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CATCHING THE WAVES OF COOPERATION

BlueDiversity

2 - Green and resilient shared environment
SO 2.2 - Protection of nature and biodiversity

BlueDiversity

ITHR0200404

Shared BLUE knowledge and skills to sustain BIODIVERSITY in mariculture

Activity 1.1 - State of the art context analysis

Deliverable 1.1.1 - BlueDiversity Database

REPORT ON PILOT AREAS

TABLE OF CONTENTS

1. Project Overview

Information

Start date
01/03/2024
End date
31/08/2026
Total budget
2.022.051,66
Partnership
IT - 4
HR - 3
Project typology:
Standard

Project specific objectives

Priority: Green and resilient shared environment

Specific Objective: 2.2: Enhancing protection and preservation of nature, biodiversity and green infrastructure, including in urban areas, and reducing all forms of pollution.

Project Duration: 30 months

Project main outputs

The project aims at creating innovative instruments and methods to reduce the impact of human activities on biodiversity in the small-scale fishing sector, by reevaluating the role of local actors and providing them with concrete means and tools. These innovative instruments are both material and cognitive (upskilling, reskilling and education) to gain an active role in the protection of nature and in the

sustainable transition and to exploit new economic opportunities through a shared framework.

2. Activity 1.1 - State of the art context analysis

Objectives

Review of the available data on diversity of species inhabiting each of the selected pilot sites, along with the available data on physical parameters as well as nutrients and chemical pollutants, aiming to identify environmental pressures which threaten the health of local marine ecosystems.

Eight pilot sites have been selected by project partners, 3 are located on the eastern Italian coastline, whereas 5 are located on the Croatian coastline. Data on each of the pilot areas were collected by PPs through comprehensive review of the existing literature and databases. Compiled information is essential to proceed with the subsequent activities in the WP1. It has been organized and stored into a database which will be made available to stakeholders and general public.

The assembled data will provide a comprehensive overview of the pilot areas and represent a basis for development of solutions and management plans, focusing on protection of the ecosystem services and biodiversity in the selected pilot sites.

3. LP1 - Aquatina di Frigole and Ionian Sea mariculture Pilot Area

3.1. Pilot area overview

The Salento Peninsula (Italy) juts out into the Mediterranean Sea and is thought to play a crucial role as a crossroad between different biogeographic areas, presenting affinities with both western and eastern Mediterranean coastlines. Specifically, this region is at the southeastern terminus of the Italian Peninsula, bordered by both the Adriatic Sea and the Ionian Sea. The Salento Peninsula is characterised by coastal and marine ecosystems that constitute essential biodiversity hotspots, supporting rich assemblages of endemic species and critical habitats. Local productive activities, such as mariculture and mussel farming, prioritise environmentally sustainable practices, aligning with global conservation objectives. However, the region is increasingly subjected to worldwide pressures extending beyond the local or macro-regional levels. Such pressures are mainly represented by non-indigenous species (NIS), climate changes and marine litter, leading to long-term impacts on the species and habitat biodiversity that characterise this region. Non-indigenous species have been increasingly detected within the Mediterranean Sea and coastal ecosystems, which can be severely disrupted due to the competition with native species for resources, alteration of the habitat structure, and the introduction of new diseases. One peculiar example is the presence of the blue crab (*Callinectes sapidus*), whose arrival and expansion raised particular concern because of its capacity to outcompete native species and alter the food webs easily. At the same time, climate change represents a pervasive global threat impacting ecosystems on a broad scale. The effects of climate change include, for instance, the rise of sea levels, which in turn can result in flooding of coastal habitats, leading to a severe loss of critical habitats like dune systems and coastal lagoons. The presence of marine litter is mainly represented by beached plastics coming from the Adriatic Basin. Plastics from coastal-marine economic activities represent a significant percentage of marine litter requiring the attention of various target groups. Given the unique ecological profile of the region and the escalating pressures acting on it, the Aquatina di Frigole and Ionian Sea mariculture pilot area (Figure 1) was strategically individuated across the Adriatic Sea and the Ionian Sea. This pilot area encompasses two distinct zones: the NATURA 2000 Site "Aquatina di Frigole" (IT9150003), a protected area adjacent to the Adriatic Sea, and the Ionian Sea mariculture, which interfaces with the Ionian Sea.

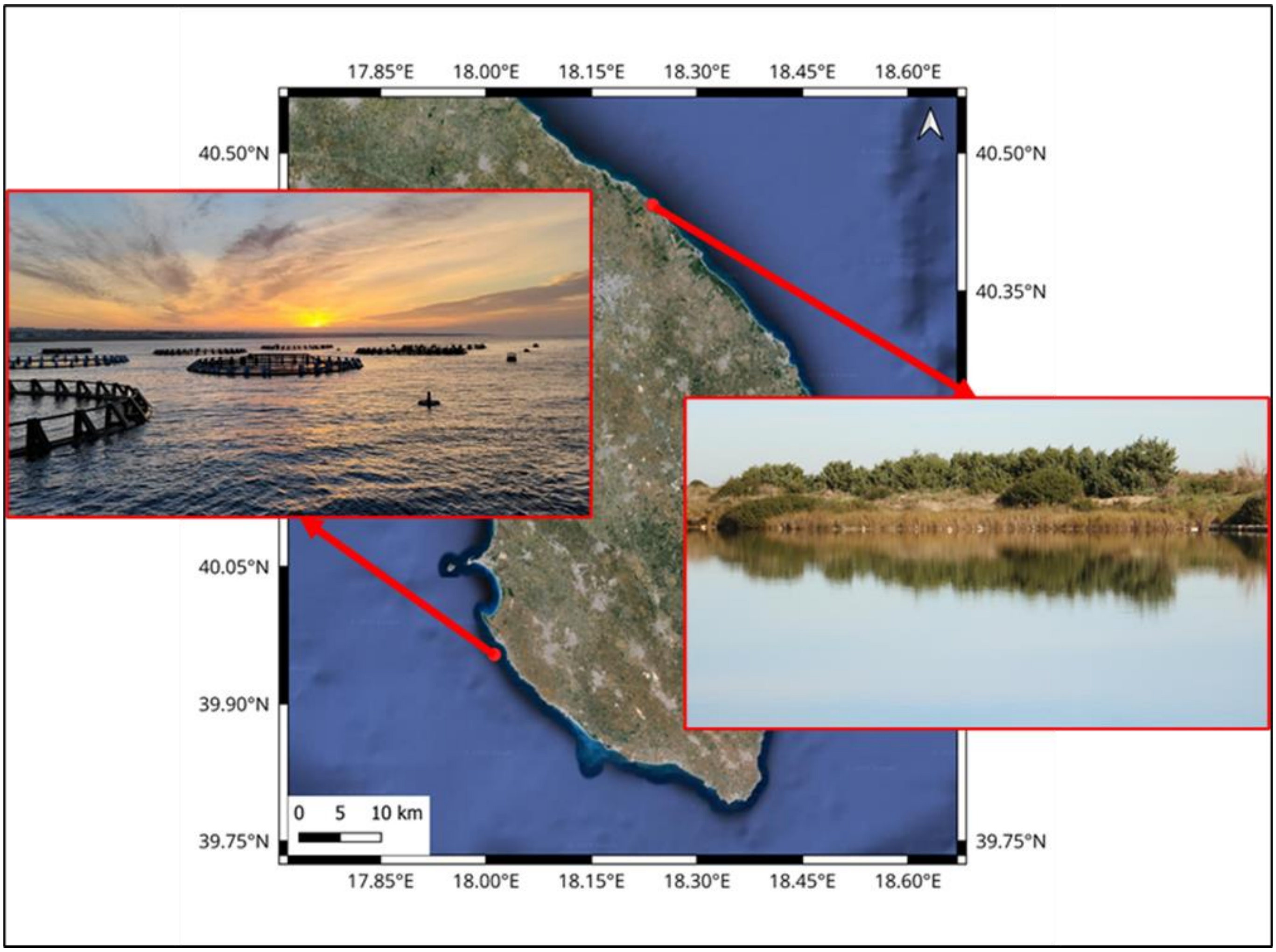

Figure 1. Geographical overview of the Salento Peninsula, highlighting Aquatina di Frigole (northern Adriatic zone) and the Ionian Sea mariculture (southern Ionian zone).

3.1.1. Aquatina di Frigole

Aquatina di Frigole is a protected area designated under the EU NATURA 2000 Network (Site code: IT9150003) in southeastern Apulia (Figure 2).

Figure 2. Geographical overview of the NATURA 2000 Site "Aquatina di Frigole" (left) and focus on the Aquatina di Frigole lagoon (right).

The protected area extends for 3,163 ha, 95% of which is represented by the marine area. The site includes a coastal lagoon that represents about 3% of the entire protected area. The surface area of the lagoon is about 42 hectares, and its length is about 2.5 km parallel to the dune cordon. The maximum registered depth is about 1.5 m, and the annual maximum registered tidal excursion is about 34 cm. The coastal lagoon directly connects with the Adriatic Sea through a 400 m long and 15 m wide channel on the southern boundary. On the northern boundary, a lateral ramification of a canal named "Giammatteo Canal" represents the main freshwater input. The NATURA 2000 Site is under the management of the Department of Biological and Environmental Sciences and Technologies (DiSTeBA, University of Salento) and hosts the Research Centre for Fisheries and Aquaculture of Aquatina di Frigole (University of Salento). The Research Centre conducts systematic biodiversity monitoring and abiotic gradient analyses across different designated sampling stations following a salinity gradient from the lagoon mouth to the freshwater input. This NATURA 2000 Site represents an important hotspot for biodiversity conservation. The protected area comprehends a wide range of habitats rich in species biodiversity, facing several environmental pressures. Because of that, Aquatina di Frigole represents a pillar for scientific research, biodiversity conservation, and sustainable management practices development. In particular, Aquatina di Frigole protects different Mediterranean NATURA 2000 priority coastal habitats and species included in the Habitat Directive

(92/43/EEC) and Birds Directive (2009/147/EC). Protected priority habitats include *Posidonia oceanica* meadows (1120)*; *Coastal Lagoons* (1150)*; and Coastal dunes with *Juniperus* spp. (2250)*. Other habitats are: Mediterranean maquis, beaches, and freshwaters around the lagoon. Regarding protected species, organisms such as *Pinna nobilis* and *Monachus monachus* have recently been recorded in the area, joining other species of interest already known to inhabit the region (e.g., *Aythya nyroca*, *Himantopus himantopus*, *Aphanius fasciatus*, *Anguilla anguilla*, etc.).

This protected area is integrated into a broader context, represented by the surrounding socio-economic landscape. The small village of Frigole, in which the protected area is integrated, hosts different socio-economic activities, mainly represented by small-scale fisheries, agriculture, beach resorts, bars, restaurants, schools, and cultural and environmental associations. Due to the constant involvement of the local community towards the conservation actions for Aquatina di Frigole, this protected area represents a highly cultural value site for the local community. Further to the local initiatives for Aquatina di Frigole conservation, the protected area is subject to regional, national, and international regulations for species and habitat biodiversity conservation.

At the local scale, Aquatina di Frigole faces environmental pressures originating from the activities directly linked to the NATURA 2000 Site. Such pressures can be generated from the activities related to tourism, agriculture, and small-scale fisheries, which directly interact with the coastal ecosystems included in the whole area. At the macro-regional scale, the protected area faces broader environmental pressures that extend over the local community and affect the entire Adriatic-Ionian region. These pressures, mainly represented by macro- and micro-plastics transported by the Adriatic and the Ionian Sea currents and accumulating on the beach and in the coastal lagoon, can have important impacts on the ecosystems within the NATURA 2000 Site and the surrounding areas. Finally, the protected area is influenced by worldwide environmental pressures extending beyond the regional and local levels, such as non-indigenous species like the blue crab (*Callinectes sapidus*) and the effects of climate change.

