. The strongest maestral can be expected in the Mirišta location.

The Rose location is the only one partially sheltered by Cape Kabala from the direct impact of waves from the southern directions, but even there, due to diffraction and refraction, the southern wind will create heavy sea and high waves. This position is exposed to the north, but due to the relatively short fetch, waves caused by the bora no larger than 1 m can be expected there.

The Dobreč location is completely open to the south and destructive waves from the southern direction can be expected there. This position is sheltered from bora waves, and the maestral has a short fetch, so it cannot create larger waves.

The Mirište location is also exposed to waves from the southwest direction (SW), which will be destructive in extreme cases. Waves from other southern directions (S, SE) will also create high waves in the bay due to refraction, diffraction, and reflection from the northern shore of the bay. It is well sheltered from the bora, while the maestral has a longer fetch than the other two locations, but not so much as to develop waves larger than 1 m.

In general, the entire area from the Rose location to Mirište is exposed to destructive waves from the south, and this should be kept in mind when designing and building infrastructure and mariculture facilities.

3.2.3 Tides

On the Montenegrin coast, the mean amplitude of tides (the difference between mean high waters and mean low waters) is 23 cm. The mean amplitude between the mean higher high waters and the mean lower low waters is 29 cm. The amplitude between the highest and lowest monthly mean values is 64.1 cm.

The absolute registered extremes in relation to the chart datum to which the depths on the nautical charts have been reduced are 87 cm above and 42 cm below the hydrographic level. It follows that the maximum registered amplitude of sea level change off the coast of Montenegro, caused by tides, is 129 cm.

For the Herceg Novi Bay, there is no long-term data that could be used for the analysis of tides. However, due to the small distance and the high speed of the tidal wave, data from the permanent tide gauge station in Kotor can be used for this purpose.

For Kotor Bay, there are old data on the four-year measurement of tides, according to which the maximum sea level above mean sea level was 74 cm, and the minimum sea level below sea level was 52 cm, which means that in that four-year period the range was 126 cm.

On May 15th, 2010, the Hydrometeorological Institute of Montenegro established a permanent tide gauge station in the Port of Kotor, where the sea level is registered every 6 min (Table 2).

Table 2 Significant sea levels registered in Kotor in the period May 2010–March 2016

Absolute maximum	185.0 cm
Absolute minimum	67.0 cm
Maximum range	118.0 cm
Medium Sea level	115.5 cm

Values are in cm above the mareographic zero

A similar range of sea level due to the influence of sea changes can be expected at the entrance to the Boka Kotorska Bay (area of three locations intended for mariculture), which should be kept in mind when designing and building mariculture facilities on the coast, as well as planning the length of anchoring ropes at sea.

3.3 Analysis of Heavy Metals in Sediment

According to this study, obtained results of the heavy metals analyses in sediment at all three locations during four seasons in 2019 show that Fe concentration was 6,347–12,586 mg/kg; Mn 307–436 mg/kg; Zn 9.2–42; Cu 7.2–15.2 mg/kg; Ni 42.5–82.5 mg/kg; Pb 9.2–26.7 mg/kg; Cr 28.4–89.2 mg/kg and Hg $<$ LOD-0.08 mg/kg. The results showed that there are differences in the concentrations of the tested elements in the sediment at the investigated sites.

In the absence of domestic criteria for assessing the quality of in situ sediment, the assessment was made referring to the legal framework of the European Union and standards for sediments of developed countries (Canada, Netherlands, UK and others), as well as to the comparison of the sediment quality with data published in the region. Here are, for comparison purposes only, the standards prescribed by the British Center for Environment, Fisheries and Aquaculture – CEFAS, which refer to the disposal of excavated material, as well as the Canadian quality criteria prescribed in the Guide for sediment quality to protect the aquatic world (Canadian Sediment Quality Guidelines for the Protection of Aquatic Life) [31, 32].

The Canadian recommendations address two levels of assessment. The lower level of ISQG [32] is the limit below which the adverse effects of contaminants on aquatic organisms can be expected, but rarely (say in cases of sensitive species). Such sediments are of acceptable quality and no further sediment quality testing is usually required. The higher level of PEL (Probable Effect Level) is the concentration above which the sediment represents a significant and immediate danger for exposed organisms.

Based on the obtained values, we see that the concentrations of most of the analyzed elements are below the maximum allowed values. The examined sediment is loaded only with chromium content at the Mirište location as well as nickel at the Rose and Mirište locations, i.e., nickel and chromium concentrations are above the level of action 1 according to CEFAS and the Rulebook of Montenegro [33].

3.4 Sedimentological Analyses: Granulometric Composition of Sediment

For the needs of granulometric analysis, surface sediment was sampled using a Ponar grab measuring 15 × 15 cm with a volume of about 2.4 l. With this grab, sediment can be sampled up to a depth of 70 mm.

Sediment sampling and analysis were performed in accordance with the recommendations set out in the UNEP/MAP Manual for Sediment Sampling and Analysis [34].

According to the Udden-Wentworth scale of sediment classification, sand and mud fractions were present in all sediment samples at all investigated locations. The sediment of the Dobreč and Rose sites was dominated by sand fractions with a share of over 90%, while the share of mud was insignificant. Analyses of sediment at the Mirišta location showed 63.2% of sand, and the rest was mud. At the Rose location, larger fractions of sand predominated in relation to the Dobreč location, while at the Mirište location the significant presence of fine-grained sand fractions was found.

According to Folk's classification, the sampled sediment at the Dobreč and Rose locations was sand, while at the Mirišta location the sediment type was muddy sand.

The highest average grain size was present in the sediment at the Rose location, which belongs to the category of coarse sand, and the lowest average grain was present at the Mirište location, which belongs to the fraction of very fine sand. At the Dobreč location, the average grain size in the sediment ranges from fine to medium sand, according to Udden-Wentworth scale [35].

3.5 Qualitative and Quantitative Composition of Ichthyoplankton

The study of ichthyoplankton diversity conducted at three mariculture locations in the period from January to May 2019 confirmed the presence of early developmental stages of 14 different fish species, while two species remained determined only by genus, and one was undetermined. The most numerous species belonged to the families Sparidae, Scombridae, Labridae, Clupeidae, and Engraulidae, i.e., species of high economic value. Each investigated position was positive for ichthyoplankton findings, while the diversity and number of species varied depending on the position.

The Shannon diversity index (H') and the Simpson reciprocal index (D) were calculated at the species level by location [36, 37]. The calculated values of the Shannon diversity index ranged from 0.0 to 1.68, while the Simpson reciprocal index ranged from 1.0 to 4.80.

The research conducted in the period from June to December 2019 confirmed the presence of early developmental stages of 30 different fish species (Fig. 18). Three species remained determined only up to the genus level, one up to the family level,

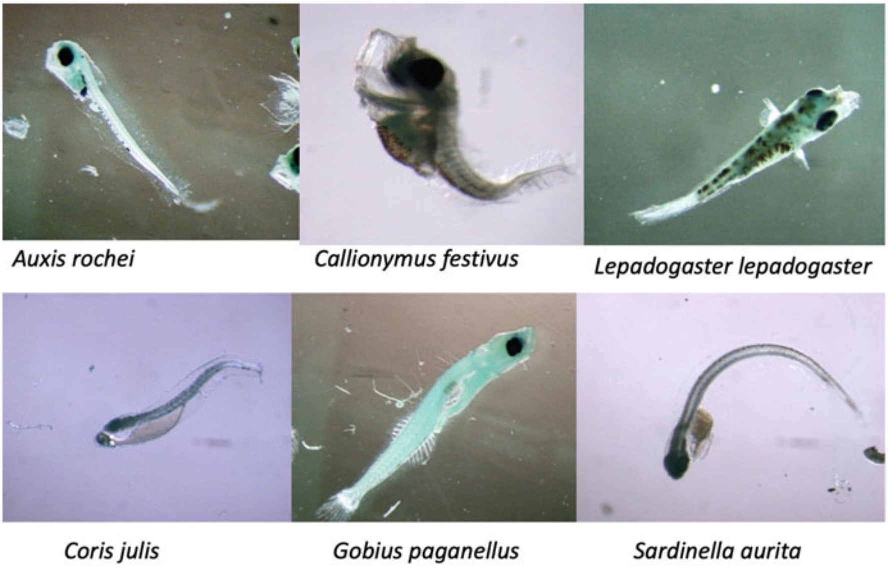

Fig. 18 Some representatives of fish larvae found during the research (Photo by M. Mandić)

while one species was undetermined. The most numerous species belong to the families Sparidae, Pomacentridae, Labridae, Clupeidae, and Engraulidae.

The Shannon diversity index (H′) and the Simpson reciprocal index (D) were calculated at the species level by location. The calculated values of the Shannon diversity index ranged from 0.0 to 1.95, while the Simpson reciprocal index varied from 0 to 5.55.

3.6 Traditional Fishing Zones

In the vicinity of the Rose location, one traditional fishing post is present, with a total length of 70 m [38]. The fishing post is a place on the coast where a fishing net is pulled out. It is a part of the coast with a gravelly or sandy bottom, which is not fenced and where no pontoon or mule has been built, i.e., a place where the fishery net with a catch can be pulled ashore. Fishing posts are used exclusively at night and in the early morning hours, when fishing activity is performed in this manner. For the rest of the day, they can be used for swimming activities.

At a distance of 100 m from the fishing post it is forbidden to deposit stones, rubble, and other solid objects that would interfere with the extraction of the fishing net, nor should the sea be fenced with ropes, buoys, nor should strong street lights be placed near the post [38].

3.7 *Analyses of Basic Data*

For the purpose of collecting basic and administrative data, an analysis of the existing State Baseline Studies was conducted, which refer to the planning of the purpose of the areas within which the proposed locations for mariculture are located.

For detailed analyses of basic parameters, all available strategic documents relevant to the study were used: strategic plans and sector-specific studies, standards and technical studies and projects related to the subject matter, mapping, satellite images, and others.

3.7.1 Infrastructure

By the analysis of available data for road infrastructure, it was established that there is a road at the Rose location that represents a municipal road with a width of 4–5 m. Besides this road, there are remains of access roads or former military facilities from the Austro-Hungarian period, approximately 3.4–4 m wide, which could be used for the needs of the farm.