3.1.2. Ionian Sea mariculture

The mariculture practices along the Salento Peninsula Ionian Sea coastline represent a concrete example of how the exploitation of unique hydrogeological conditions can help the development of sustainable aquaculture systems. In this context, the harmonious integration of mariculture activities within the Pilot Area is framed as an innovative pathway aimed not only at the enhancement of natural resources but also at the consolidation of a production model that is attentive to the environment. This initiative has the primary objective of deepening the study and monitoring of biodiversity, being part of a broader vision that embraces both the peculiarities of the local marine ecosystem and the needs of the local productive activities. This approach makes it possible to observe natural dynamics in an innovative way, promptly detecting any variations that could compromise the ecological balance. In this way, monitoring activities become a valuable tool for the prevention and management of production-related risks, helping to maintain the integrity of the ecosystem.

At the same time, there is a constant commitment aimed at limiting the use of plastic materials, demonstrating how environmental sustainability can be effectively integrated with production needs. This strategy, in fact, not only reduces the negative impact on the environment but paves the way for innovative solutions that aim to minimise the consumption of non-renewable resources. In addition, the continuous attention paid to the monitoring of the species present allows for prompt intervention if signs of the arrival or spread of non-indigenous species (NIS) are detected, whose presence could alter the pre-existing balances and have significant consequences for local biodiversity and mariculture productivity.

Finally, the Ionian Sea mariculture along the Salento coastline represents a virtuous model in which the interaction between scientific knowledge, technological innovation and respect for the environment translates into benefits both for production and ecosystem protection. This integrated approach represents a stimulating challenge, which aims to combine economic development and environmental protection, demonstrating how the prudent management of natural resources can make a difference in an era in which sustainability has become an essential priority.

Offshore from the Torre Suda coastline, the mariculture cages of “inmare” (Figure 3) are strategically positioned in an area characterised by strong and constant underwater currents.

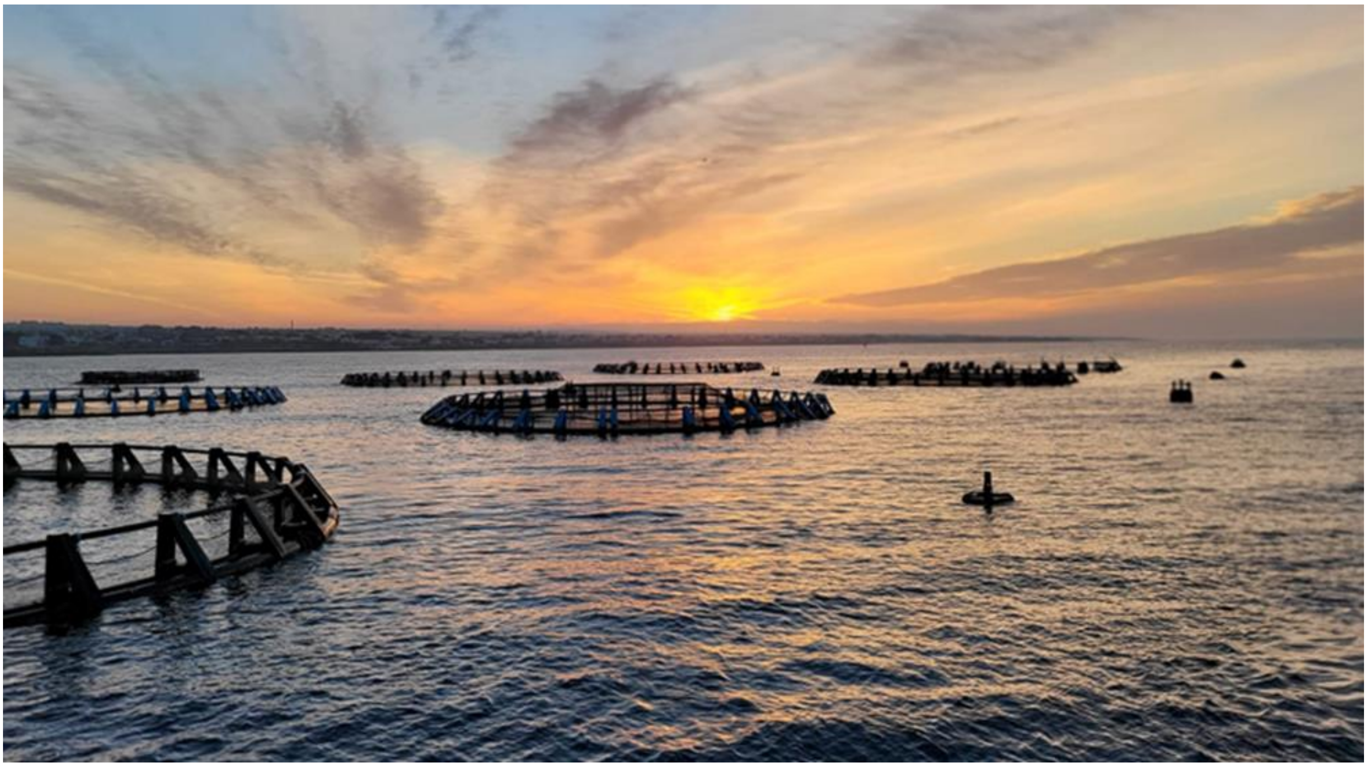

Figure 3. Picture of the "in mare" mariculture cages.

These dynamic hydrological conditions facilitate optimal growth conditions for species such as European sea bass (*Dicentrarchus labrax*), gilthead sea bream (*Sparus aurata*), and meagre (*Argyrosomus regius*), as the high-energy flow ensures consistent oxygenation, nutrient dispersion, and waste mitigation, which represent some of the critical factors for robust fish health and productivity.

At the same time, the cultivation of "Cozza Castrense" mussels (Mediterranean mussel, *Mytilus galloprovincialis*; Figure 4) finds the optimal conditions in a distinct ecological niche located seaward of Castro Bay.

Figure 4. Picture of the “Cozza Castrense” ropes.

This area is distinguished by 34 submerged karstic freshwater springs, locally termed “*citri*”, which discharge into the marine environment. The resulting brackish water interface creates a unique habitat enriched with dissolved minerals and organic particulates, fostering the phytoplankton growth that serves as a primary food source for mussels. Furthermore, the stable salinity gradients and nutrient influx from the *citri* enhance bivalve growth rates and shell integrity, positioning this zone as an ideal locus for high-quality mussel farming.

Together, these mariculture systems underscore the interplay between geomorphology, hydrology, and biodiversity in optimising aquaculture yields while leveraging natural ecosystem dynamics. The main threats faced by the mariculture systems are represented by non-indigenous species (NIS), which may spread dangerous diseases menacing these systems’ equilibrium, as well as climate change which, through the rise of seawater temperatures, may trigger localised or broadly extended harmful algal blooms (HABs), with consequent fishes mass mortalities and risks for the human health.

3.2. Conclusions

The Pilot Area Aquatina di Frigole and Ionian Sea mariculture is characterised by a broad spectrum of ecological habitats and includes a high variety of fauna and flora species. To improve conservation efforts and facilitate biodiversity monitoring and research, the area was defined to be part of the BlueDiversity project, with the aim to study and manage the ecological integrity of the area, as well as develop new biodiversity monitoring and conservation tools and strategies. Specific objectives in the Pilot Area are: monitoring, early warning and management of non-indigenous species applying innovative tools; environmental DNA (eDNA) applications for biodiversity monitoring; monitoring in mariculture concerning the presence of potentially harmful phytoplankton species and non-indigenous harmful species for fish and molluscs production; monitoring and management of plastics and microplastics; monitoring stress responses through innovative microRNA (miRNA) studies; stakeholder involvement, communication, and dissemination activities. According to these objectives, to face the threats acting on the Aquatina di Frigole and Ionian Sea mariculture Pilot Area and ensure best practices for environmental protection and biodiversity conservation, a multi-scale approach has to be adopted to enhance the integration of scientific research, stakeholder involvement, and innovative monitoring technologies. The final objective is to enhance the conservation practices towards this ecologically important region while addressing the needs of the local productive activities other than the local, regional, and global environmental challenges.

4. PP2 – Pilot areas around city of Split

4.1. Pilot areas description

There are 3 pilot areas around the city of Split in an approximately small geographic area. Pilot area 1, Cetina estuary, is in the middle, 35 km away from Pilot area 2, Pantan, and 17 km away from Pilot area 3, Vrulja. Each area is ecologically specific but has some mutual characteristics such as continuous fresh water inflow.

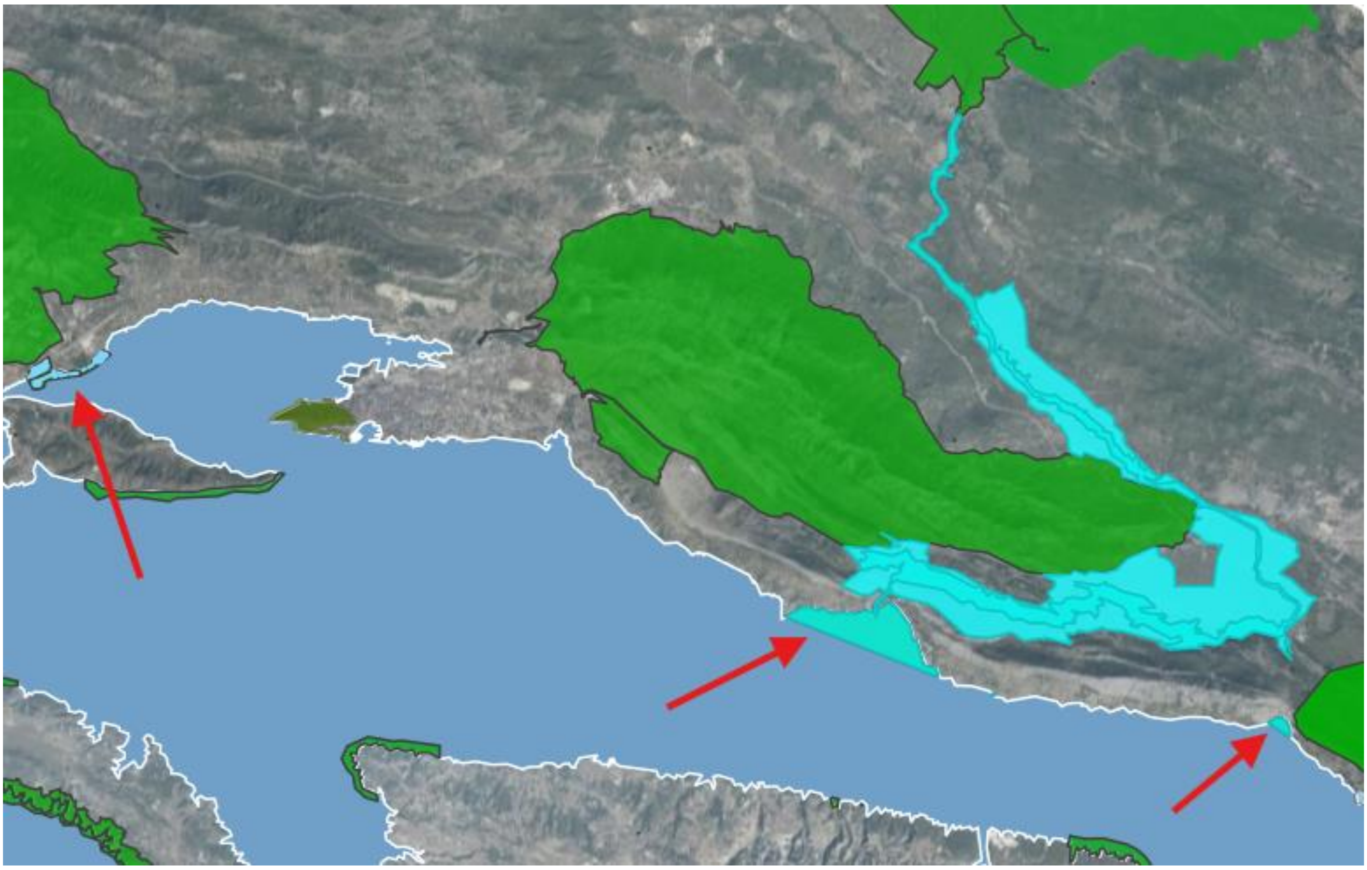

Figure 1. Pilot areas

4.1.1. Pilot area 1 – Cetina River and Estuary

Pilot Area 1 - Cetina River and Estuary includes 2 Natura 2000 sites and protected landscape with total of 7160 ha.