During 2019, the construction of the new Rose-Dobreč road began (Fig. 19), which can be used for the needs of the farm at the Dobreč location, while part of the

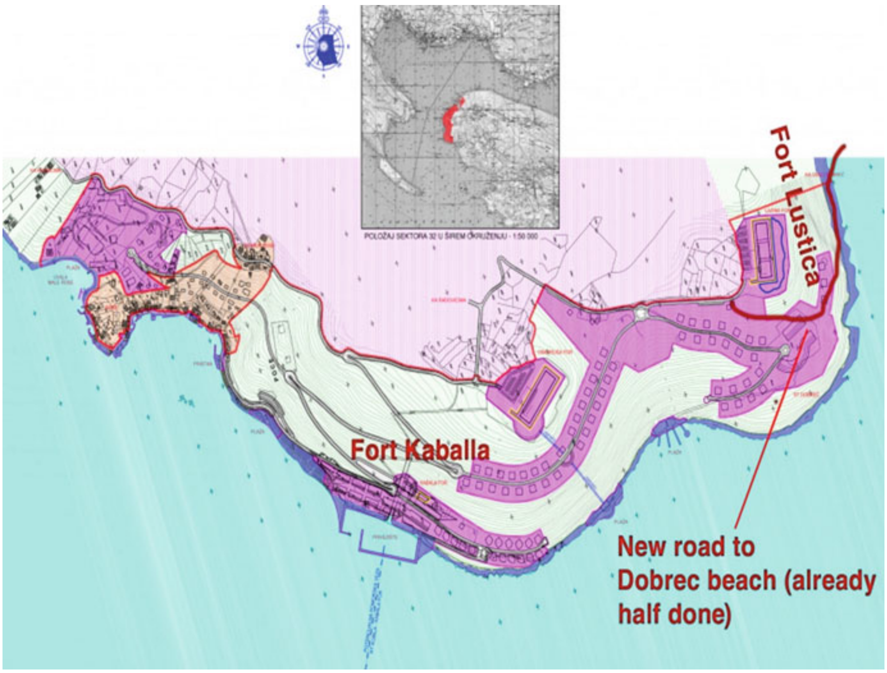

Fig. 19 Overview of road infrastructure and planned facilities (excerpt from the [39] with marked locations suitable for mariculture (red dots – Rose and Dobreč))

activities at that farm would be performed by marine transport. Given that the location is planned close to the coast, the sea route should not be a problem for future investors.

At the Mirište location, there are available roads that represent local roads from the direction of the Municipality of Tivat that can be used for the needs of the farm. Considering that the roads are in poor condition and only partially asphalted, and having in mind the complete tourist purpose of the area in which the Mirište location is located, a complete reconstruction of the roads and adaptation in accordance with the planned tourist facilities is planned.

3.7.2 Archeological Sites

One of the basic guidelines for the protection of the marine area is the existence of an archeological site. An amphora site is located at “Malo Rose” (near the Rose location) and is one of the 27 recorded archeological sites in the Montenegrin marine area [39]. The proposed mariculture location is located outside this archeological site, but it is certainly suggested that additional bottom research survey should be done immediately prior to the installation of breeding installations.

There are no archeological sites at the Dobreč location, while in the immediate vicinity of the Mirište location there are several significant underwater archeological sites that are located outside the zone of the planned farm.

3.7.3 Water Supply, Sewerage and Energy

In the area of the Luštica Peninsula (to which all 3 planned locations for mariculture belong), water was brought from the water supply system of the Municipality of Herceg Novi by submarine pipeline to the Pristan reservoir of 1,000 m^3, located in the northern part of the Luštica Peninsula. For the most part, including the Rose-Luštica area, it is not covered by the city’s water supply system. The Luštica peninsula, as well as the Rose settlement itself, is not covered by the water supply network. Water supply is solved individually, i.e., within each facility separately [39].

The area from Rose to Dobreč is not covered by the sewerage network, as well. Fecal communal water is drained from the facilities through “septic tanks,” which are in fact absorbent wells and two-chamber pits. As far as the Rose area is concerned, the Fortica facility has a sewer with a profile of 300 mm and a length of 50 m, with a discharge into the sea at a depth of about 10 m (Fig. 20).

The situation is similar with the Mirište location, where there is no organized sewerage system, but the solutions rely on the formation of septic tanks and/or direct sewage inflow into the sea. According to the plan of state studies of the location, the construction of a water treatment plant before discharge into the sea is planned.

There are no high-voltage (HV) power facilities in the area, as well; there is only a low voltage network in the area of “Malo Rose” for the needs of connecting

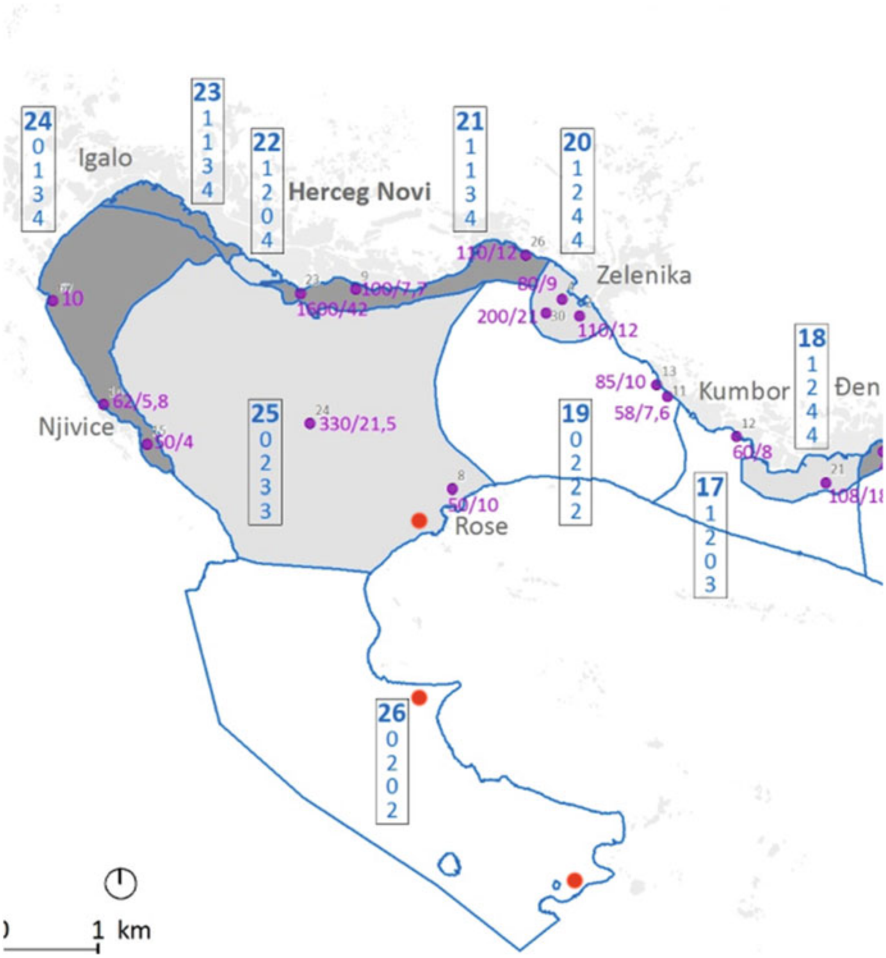

Fig. 20 Sewage outlets in Herceg Novi Bay, with a view of the existing outlet at the Rose location [40] and marked locations for mariculture (red dots)

individual residential buildings and public lighting on the landscaped shore with the pier. The area of the Luštica peninsula is characterized by frequent and strong atmospheric discharges, especially during summer storms, which result in frequent and long interruptions in the supply of electricity to the existing HV network configuration [39].

3.7.4 Marine Transport Route

In order to determine the conditions for accurately defining the spatial points (coordinates) for setting up a future fish farm, the following figure shows the marine

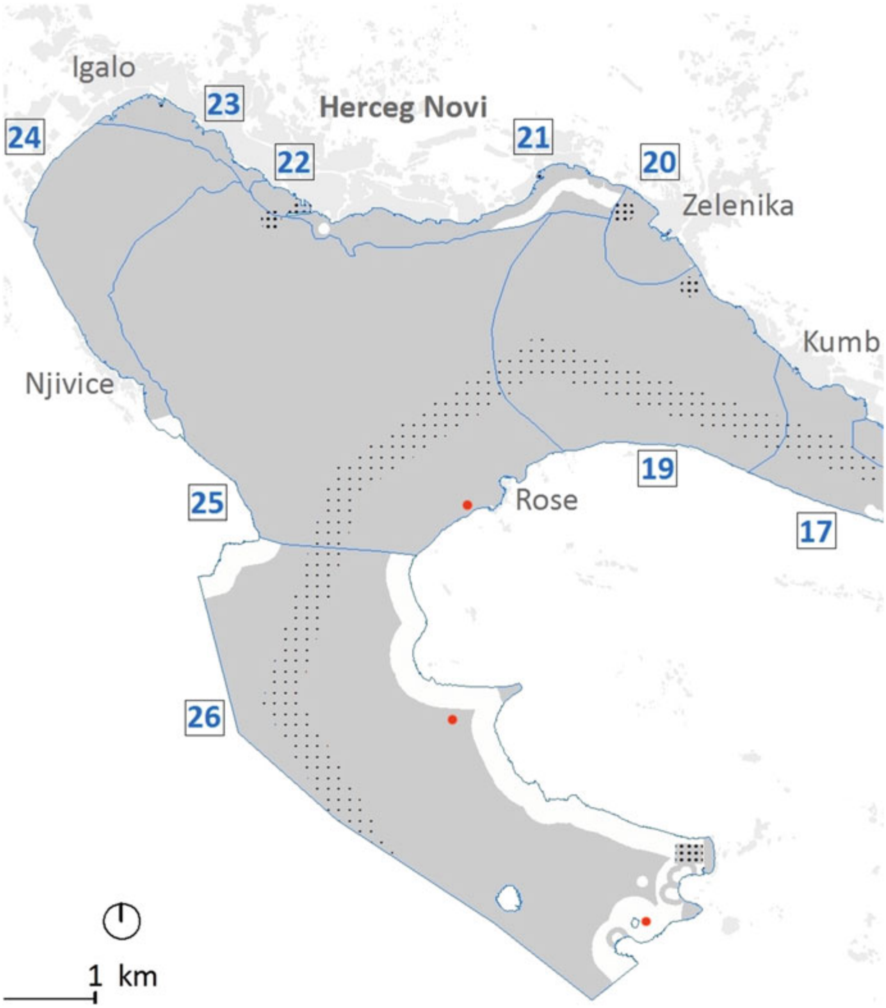

Fig. 21 View of the marine transport route at the entrance to the Boka Kotorska Bay [40] with marked locations for mariculture (red dots)

transport route at the entrance to the Boka Kotorska Bay (Fig. 21) with marked locations planned for mariculture.