- HR3000126 Cetina Estuary
- HR2000929 Cetina River
- Protected Landscape: Canyon of the Cetina River

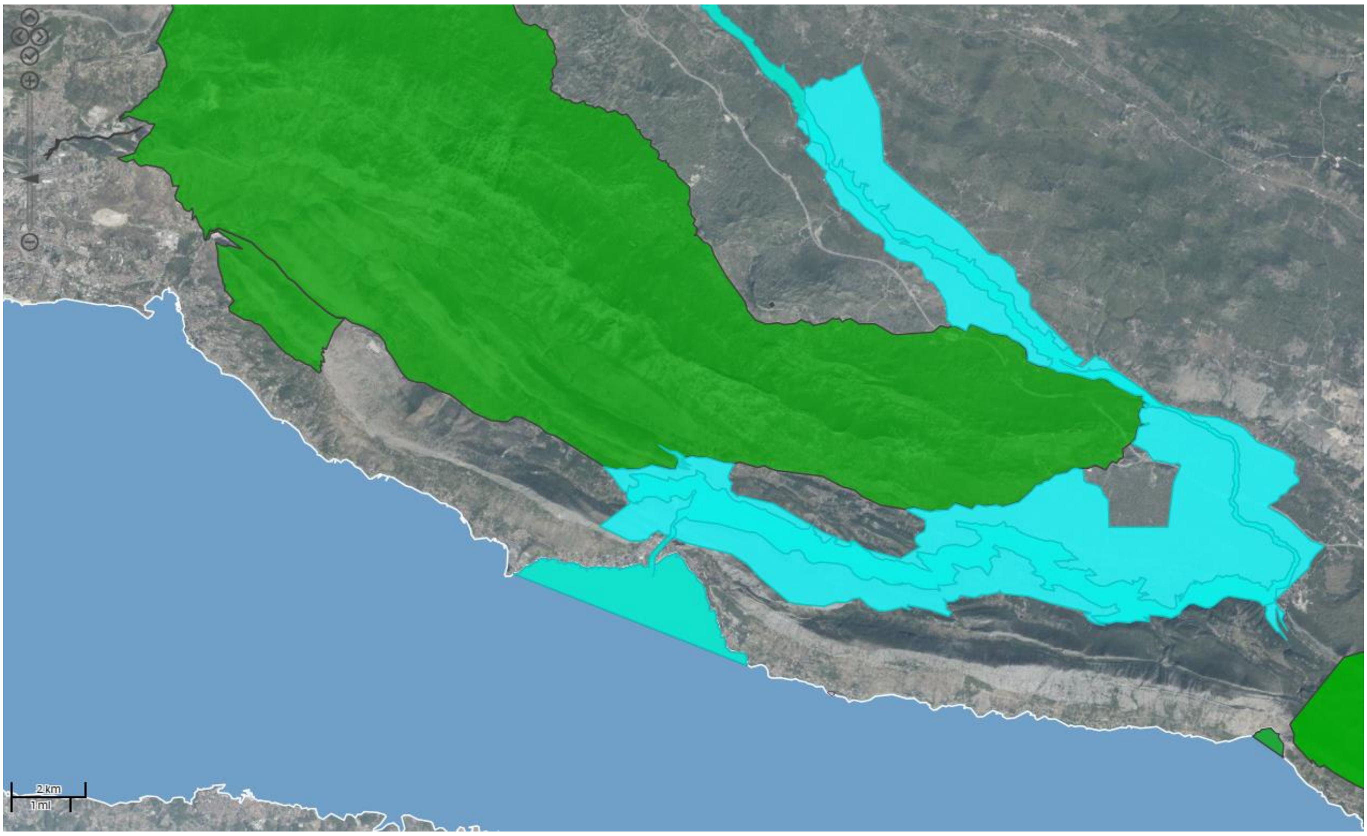

Figure 2. Pilot area 1, Cetina River and Estuary

Ecosystems:

Marine, brackish (transitional waters), and freshwater ecosystems, which are sensitive to changes in species composition.

The Cetina River is uniquely characterized by its specific ecological conditions, including its connection to the karst fields of southwestern Bosnia and Herzegovina, and the mixing of fresh and saltwater in its lower reaches. These factors contribute to a highly distinctive ichthyofauna, comprising numerous endemic fish species (COAST, 2009). To date, 24 fish species have been documented in the Cetina, nine of which are endemic to the Adriatic basin (Mrakovčić et al., 2006). The most abundant native species include the Adriatic trout (*Salmo faroides*), the Illyrian chub (*Squalius illyricus*), and the European eel (*Anguilla anguilla*) (Vitas et al., 2012). While the Adriatic trout and Illyrian chub are distributed throughout the river except for its brackish sections, the European eel is most commonly found in the lower part of the river.

In the canyon section of the Cetina, four target fish species are also found, which are strictly protected under the Regulation on Strictly Protected Species (Official Gazette NN 144/13 and NN 73/16). The Cetina loach (*Cobitis dalmatina*) stands out as an endemic species of the river, inhabiting slow-flowing and still-water sections. It prefers areas with cooler water, sandy or gravelly riverbeds, or dense underwater vegetation. This species is found between Čikotina Lađa and Blato na Cetini, Galići (Budimir-Bekan and Kurtović Mrčelić, 2019). Another endemic species, the Cetina bleak (*Telestes ukliva*), migrates seasonally to springs and underground habitats.

Additionally, two endemic gobies of the Adriatic basin,the *Knipowitschia panizzae* and the *Pomatoschistus canestrinii* are found in transitional brackish waters, including the lower reaches of the Cetina River. Their habitats include muddy bottoms, coarse sand, gravel, and occasionally rocky substrates. The Dalmatian barbelgudgeon (*Aulopyge huegelii*) inhabits karstic flowing waters, primarily sinking streams. It thrives in fast-flowing, clear watercourses and the lakes or reservoirs associated with them.
These fish species form schools that are thought to migrate to underground waters during the autumn and return to surface watercourses in the spring when water levels rise (Zonacija HR2000929 Cetina River – Canyon Section). All four target fish species are small in size, ranging from 4 to 10 cm (with the exception of the softmouth trout, which can grow up to 20 cm). They are highly dependent on specific, small, and scarce habitats.

In the lower reaches of the Cetina River and near its mouth, another target species, the sea lamprey (Petromyzon marinus), is also present. This poorly researched anadromous species migrates into the freshwater of the Cetina to spawn (Zonacija HR2000929 Cetina River – Canyon Section).

Importance:

This area supports rich biodiversity, including fish, bird species, and native aquatic flora, all of which are threatened by the invasive blue crab.

Challenges:

Possible threats of hydrological modifications, urban pollution, habitat damage, degradation and habitat loss and eutrophication. The blue crab's (*Callinectes sapidus*) adaptability to both brackish and freshwater environments makes control difficult in this area.

4.1.2. Pilot area 2 – Pantan Coastal Lagoon

Pilot Area 2 - Pantan Coastal Lagoon occupies total area of 138 ha.

Natura 2000 Sites:

- HR3000430 Pantan
- HR3000459 Pantan – Divulje
- Ornithological & Ichthyological Reserve: Pantan

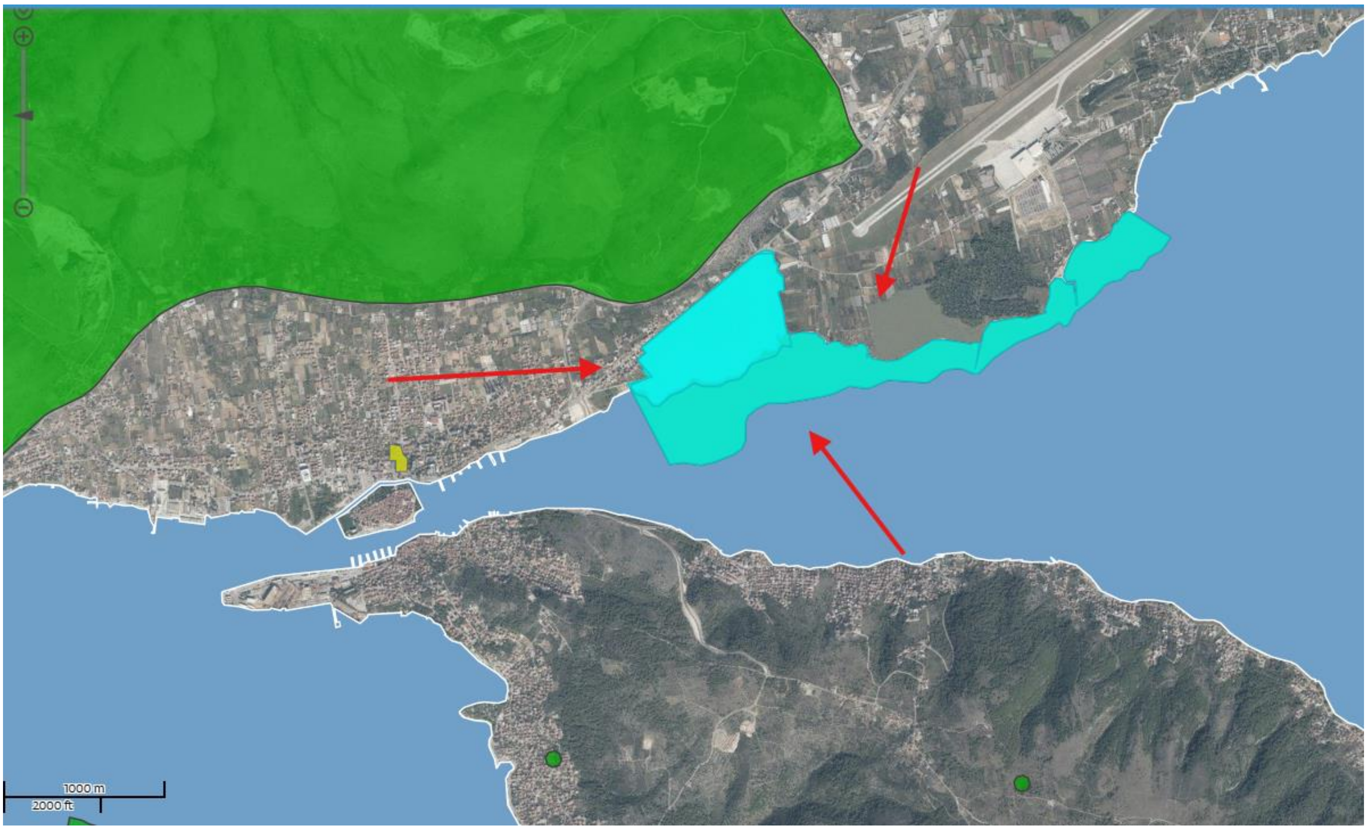

Figure 3. Pilot area 2, Pantan Coastal lagoon

Ecosystems:

Marine and brackish ecosystems, with coastal lagoons being crucial habitats for various fish and bird species.