3.7.5 Access to Ports and Airports

The nearest port for all three planned locations is the Port of Zelenika, which belongs to the Municipality of Herceg Novi and is in the Boka Kotorska Bay area. The distance of the port from the Rose locality is about 3–4 n.m. from the Dobreč locality

Fig. 22 Accessibility of port and airport (Source: modified from Google Earth)

about 7 n.m. and from the Mirišta locality about 8 n.m. The nearest airport is in the City of Tivat and from it there are several local roads to all three locations planned for mariculture (Fig. 22).

3.7.6 Potential Conflicts with Future Marine Protected Areas

The analysis of available documents dealing with the protection of future marine protected areas, which covers detail data on important habitats in accordance with Natura 2020, Emerald areas, areas of special importance for future marine protected areas in Montenegro, it was found that all three investigated locations are not in conflict with important habitats, i.e., that there are no protected or endangered species in the numbers that would require eventual protection or be in conflict with the fish farming process (Fig. 23).

4 Proposal of New Locations for Mariculture

Based on a detailed research of potentially suitable locations for mariculture at the exit from the Boka Kotorska Bay area (Rose-Dobreč-Mirišta), and analysis of all available data, the following locations for the development of mariculture on the open sea of the Montenegrin coast have been proposed (Fig. 24):

- Rose Location.
- Dobreč Location

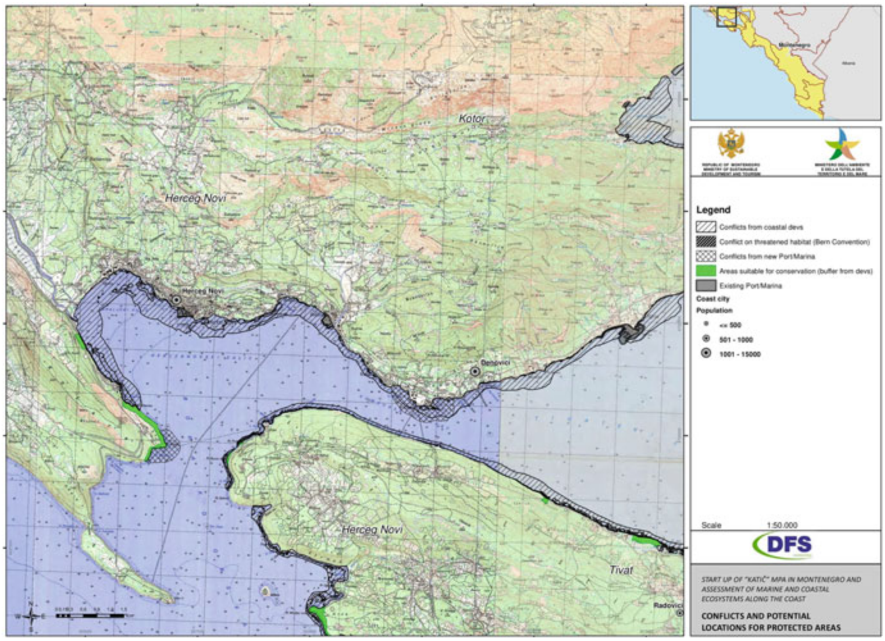

Fig. 23 Map of conflicts and potential sites for protection. The zones proposed for protection are marked in green (modified from [41])

Fig. 24 Proposal of new mariculture sites at Rose and Dobreč (marked with red rectangles) (modified from Google Earth)

Due to the small depth, extremely strong wind gusts, but also the conflict with the tourism sector, the Mirišta location is not proposed for the mariculture program.

The breeding of indigenous species of white fish is proposed, considering the diversification of production and the possibility of breeding other species in relation to existing ones (e.g., *Diplodus puntazzo, Dentex dentex, Argyrosomus regius*). Also, the possibility of breeding salmonid fish species (exclusively *Oncorhynchus mykiss*) during the cold period of the year should not be ruled out. In the latter case, breeding should be strictly controlled by the competent institutions.

The proposed locations are outside the planned zones for settlement development, tourism or construction of marinas/ports. At the Rose location, in the zone recommended for mariculture, an undeveloped coast is planned, and the zone is ideal for the planning of fish farming.

At the Dobreč location, above the recommended mariculture zone (on the mainland), no construction of settlements or other facilities that would affect water quality and the well-being of cultivated organisms is planned.