Pantan is a wetland area located between Divulje and Trogir, just south of the Split-Trogir road. Its marshy landscape is shaped by a freshwater spring and a small lake situated near the road. The water flows southwest through a stream, branching into numerous channels that weave through the entire area.

Pantan is a permanent but brackish (160–10,600 mg/L chlorides) ascending spring located at an elevation of 2.7 meters above sea level, with a minimum discharge of around 200 L/s. Due to its close proximity to the sea, this small area of brackish water is of particular interest from an ichthyological perspective. Previous research in the area has recorded the presence of the endangered species *Aphanius fasciatus*. Water from the lake flows into the sea through a shallow river, which partially drains into an artificially excavated channel.

The vegetation consists of five main plant associations, which, although not highly diverse, cover a significant portion of the area. A total of 196 species of birds are recorded for the area of Pantan, and the wetland provides a home for 45 species of nesting birds.

Situated in the heart of the Dalmatian coast, Pantan remains one of the few preserved salt marsh habitats, making it an important refuge for many bird species.

Despite being increasingly threatened by human encroachment, Pantan remains a biologically and ecologically valuable oasis. Urgent action is needed to protect this small but significant natural reserve, which is already confined on all sides, from further human intervention.

Importance:

The Pantan coastal lagoon is a key feeding and breeding ground for migratory birds and native fish species. These ecosystems are delicate and can be easily disturbed by invasive species.

Challenges:

Possible threats of hydrological modifications, urban pollution, habitat damage, degradation and habitat loss and eutrophication. The blue crab (*Callinectes sapidus*) competes with native fish for food resources and may disrupt the ecological balance of these coastal lagoons.

4.1.3. Pilot area 3 – Uvala Vrulja kod Brela

Pilot Area 3 - Uvala Vrulja kod Brela occupies an area of 30,3 ha.

Natura 2000 Site:

- HR3000123 Uvala Vrulja - Brela

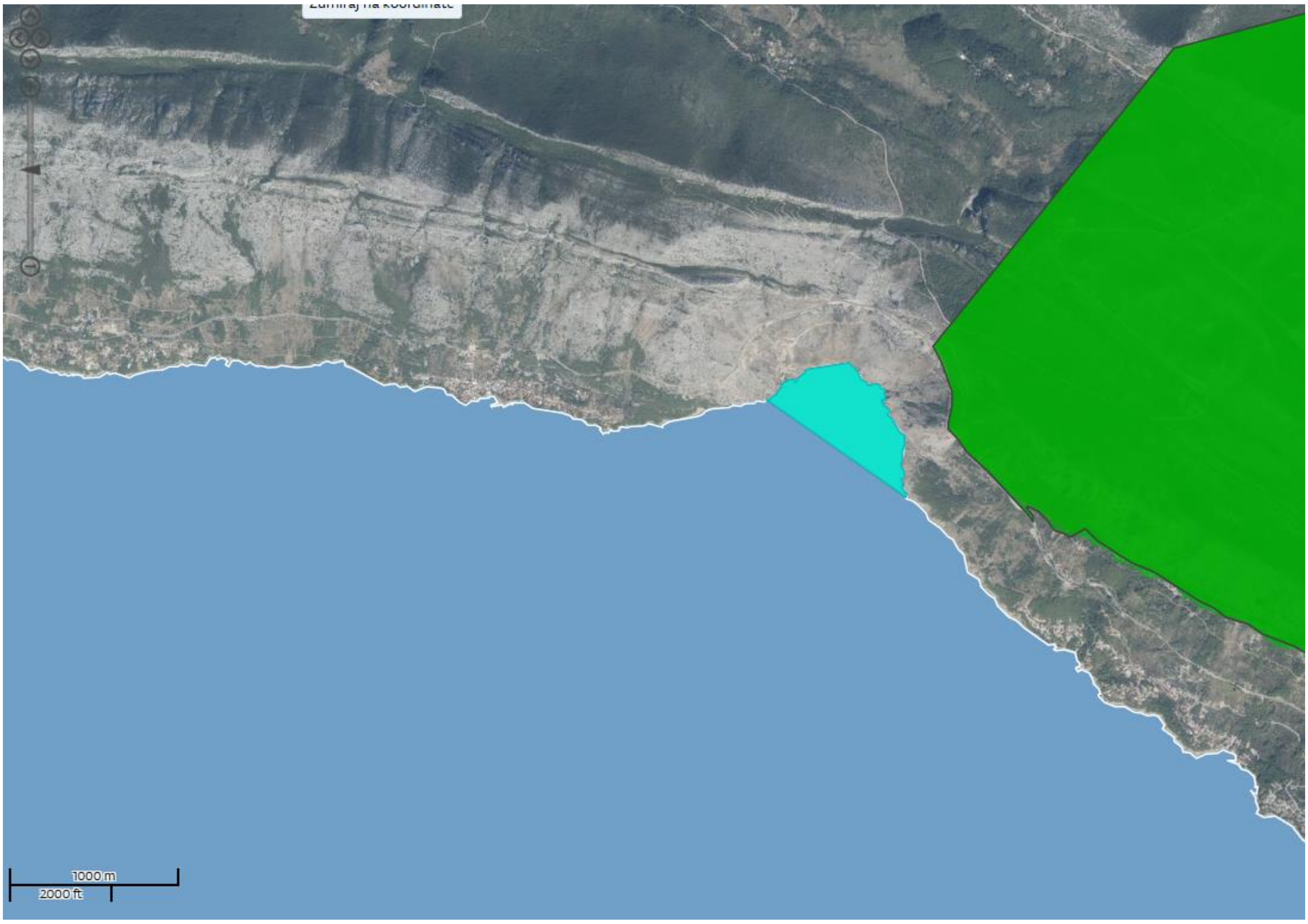

Figure 4. Pilot area 3, Uvala Vrulja

Ecosystem:

A marine ecosystem is influenced by underwater brackish water sources known as vrulja (a specific type of karst feature through which freshwater passes). These sources create a unique habitat, supporting species adapted to both marine and freshwater conditions. Two significant habitats are recorded in the area submerged or partially submerged sea caves (CODE 8330) and reefs (CODE 1170).

Importance:

The Vrulja area is a rare ecosystem that serves as a refuge for various species, including fish, marine invertebrates, and aquatic plants. This site is important for Reefs (there is an area of infralittoral algae up to 20 meters depth, with *Codium bursa* and *Dyctiota sp*. as dominate species. In a slightly deeper parts there is big *Axinella cannabina* community. At 20 meters there is a *Corynactis viridis* community, which in some area completely covers the walls.)

Challenges:

The blue crab's presence in this area may disturb the balance of the unique vrulja ecosystems by preying on or outcompeting native species.

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5. PP4 - Pilot area Neretva delta

5.1. Pilot area description

Neretva river occupies a total area of approximately 5.580 square kilometers. Its upper estuary lies in Bosnia and Herzegovina while its lower estuary with a delta shaped river mouth lies in Croatia (Figure 1). Neretva is the only river in Croatia with a delta at its mouth. The area of Neretva's delta covers 196 square kilometers.

Figure 1. Neretva river estuary coastline area.

Neretva estuary is a highly productive and biologically diverse ecosystem, however, human activities significantly affected the lagoon and wetland landscape. The remaining wetlands and lagoons support several ornithological and ichthyological reserves which are protected by the Natura 2000 network as well as national legislation. Wetlands with protective vegetation serve as a bird nesting area (Stumberger and Schneider-Jacoby, 2010), fish spawning and migration route (Glamuzina et al., 2019). Neretva estuary is crucial for the conservation of several freshwater fish species (Tutman et al., 2017). It is considered the most important nursery ground for marine fish and crustaceans along the Eastern Adriatic coast (Bartulović et al., 2007; Dulčić et al., 2007).

Pressures:
The increasing pressure from human activities such as intensive agriculture, port development (port of Ploče), urbanization, overfishing, illegal hunting, unregulated recreational activities and tourism, watercourse alterations and fluctuations in hydrological regime threaten the estuarine habitat.

5.2. Eutrophication status

Eutrophication is mainly caused by excessive inputs of nutrients (nitrogen and phosphorus), resulting from various human activities such as agriculture, industry and urban wastewater management. Increased nutrient loads accelerate phytoplankton production, causing algal blooms, low levels of dissolved oxygen in water and associated anoxia and hypoxia.

Eutrophication status assessment is based on data on nutrient concentrations in the water column, chlorophyll concentrations, and dissolved oxygen levels.

Nutrient concentrations have been continuously monitored at several sites in the pilot area, under the National monitoring program of coastal and transitional water quality in Croatia (Figure 2).

Figure 2. Sampling sites in the area of the Neretva delta.

Nutrient thresholds supporting the ecological assessment based on nutrient enrichment have been set at the national level (NN 20/2023). Very good status (concentrations below the threshold values) for total nitrogen and dissolved inorganic nitrogen (DIN), referring to the sum of ammonium, nitrite and nitrate concentrations, has been achieved at all of the investigated sites in the pilot area (Figures 3 and 4).

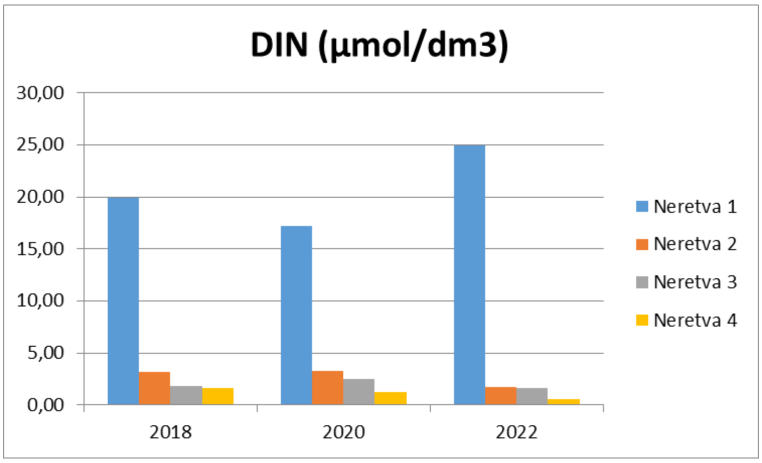

Figure 3. Annual mean concentrations of dissolved inorganic nitrogen in the surface water layer.

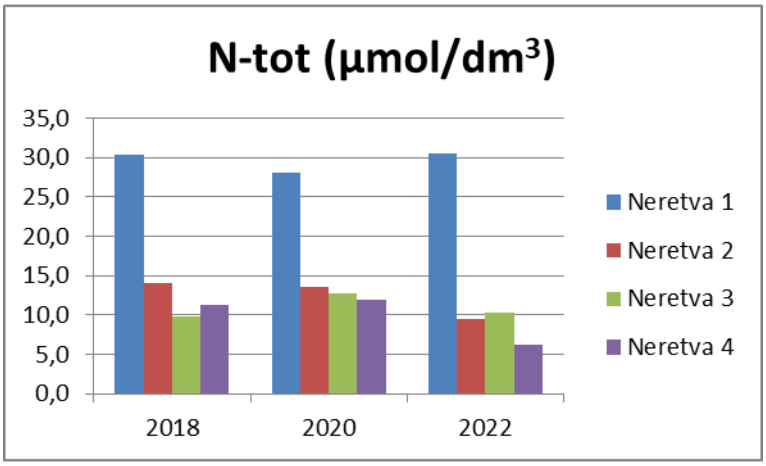

Figure 4. Annual mean concentrations of total nitrogen in the surface water layer.

Concentrations of orthophosphate and total phosphorous were below the set threshold values referring to very good ecological status, therefore the ecological status at all of the investigated sites in the pilot area is assessed as very good (Figures 5 and 6).

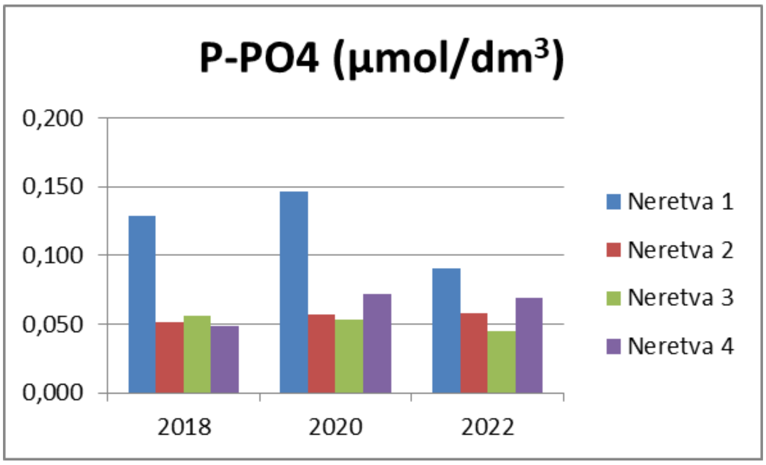

Figure 5. Annual mean concentrations of orthophosphate in the surface water layer.

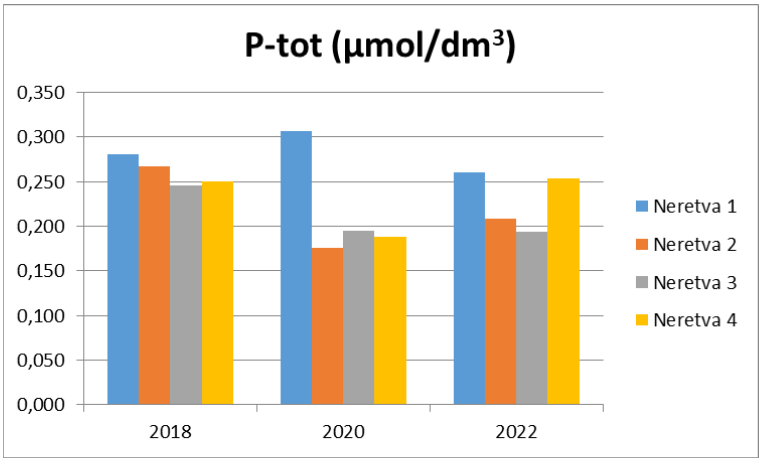

Figure 6. Annual mean concentrations of total phosphorous in the surface water layer.

The threshold for dissolved oxygen concentrations in the surface water layer has been set at the national level (20/2023). All of the measured concentrations lied below the threshold characterizing very good ecological status, therefore, the ecological status at all of the investigated sites in the pilot area is assessed as very good (Figure 7).

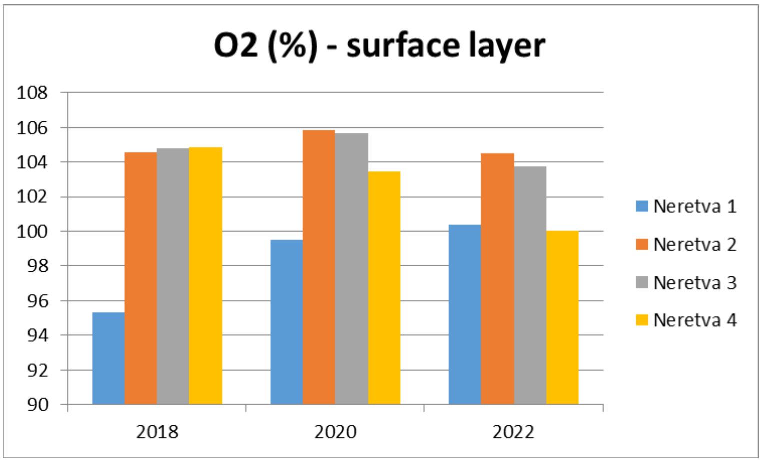

Figure 7. Annual median concentrations of dissolved oxygen in the surface water layer.

Chlorophyll a concentrations in the Neretva estuary are relatively low. Concentrations of chlorophyll a at all of the investigated sites in the pilot area were below 1 mg m^{-3} (Figure 8). The concentrations of chlorophyll a at all of the investigated sites were also below the threshold values supporting very good ecological status.

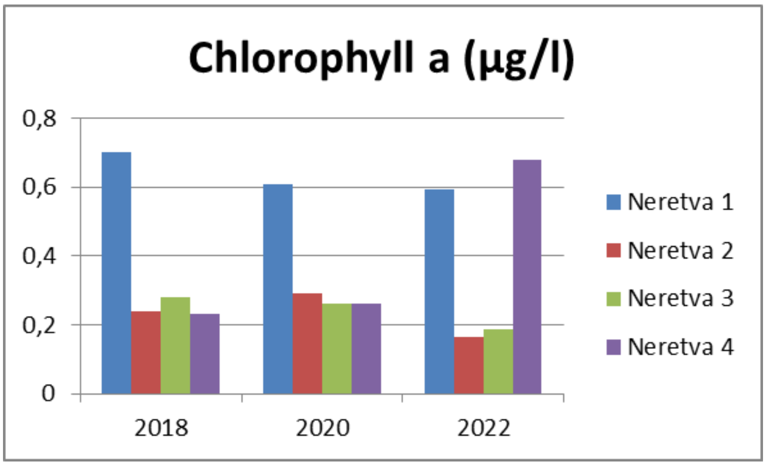

Figure 8. Annual median concentrations of chlorophyll a in the surface water layer.

5.3. Biological quality elements

The Water Framework Directive (2000/60/EC) proposes the assessment of ecological status based on abiotic parameters like nutrients, chemicals, or physical degradation, as well as the assessment based on biological quality elements (phytoplankton, macrophytes and phytobenthos, benthic fauna and fish) which provides an insight not only on the intensity of anthropogenic pressures, but also on their effects.

5.3.1. Biological quality elements – Fish

48 fish species were identified in the lower course of the Neretva river during the National monitoring program of coastal and transitional water quality in Croatia, in 2022. No freshwater species were found in the upper course of the estuary where the Atherinidae family was strongly dominant. Marine species were dominant in the lower course of the Neretva estuary, i.e. *Sarpa salpa*, *L. mormyrus*, *P. acarne*, *Pagellus erythrinus*, and *S. aurata*. The most abundant species in this area was *Sarpa salpa*, due to the presence of seagrass beds *Z. marina* and *C. nodosa*, as well as species representing the *Signathidae* family. *Liza saliens*

and *Liza ramada* were also abundant. The abundance of the European eel, *Anguilla anguilla*, was low – only one individual of this species was found in the Neretva estuary in 2022. According to the monitoring data collected in 2022, introduction of new alien species was not observed.

5.3.2. Biological quality elements – Benthic fauna

28 benthic invertebrates were identified in the Neretva estuary area during the National monitoring program of coastal and transitional water quality in Croatia, in 2020. The benthic macrofauna community structure was dominated by marine bivalves *Corbula gibba* (45,2%) and *Nucula ntidosa* (18.5%), followed by bivalves *Thyasira flexuosa* (8.1%) and *Abra alba* (3.1%), and marine polychaete worm *Sternaspis scutata* (3.9%).

5.4. Chemical pollution

5.4.1. Contaminants in sediment

Data on the levels of contaminants in sediments, including trace metals (cadmium, lead and mercury), polycyclic aromatic hydrocarbons (benzo[a]pyrene, anthracene, and fluoranthene) and organochlorine pesticides (hexachlorobenzene and hexachlorocyclohexane) have been collected at several sites in the pilot area, during the National monitoring program of coastal and transitional water quality in Croatia.

So far, no thresholds have been set for contaminants in sediments at the national or EU level, therefore, Norwegian system for classification has been applied to assess the status of sediment pollution (Bakke et al., 2010).

The Norwegian classification system sets five quality classes. Class I and II represent background concentrations or concentrations characteristic for an unpolluted environment. Classes III-V represent concentrations which may cause harmful effects on marine organisms after long-term (class III) or short-term (classes IV and V) exposure.

According to the aforementioned classification, the levels of metals (Cd, Pb and Hg) measured in sediments in the pilot area during 2018-2022 correspond to environmental background levels (Figures 9-11). Levels of polycyclic aromatic hydrocarbons (benzo[a]pyrene, anthracene, and fluoranthene) measured in sediments during the same period were below the threshold values above which long-term exposure may cause harmful effects to marine organisms. Levels of organochlorine pesticides (hexachlorobenzene and hexachlorocyclohexane) measured in sediments in the pilot area were very low - mostly below or just above the limit of the quantification of the applied analytical method.

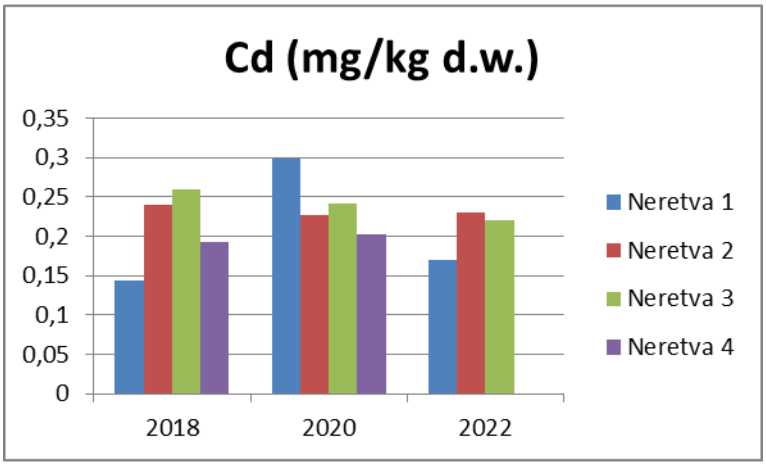

Figure 9. Concentrations of cadmium in sediment.

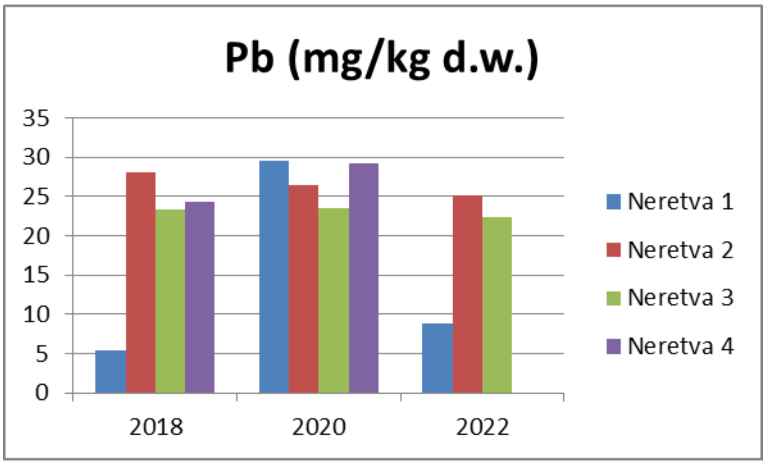

Figure 10. Concentrations of lead in sediment.