4.1 Breeding Technology

Cages with flexible platforms (made of polyethylene pipes) with a larger pipe diameter are recommended, which would provide stronger construction and better buoyancy. Platforms should be anchored with the help of a so-called anchor net which is submerged at a depth of 3–4 m, which is maintained on the surface by buoys and anchored towards the bottom by heavy anchor blocks (Fig. 25).

Figures 26 and 27 (processed in the GIS) define the zones proposed for fish farming and development of the mariculture sector. The maps clearly show the breeding installations, which must be placed at a distance from the shore of at least 30 m, or in the part of the sea where the depth is at least 20 m. The proposed farm, which is shown on the map for the Rose locality, includes the installation of circular, floating cages with a diameter of 16 m, which will be used for breeding up to consumption size, as well as smaller, rectangular or square cages for pre-consumption fish, with a diameter of 6 m.

It is important to note that placing 6 cages in a row (Fig. 25) is proposed, or a total of 4 rows of floating cages for the farm.

The distance between each cage (which are in one row) should be a minimum of 10 m, while the distance between two rows of cages should be at least 20–25 m. This space is proposed due to the reduction of the negative impact of the farm on the environment and simpler monitoring of the condition after the installation of breeding equipment.

Detailed coordinates of a specific farm must be obtained from the Port Authority of Kotor, in accordance with the Law on Navigation Safety [42].

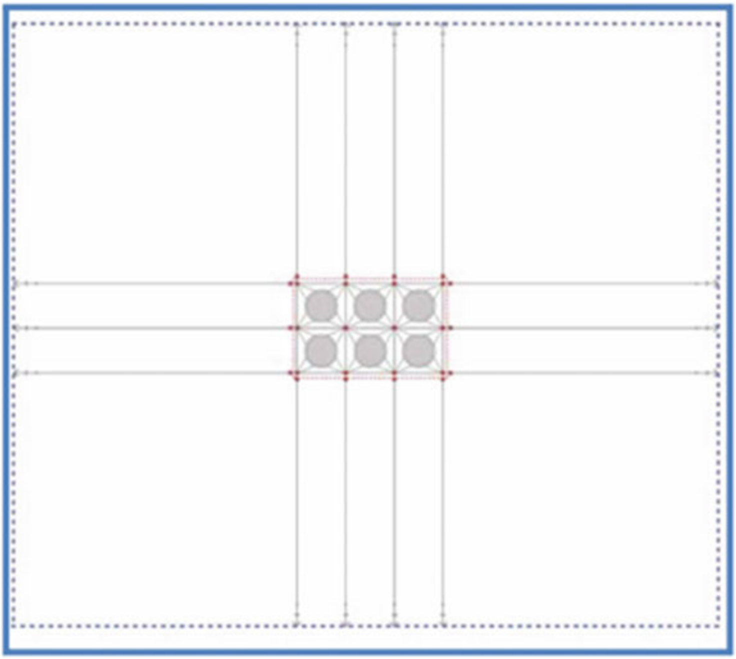

Fig. 25 Setting up 6 circular cages in a row

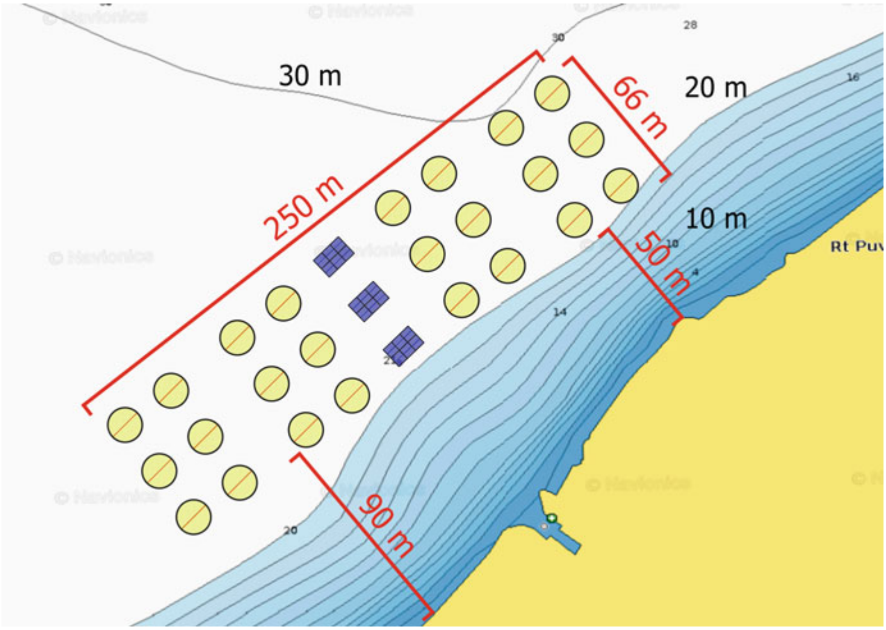

Fig. 26 Proposed mariculture site with setup for breeding installations (Rose location)