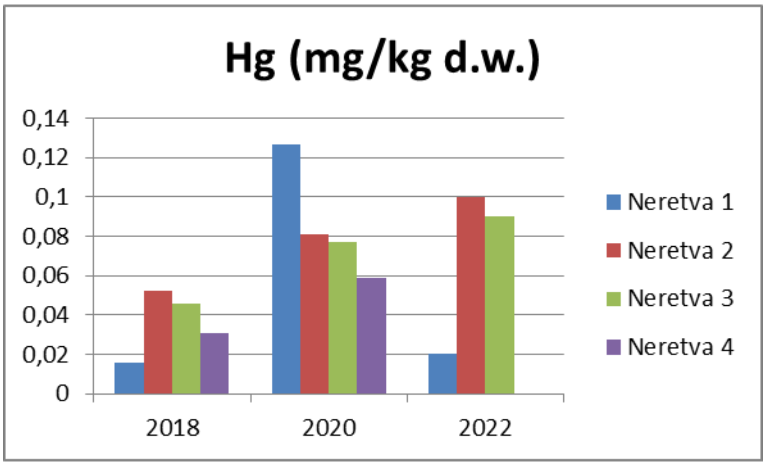

Figure 11. Concentrations of mercury in sediment.

5.4.2. Contaminants in seawater

Data on the levels of contaminants in seawater, including trace metals (cadmium, lead and mercury), polycyclic aromatic hydrocarbons (benzo[a]pyrene, anthracene, and fluoranthene) and organochlorine pesticides (hexachlorobenzene, hexachlorocyclohexane and cyclodiene pesticides: aldrin, isodrin, dieldrin and endrin) have been collected at several sites in the pilot area, during the National monitoring program of coastal and transitional water quality in Croatia. The threshold values for contaminants in seawater are set in accordance with the Directive 2008/105/EC and national legislation (NN 96/2019). Average annual concentrations of trace metals (Cd, Pb and Hg) in seawater at several sampling sites in the pilot area were below the threshold values supporting good environmental status. Average annual concentrations of polycyclic aromatic hydrocarbons (benzo[a]pyrene, anthracene, and fluoranthene), measured at several sampling sites in the pilot area in 2022, were below the limit of quantification of the applied analytical methods and below the threshold values supporting good environmental status. Similarly, concentrations of organochlorine pesticide compounds (hexachlorobenzene, hexachlorocyclohexane and cyclodiene pesticides: aldrin, isodrin, dieldrin and endrin) measured in seawater at several sampling sites in the pilot area during 2020 and 2022, were below the limit of quantification of the applied analytical methods and below the threshold values supporting good environmental status.

5.5. Introduction of non-native species

According to the study by Glamuzina et al. (2021), 12 species of non-native aquatic organisms have been identified in the River Neretva Estuary. At the time of the study, ten of these species, including freshwater fish species *Esox lucius* L., *Micropterus salmoides* (Lacepède), *Silurus glanis* L., *Synodontis eupterus* Boulenger; marine fish species *Epinephelus aeneus* (Geoffroy Saint-Hilaire) and *Pseudocaranx dentex* (Bloch & Schneider); brackish invertebrates *Callinectes sapidus* Rathbun, *Ficopomatus enigmaticus* (Fauvel); marine invertebrate *Arcuatula senhousia* (Benson) and tunicate *Mnemiopsis leidyi* A. Agassiz, were present in the area. Two species (marine invertebrates *Crassostrea gigas* (Thunberg) and *Ruditapes philippinarum*) were found in close proximity and likely to enter the area in the near future.
The largest population of blue crab, *Callinectes sapidus*, in Croatia is present in the area of the Neretva estuary. The species is particularly abundant in the Parila lagoon. The species carries a high risk of invasiveness under current climate conditions. According to reports from citizens and data collected through interviews with fishermen, it can be concluded that the population of blue crab is constantly expanding. Comprehensive research in coordination with fishermen, local NGOs and agencies for environmental protection is required to map the blue crab distribution and assess the ecological impacts of blue crab invasion, in order to support the development of adequate measures aiming to control the population of this species.

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6. PP5 - Pilot area Mali Ston Bay

6.1. Pilot area description

Mali Ston Bay is located in the southern part of the Adriatic Sea, between land and Pelješac Peninsula, continuing into the Neretva River channel. Mali Ston Bay, with its numerous coves and islets, has a highly indented coastline that stretches for about 100 km. The maximum depth in the outer part of the bay reaches 29 meters, while in the inner part, it does not exceed 10 meters.

Since 1983, the bay has been designated as a special nature reserve due to its exceptional natural and economic value. The total surface area of the special marine reserve is 14,898.97 km^2 (land section 9,181.09 km^2, marine section 5,717.88 km^2).

According to data from the climatological meteorological stations (KMP) Ston and (GMP) Ploče for the period 1999-2018, the average annual temperature was 16.1 °C. The average monthly air temperature of the coldest month (January) was 7.6 °C, while the average monthly air temperature of the hottest month (July) was 25.7 °C. The average annual precipitation for the mentioned period was 1315 mm of water.

Mali Ston Bay is a relatively shallow area, characterized by significant seasonal variations in sea water temperature, with extreme values occurring in the surface layer. The maximum temperature in July can exceed 26 °C, while the average temperature in January is 9.5 °C. In the outer part of the bay, the surface temperature is rarely below 10 °C, while in the shallow inner parts of the bay, during harsh winters, it can approach 0 °C.

Salinity values vary considerably. The salinity in Small Ston Bay is lower than that of the open sea, and it is especially variable in the surface layer. Low surface salinity values are associated with increased inflow of rainfall and freshwater from springs and the Neretva River. The highest salinity, with small annual fluctuations, occurs below 10 meters of depth. In the outer part of the bay, bottom salinity values can reach up to 38. In the inner part of the bay at the Usko station, according to data from several sources and years, salinity ranged from 21.97 to 38.65. The distribution of water density generally follows the distribution of salinity, with the lowest density values corresponding to the lowest salinity values.

The bay’s proximity to the Neretva River, tidal currents, submarine freshwater springs (vruljas), and increased nutrients create a unique ecosystem. These factors contribute to a high abundance of plankton and suspended organic matter, supporting dense populations of suspension-feeding organisms. These specifics have long been recognized and used for the cultivation of oyster shellfish, *Ostrea edulis*.

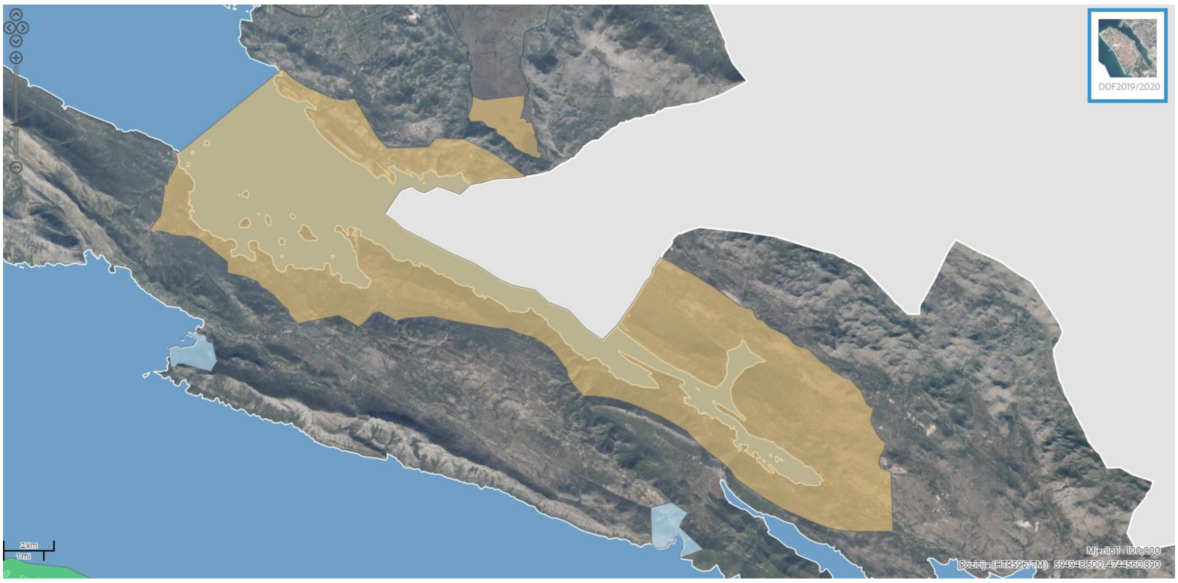

Figure 1. Mali Ston Bay area

6.2. Biodiversity of Mali Ston Bay

Mali Ston Bay has a deeply indented coastline, featuring many islets and reefs. The bay's unique enclosure, tidal currents, the influence of the Neretva River, numerous submarine springs, and the abundance of nutrient salts and minerals all combine to foster high primary biological production, supporting a wide variety of species.

The reefs of Mali Ston Bay are the habitat of numerous species of organisms including fish, sponges, cnidarians, crabs, bivalves, echinoderms and many others. A total of 16 strictly protected species have been recorded in Mali Ston Bay so far, in accord with national Regulation on strictly protected species (Official Gazette of The Republic of Croatia, No. 144/13 and 73/16). These include brown algae of Cystoseira genus (*Cystoseira corniculate*, *Cystoseira crinitophylla*, *Cystoseira foeniculacea*, *Cystoseira spinosa*, *Fucus virsoides*), flowering marine plants (slender seagrass – *Cymodocea nodosa*, and Neptune grass – *Posidonia oceanica*), bivalves (date mussel – *Litophaga litophaga*, common piddock – *Pholas dactylus* and noble pen shell – *Pinna nobilis*), false black corral (Savalia savaglia), sponges (*Geodia cydonium, Sarcotragus foetidus, Sarcotragus spinosulus, Tethya aurantium*), as well as long-snouted seahorse (*Hippocampus guttulatus*). Strictly protected species bottlenose dolphin (*Tursiops truncatus*) and strictly protected and sensitive species loggerhead sea turtle (*Caretta caretta*) can often be spotted in Mali Ston Bay, as they come here to feed.

The main threat to *Fucus virsoides* in Mali Ston Bay is overgrazing by sea urchins, which requires urgent monitoring and removal efforts. The pen shell (*Pinna nobilis*) is widespread in the bay, though its population has suffered heavy mortality (20% to 100% per site). Detailed monitoring is needed to identify surviving specimens and protect them for population restoration across the Mediterranean.

The bay's shallow rocky bottom was previously damaged by the harvesting of *Lithophaga lithophaga*, a practice now prohibited but still occurring to a limited extent. This harvesting likely contributed to the spread of sea urchins, which have eliminated macroalgae, creating barren areas that may last for decades. Recovery of *Cystoseira* species and associated marine life is not expected soon.

Some areas, particularly around Ostrog Peninsula and Duba Stonska, still feature algal communities dominated by *Cystoseira* and *Sargassum*, but these are also threatened by sea urchins. Controlling sea urchins could help protect these valuable ecosystems, which are home to several legally protected species.

Research found no significant populations of commercially important species like *Ostrea edulis* and *Mytilus galloprovincialis*, with mussels absent from six out of eight surveyed transects.

6.2.1. Threats to biodiversity

The biodiversity is influenced by the geographical position, geology, climate, and soil. Anthropogenic influences also have an important effect on the flora and the vegetation.