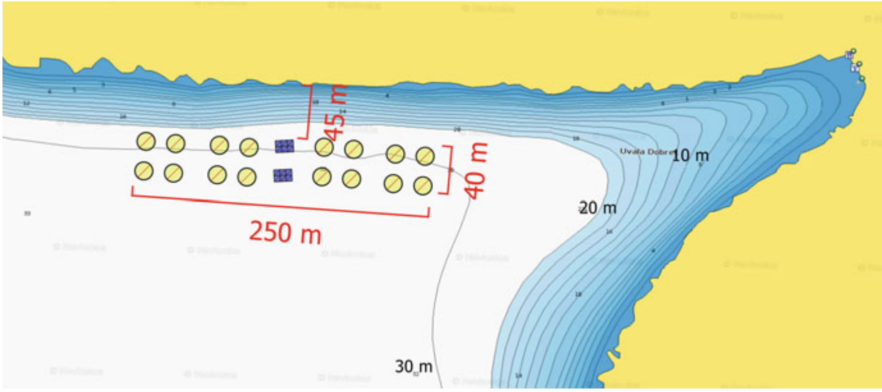

Fig. 27 Proposed location for mariculture with set breeding installations (Dobreč locality)

4.2 Estimation of Production Capacity at the Rose Location

Production capacity at the Rose location was calculated based on the number of proposed breeding installations (cages), the average height of the cages/nets, the average weight of adult farmed fish, and the average mortality of about 20%.

The calculation is given for the cultivation of gilthead seabream (*Sparus aurata*) and/or Europeaen seabass (*Dicentrarchus labrax*), while the detailed elaboration of the production estimate will be carried out through a detailed technology project, depending on the species which will be grown on this location.

If we take the diameter of the cage as 16 m, the height as 8 m, and the average value of the weight of farmed individual fish, which is about 10 kg of adult fish per m^3 of cage, the average production capacity of gilthead sea bream and/or sea bass is about 190 tons per year, i.e., about 385 tons per one breeding cycle (a period of 2 years). In order to obtain the mentioned production, about 1,350,000 units of fry is needed.

At the Dobreč locality, due to the influence of winds and waves, it is proposed to install breeding technologies that are more advanced in terms of resisting the effects of the environment, and the technology of semi-submersible or submersible cages can be used as a potentially suitable technology. Figure 27 shows the zone proposed for mariculture, with the maximum spatial coverage.

4.3 Estimation of Production Capacity at the Dobreč Locality

By using the same methodology as for the Rose location, it was calculated that production capacity at the Dobreč location is about 128 tons per year, i.e., about 257 tons per one breeding cycle (period of 2 years). In order to obtain the mentioned production, about 950,000 units of fry is needed.

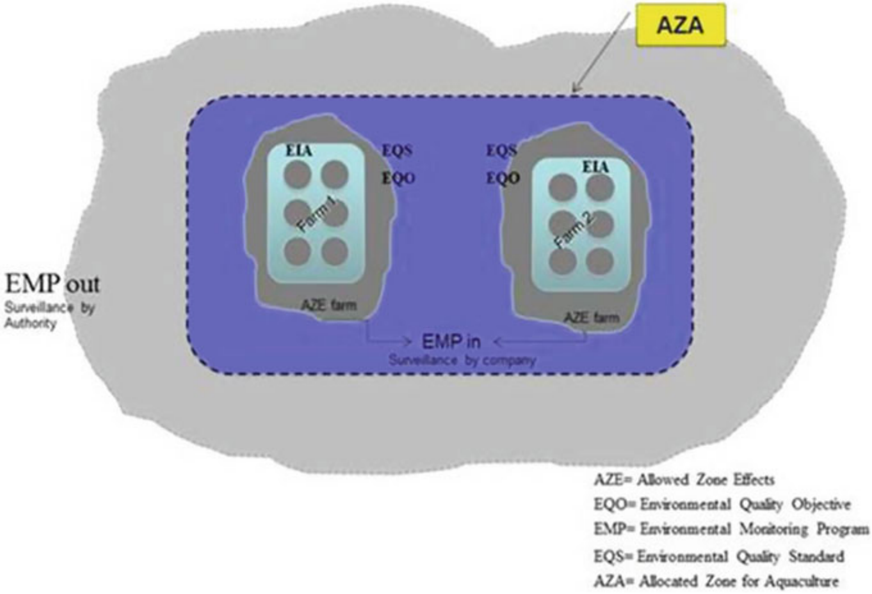

Fig. 28 Zoning in accordance with FAO AZA principles [18]

After setting up the breeding facilities, the monitoring of the state of the environment should be harmonized according to the guidelines on a harmonized environmental monitoring programme for marine finfish cage farming in the Mediterranean and the Black Sea, as indicated by GFCM and presented in Fig. 28.

5 Conclusions

The research on the suitability of locations for mariculture presented in this paper differs from most previous research primarily in terms of proximity to the coast. Namely, due to the specificity of the Boka Kotorska Bay, i.e., the fact that greater depths are located near the coast, the proposed locations are partly sheltered from the influence of the open sea, and can be considered as semi-offshore locations. In any case, the proximity of the coast is one of the parameters used in assessing the carrying capacity of the farm, so it is not an aggravating factor for proposing new mariculture sites.

In order to respect the goals set in the Fisheries Development Strategy of Montenegro, and in accordance with the EUSAIR Strategy, FAO-GFCM Strategy for the sustainable development of Mediterranean and Black Sea aquaculture [43], Blue Development Strategy and the FAO-GFCM resolution of 2012 [44] defining new, suitable locations for mariculture represents the basis for increasing the production of healthy food from the sea, economic growth, increasing employment, and social benefits in Montenegro.

The results obtained in this study show that from a biological point of view there are no obstacles for proposing any of the investigated locations for mariculture programs. Although the analysis of phyto and zoobenthos showed the presence of several protected or endangered species, they were found in small numbers or their benthic settlements were mostly already degraded.

The results of the phytoplankton and ichthyoplankton analyses showed that the research area belongs to the mesotrophic area and that there are no spawning or feeding areas of fish populations, which would negatively affect the proposal of locations for mariculture. Therefore, plankton research and sanitary water quality analyses at all three researched locations show that mariculture programs can be recommended.

The analysis of oceanographic parameters shows that at all three locations, at a small distance from the coast, there are greater depths that favor fish farming. A general feature of the entrance to the Boka Kotorska Bay, where the positions intended for mariculture are located, is the openness to the southern wind in the direction of the open sea. The lee for waves from these directions is very large and stretches across the entire Adriatic all the way from the Italian coast. Therefore, the destructive waves from the southern directions towards this area will advance directly from the open sea, undisturbed by obstacles. However, analyses show that there will be no destructive waves at the Rose location due to the sheltering of the location, and storm waves not larger than 1 m can be expected there. At the Dobreč location, complete openness to the south wind was established, and destructive waves from the south can be expected there. This position is sheltered from bora waves, and the maestral has a small leeward so it cannot create larger waves. Due to the situation with possible destructive waves, special attention should be taken during the design and construction of infrastructure and mariculture facilities.

Sediment grain size plays a major role in sediment biogeochemistry, and sediments of different grain sizes are expected to respond differently to organic enrichment. Most of the samples showed the presence of sand in over 60% of the analyzed material (from 63 to more than 90% of the material), so the results indicate that at the Rose and Dobreč locations the sediment composition is suitable for fish farming. Enrichment of sediment with organic matter due to fish farming and its decomposition significantly depend on the grain size of the sediment. According to the literature, phosphorus content is positively correlated with the proportion of sand grains below the farm, while it is negatively correlated with mud and clay grains [45].

At high levels of organic enrichment, sandy sediments accumulate less organic matter, less sulfide, and less ammonia than mud sediments, while oxygen uptake into sediment and total CO_2 show similar levels between sandy and muddy sediments [45]. Enrichment of organic compounds in sediments primarily depends on sediment type, where muddy sediments accumulate halogenated and sulfur-containing compounds, while sandy sediments accumulate more aldehydes and BTEXs [46, 47].

Analysis of heavy metals in the sediment showed a slightly higher content of chromium and nickel compared to other analyzed elements. The results are most likely a consequence of natural phenomena, because the mentioned elements are found in large quantities in rocks and natural processes of decomposition and sedimentation [48–50]. The surface sediment in Boka Kotorska Bay contains relatively high organic matter and carbonates. The amount of organic matter and carbonate in the sediment is largely dependent on the water depth, production from marine organic sources, and the hydrographically related disposition of the bay [51].

Fish diets are enriched with various inorganic elements, such as Cu, Fe, Mn, Co, Cr, and Zn [52–56] and regular monitoring of water and sediment quality is necessary in order to track changes and to react in time in case of more intensive pollution.

Although the analysis of basic and administrative data confirmed that there is no adequate infrastructure for water, electricity, and sewage connections at any of the locations, this should not interfere with proposing new locations. Namely, the same situation is present in the area of the Boka Kotorska Bay, where the complete mariculture of Montenegro is concentrated (fish and shellfish farming). This is certainly one of the great shortcomings of the system and organization of the mariculture sector.

The analysis of the fish production carrying capacity at the Rose and Dobreč localities roughly calculated the approximate production of 190 and 128 tons of fish per year, which is in line with the recommendations that no more than 150 tons of fish should be farmed per hectare [57]. If the principle of calculation of annual production carrying capacity (D) is used based on the equation:

$$D = [150 + 80 * (E - 1)] * fa * fb * fk, [52]$$

where: fa: fish farm's distance from the coast, fb: water depth under the fish farm, fk: openness/exposure of the fish farm location or current speed, E: area of the fish farm site (ha), the annual production of fish at the locality of Rose is about 303 tons of fish, while at the Dobreč locality the annual production is about 225 tons of fish.

Given that the calculation of annual production capacity is quite complicated and the subject of various debates [57, 58], during the preparation of a detailed technological project for each farm, the ecology of the species should be also taken into account. Additional analysis based on the degree of compatibility [18], in which all the information collected are integrated could give further level of suitability for mariculture activities.

In general, it can be concluded that during many years of work and cooperation with Mediterranean countries, significant progress has been made in the field of mariculture development in Montenegro in order to unlock its potentiality. In addition to the progress of exchanging experiences, introduction of new technologies, application of AZA principles according to the FAO GFCM resolution adopted in 2013 by the countries have contributed to such development of an approach in defining new locations for mariculture that will provide security for investments and contribute to achieving some of the strategic goals of mariculture sector development in Montenegro.

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