The survival and growth of both wild and farmed species in Mali Ston Bay, including the endangered European flat oyster (*Ostrea edulis*), Mediterranean mussels (*Mytilus galloprovincialis*), and protected

Pinna nobilis, are closely linked to the bay's ecosystem health. Changes that increase organic and inorganic matter flow from land, such as construction or improper agricultural practices, could harm this delicate balance.

A significant threat to both biodiversity and shellfish farming in Mali Ston Bay is plastic waste generated during shellfish cultivation. Large quantities of discarded plastic pergola bags and ropes, as well as plastic nets, eventually break down into microplastics that contaminate the sea.

Effective management of Mali Ston Bay and its Natura 2000 protected area is crucial for preserving biodiversity and ecosystem services, with bivalve shellfish aquaculture playing a key role in the local economy. It is also important to consider the broader surrounding area that impacts the bay's ecological status.

6.2.2. Non-native species

The studies identified seven alien macroscopic species: algae (*Asparagopsis armata* (falkenbergia faza), *Caulerpa cylindracea*), sponge (*Paraleucilla magna*), polychaete (*Hydroides elegans*), bryozoa (*Amathia verticillate*), sea slug (*Bursatella leachii*, *Melibe viridis*).

The green alga *Caulerpa cylindracea* is one of the most invasive species in the Mediterranean, with rapid spread. First recorded in Croatia in 2000 on Pakleni Island, it has since spread throughout the coast, excluding the Velebit Channel. While identified over a decade ago in Mali Ston Bay, it has only been found in Bistrina Cove, where it forms dense patches on the muddy seabed at around 8 meters depth. This species is expected to continue spreading, especially in nutrient-rich areas like shellfish farms.

An unexpected finding was the fouling of two alien species, *Paraleucilla magna* (a sponge) and *Hydroides elegans* (a polychaete), on shellfish farm structures. These species were found in Bistrina and Kuta coves, likely affecting most shellfish facilities. They create dense overgrowth on oysters and mussels, which hampers their development and complicates preparation for sale. Monitoring and research are needed to assess and mitigate their impact on shellfish farming.

The blue crab (*Callinectes sapidus*) is another species with a population that surpasses all others. It has established itself in the Neretva River delta and is found along the entire eastern Adriatic coast. Its spread across the globe is attributed to ballast water transportation. The first sightings in the eastern Adriatic were recorded in 2004, near Ston and the Neretva River delta. Due to its resilience, high reproductive rate, and ability to adapt to a variety of environmental conditions, the blue crab has been classified as one of the most aggressive invasive species in the Mediterranean. As the blue crab primarily feeds on molluscs, monitoring its population is crucial to assess potential risks to oyster and mussel farming in the bay

Other recorded alien species, such as the filamentous phase of *Asparagopsis armata*, do not pose significant threats. While they occur widely, their tetrasporophytic phase lacks invasive characteristics. Other alien species are rare and are unlikely to pose major ecological or economic risks.

6.3. Aquaculture in Mali Ston Bay

Aquaculture has been developed in Mali Ston Bay since ancient times. Today, oyster and mussel farming, as well as fishing, are well-established.

6.3.1. Oyster and mussel farming

Mali Ston Bay is one of the last remaining areas in Europe with a stable population and reproductive cycle of the European flat oyster. The first farms date back to the Roman Empire, and since the 16th century, during the Dubrovnik Republic, oyster farming became a well-established practice. From the early 20th century, the farming of other bivalve species, such as the Mediterranean mussel (*Mytilus galloprovincialis*), also began. The unique characteristics of the European flat oyster from Mali Ston Bay are influenced by the organoleptic qualities of its flesh. In 2019, the European flat oyster became the first seafood product in Croatia to receive the protected designation of origin. Today, nearly 86% of Croatia's total production of European flat oysters and Mediterranean mussels takes place in Mali Ston Bay. In 2019, farms in the bay produced over one million European flat oysters and around 426,000 kg of Mediterranean mussels.

6.3.2. Fish farming

Commercial aquaculture in Mali Ston Bay focuses on breeding fish from juvenile to adult stages, primarily involving two species: sea bass (Dicentrarchus labrax) and gilthead sea bream (Sparus aurata), with smaller quantities of meagre (Argyrosomus regius). As there is no hatchery within the bay itself, the production cycle starts with the collection of juveniles, aged 90-120 days, which are raised in our hatcheries or in other Mediterranean countries. This process typically occurs in the spring or early summer, when the water temperature reaches the optimal range of approximately 15°C. The usual breeding cycle from juvenile to adult fish takes about two years.

The catch of the benthic trawl showed 41 species of fish, 6 species of cephalopods and 2 species of crustaceans.Among the catch were several commercially important species, including the common pandora (*Pagellus erythrinus*), red mullet (*Mullus barbatus*), hake (*Merluccius merluccius*), bogue (*Boops boops*), and blotched picarel (*Spicara maena*).

Among the fish that are new in the Adriatic Sea and were also observed in the Mali Ston Bay there are: the yellowmouth barracuda (*Sphyraena viridensis*), the white grouper (*Epinephelus aneus*) and the Atlantic tripletail (*Lobotes surinamensis*).

6.4. Tourism in Mali Ston Bay

The Mali Ston and Malo more area is protected as a special marine reserve, primarily to preserve the region's long-standing tradition of oyster farming, which depends on the maintenance of specific ecosystem characteristics. This protection has contributed to the preservation of the ecosystem over time, benefiting other activities as well. Apart from aquaculture, tourism is the second most important economic activity in the area, relying heavily on the bay's natural beauty and local seafood gastronomy, alongside cultural landmarks.

With the main economic activities of the entire Pelješac Peninsula being tourism, agriculture, and aquaculture, Mali Ston Bay aligns well with these sectors. While tourism and aquaculture often compete, in this case, they complement each other naturally, offering significant potential for the development of this rural area. Oyster farming, by preserving pristine environmental conditions, not only supports sustainable use of marine resources but also enhances the region's tourism, exemplifying the successful coexistence of these two sectors.

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7. PP6 – The Coast of San Benedetto del Tronto – Natural Reserve Sentina

7.1. Pilot areas description

The pilot area (PP6) is included between the port of San Benedetto del Tronto (AP) and the coast up to the Tronto river, approximately 4 km south of the city.

The coastal area between San Benedetto del Tronto and Porto d'Ascoli extends along the Adriatic coast and is characterized by a strong interaction between natural factors and anthropogenic activities.

Figure 1: Pilot Area PP6

7.2. Seabed Characteristics and Sedimentology

The seabed of the area is predominantly sandy, with stretches of mixed substrate (sand and gravel) near the mouth of the Tronto river and in some deeper areas. The type of sediment present is mainly made up of:

- Fine and medium sands with good nutrient retention capacity;
- Silt fractions in the most protected areas and near river outlets;
- Organic sediments resulting from human and river input.

The influence of the Tronto River contributes to the granulometric variability and the presence of organic debris, which can affect the quality of the benthic habitat.

7.3. Marine Biodiversity

The area hosts a variety of fish species, many of which are of commercial and biological interest. Among the main species present we find:

- Pelagic fish: anchovy (Engraulis encrasicolus), sardine (Sardina pilchardus), mackerel (Scomber scombrus);
- Demersal fish: red mullet (Mullus barbatus), sole (Solea vulgaris), turbot (Scophthalmus rhombus), hake (Merluccius merluccius);
- Bottom-water species: scorpion fish (Scorpaena porcus), blenny (Blennius spp.);
- Precious species: sea bass (Dicentrarchus labrax), gilt-head bream (Sparus aurata), grey mullet (Mugilidae) etc..

Among the species present of greatest conservation interest we have: Alosa fallax, Tursiops truncatus; Stenella coeruleoalba; Delphinus delphis; Caretta caretta; Hippocampus hippocampus; Anguilla anguilla.

The sandy and mixed bottoms offer ideal habitats for benthic species, while the presence of artificial structures (breakwater reefs) favors the settlement of diversified fish communities.

The presence of non indigenous marine species such as blue crabs, can still be considered sporadic and concentrated in two main areas: the Tronto river estuary and the area near the San Benedetto harbour. The quantities fished are minimal and with strong oscillations.

7.4. Fishing Techniques Used

Fishing activity in the area is well developed and includes both industrial and artisanal fishing.

Considering that San Benedetto del Tronto is one of the main fishing harbour on the central Adriatic area; the most used techniques are:

- Trawling: practiced at different depths, it impacts the seabed and benthic communities;
- Gil nets: used to catch demersal species such as sole and turbot;
- Traps: used for gastropods and molluscs;
- Longline: used to catch valuable species such as sea bass and gilt-head bream;
- Sport and recreational fishing: widespread along the coast, with techniques such as trolling and surfcasting.

The presence of numerous fishing boats in the port of San Benedetto del Tronto testifies to the importance of fishing activity for the local economy.
It should be noted that both small-scale coastal fishing operators and hydraulic dredges for camelea galina clams fish within 3 miles of the coast, generating strong inshore fishing pressure. A mussel farming plant is located approximately one mile in front of the mouth of the Tronto River.

7.5. Conditions of Anthropization of the Coast

The coastal area between San Benedetto del Tronto and Porto d'Ascoli is heavily anthropized due to the presence of port, tourist and residential infrastructures. The main impact factors are:
- Intense urbanization with beach resorts, hotels and residences;
- Fishing and tourist port that generates maritime traffic and releases pollutants;
- River and urban discharges that affect water and sediment quality;
- Coastal defense works such as breakwaters and artificial barriers that modify coastal dynamics.

7.6 Natual reserve of Sentina

The Special Conservation Area “Litorale di porto d’Ascoli” extends for 109 ha within the Sentina Regional Nature Reserve in the municipal area of San Benedetto del Tronto.
It concerns the stretch of coastline between the mouth of the Tronto River to the south and the town of Porto d'Ascoli to the north and consists of a set of small brackish ponds and retro-dune salt meadows with plant associations highly specialized to the coastal environment and therefore completely peculiar. The area includes remnants of ecosystems typical of low and sandy coasts, once very widespread but today of great interest as they are now very rare throughout the regional coastline, almost continuously anthropized; in particular, it is the only evidence of a brackish marsh environment left in the Marche.
The nature reserve is managed by the Municipality of San Benedetto del Tronto which operates in accordance with the acts expressed by a special steering committee composed of representatives of the

Municipality of San Benedetto del Tronto, the Marche Region, the Province of Ascoli Piceno and the Municipality of Ascoli Piceno. La Sentina is included in the Natura 2000 project as ZSC IT5340001.

As indicated in the D.G.R. n. 831 of 05.10.2015 (L.R. 6/2007 - D.G.R. 617/2015 - European ecological network "Natura 2000" - Extension of the perimeter of IT5340001 "Litorale di Porto D'Ascoli" by adding the sea territory opposite the land one), by which the Marche Region approved the extension of the perimeter of the Natura 2000 site also including a marine area, in agreement with the Province of Ascoli Piceno Service, the entity responsible for managing the Site is the Municipality of San Benedetto del Tronto.

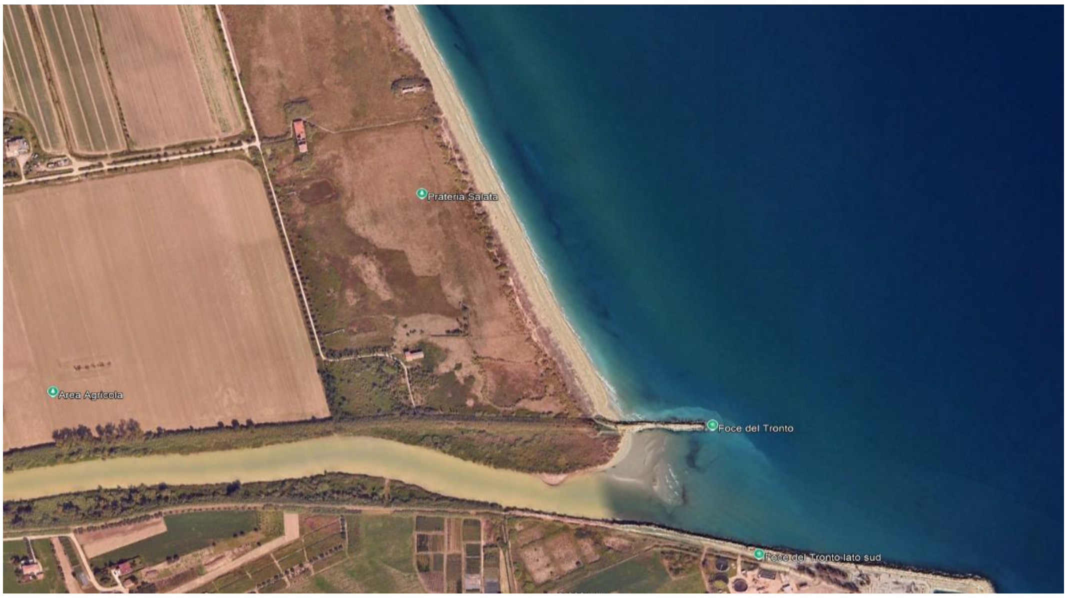

Figure 2: Tronto River estuary

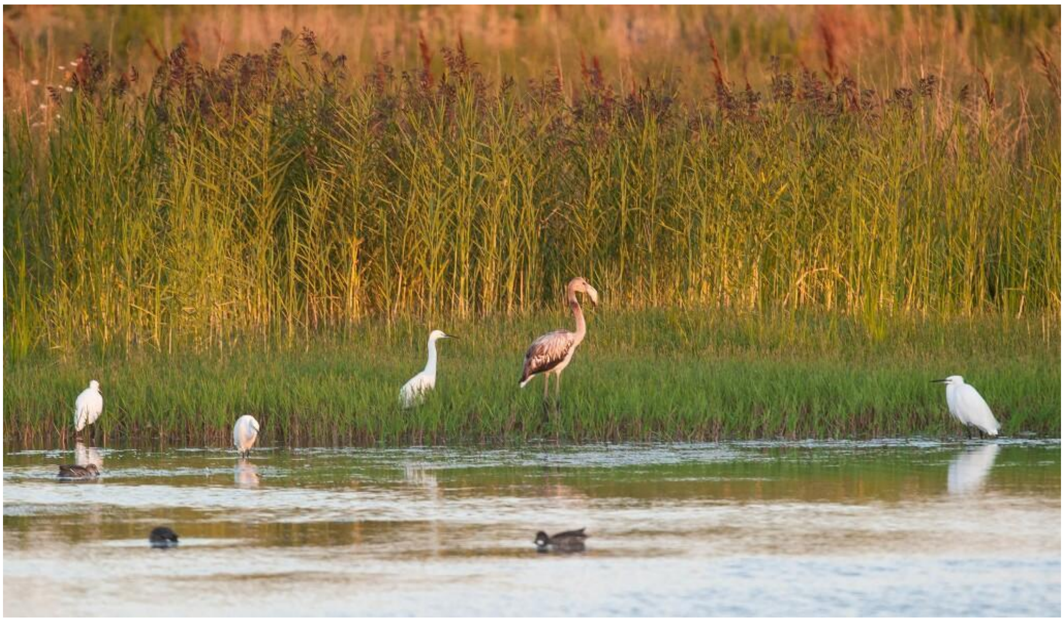
Figure 3: Sentina Natural Reserve

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8. PP7 - Venice Lagoon

8.1. Pilot area description

The Venice Lagoon, situated in the north of the Adriatic Sea, represents the largest transitional environment within the Mediterranean Sea, covering an area of almost 550 km^2 (Sfriso *et al.*, 2009; Madricardo *et al.*, 2019). It is divided into three hydrographic basins, each of which is connected to the sea by a mouth: the northern basin (Lido mouth), the central basin, including the town of Venice and the Marghera industrial site (Malamocco mouth) and the Chioggia basin, including the town of Chioggia (Chioggia mouth) (Fig.1).

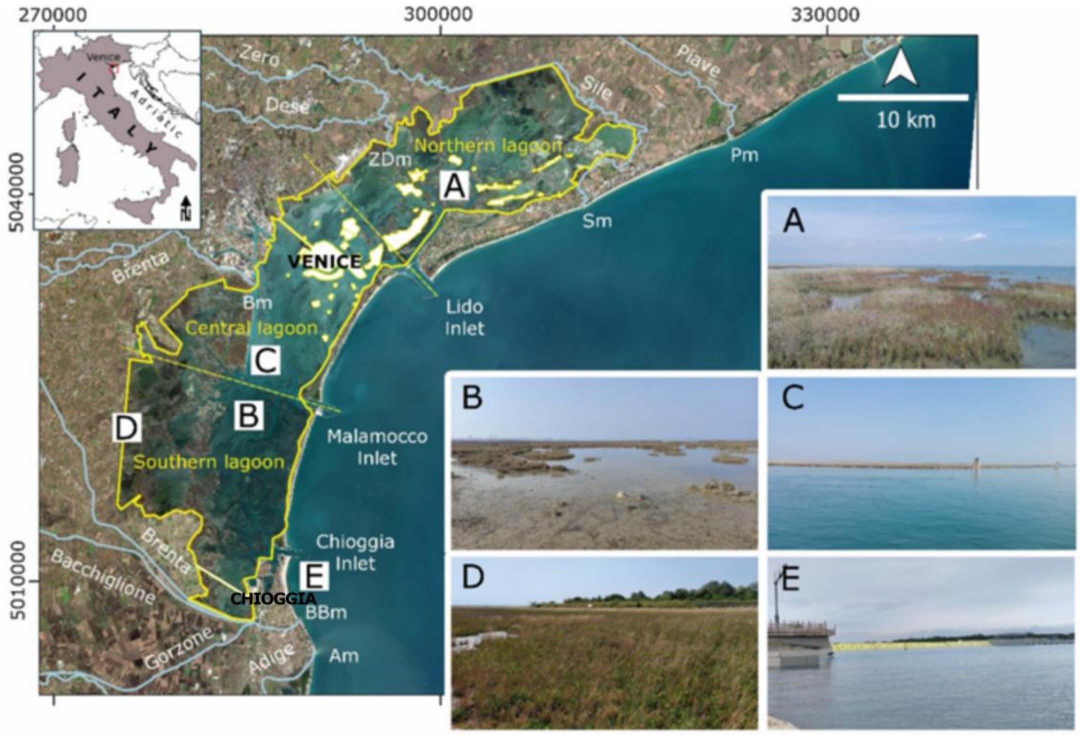

Figure 1. Satellite image showing the Venice lagoon. The yellow line delimits the lagoonal areas that are the subject of the vulnerability analysis of tidal morphologies to RSLR. The yellow dashed line separates the northern, central and southern lagoon sectors. Blue lines represent the current course of the main rivers and channels. Abbreviations refer to the river mouths, most of which were diverted from the lagoon to the sea between 1300 and 1800.The photos on the right show typical (**A**) salt marsh, (**B**) tidal flat, (**C**) subtidal flat morphologies, (**D**) the embankments bordering the lagoon margin, (**E**) the Mo.S.E. mobile barriers. Coordinate system: EPSG 32633**.** (Tosi *et al*., 2024)

The lagoon basin primarily consists of shallow waters, averaging 1.2 meters in depth, interspersed with a network of deeper channels that can reach depths over 15 meters (Solidoro *et al*. 2004; Molinaroli *et al*. 2007). The water's movement is largely influenced by winds and tides, with typical tidal fluctuations of around 1 meter. Environmental conditions in the lagoon are characterized by strong spatial and temporal gradients that are influenced by both natural processes, such as tides and the freshwater inflow of a few local rivers, and anthropogenic pressures (Solidoro *et al*. 2010). The high degree of environmental heterogeneity and the geomorphological variability contribute to creating a highly diverse seascape of islands, salt marshes, tidal creeks, mud- and sandflats with or without transient macroalgal beds, seagrass meadows, channels and man-made structures (Franzoi *et al*. 2010; Solidoro *et al*. 2010; Scapin *et al*. 2018). This impressive diversity of habitats provides a broad set of regulating, provisioning and cultural

Environmental Services. (D'Alpaos and D'Alpaos, 2021, Rova *et al*., 2022, Rova *et al*., 2019, Rova *et al*., 2015, Stocco *et al*., 2023).

The Lagoon is home to two key ports: Venice and Chioggia, serving both international and local maritime traffic. Venice's port is divided into two main areas: the commercial terminal in Marghera, accessed via the Malamocco inlet, and the passenger terminal along Venice's historic center's western edge, reached through the Lido inlet, catering to cruise ships, ferries, and hydrofoils. As one of Italy's most significant ports, the commercial terminal spans over 20 km² and boasts 30 km of dockage.

8.2. Biodiversity of the Venice Lagoon

The great variety of habitats present in the Venice Lagoon, hosts a plethora of plant and animal species and area is included in the Natura 2000 sites list, Natura and Bird directive. We can find three kinds of macroscopic photosynthetic taxa: seaweeds, seagrasses, and halophytic vegetation (which mainly colonize saltmarshes). As primary producers, they sustain the whole trophic web of the Venice Lagoon. These organisms serve as habitats and foraging areas for numerous faunal species, thereby supporting substantial populations of both commercial and recreational fish species (Macreadie *et al*., 2017). Moreover, higher plants, like seagrasses and halophytes, with their root system, compact and stabilize the soil (Macreadie *et al*., 2017; Sfriso *et al*., 2017), also providing oxygen and nutrients to the environment (Macreadie *et al*., 2017). This aspect is particularly significant in the Venice Lagoon, characterized by the prevalence of medium-fine sediments (Taramelli *et al*., 2021) and high anthropogenic impact, which significantly enhance sediment resuspension and erosion of saltmarshes. Algae shows an impressive diversity, mostly represented by the 204 species of phylum Rhodophyta. Plants are instead represented by 18 species (Drigo *et al*., 2024).

The Venice lagoon's fish population comprises 94 species, categorized primarily as marine stragglers (55 species), followed by marine migrants (16 species), and lagoon residents (15 species) (Scapin *et al*., 2019). Characteristic species of these environments include the Mediterranean killifish (*Aphanius fasciatus*), the Adriatic lagoon goby (*Knipowitschia panizzae*), and notably, the black-spotted goby (*Ninnigobius canestrinii*). Among the marine migrants are species like sea bream (*Sparus aurata*), European seabass (*Dicentrarchus labrax*), European flounder (*Platichthys flesus*), common sole (*Solea solea*), and various mullet species (*Chelon ramada, C. auratus, C. saliens, C. labrosus, and Mugil cephalus*). These species, particularly in their juvenile stages, congregate in the Venice lagoon and form significant stocks for local fisheries (Cavraro et al., 2017).

The lagoon of Venice is the largest Important Bird Area (IBA) on a national scale, counting the highest number of species of Community importance to be preserved (Coccon *et al*., 2016). A total of 140 breeding species have been recorded in the lagoon, representing around 55% of the known species for Italy. Several waterbirds' species are strongly related with the reedbeds like Pygmy cormorant, Eurasian Bittern, Purple Heron, Little Bittern, Marsh Harrier, Hen Harrier and Common Kingfisher. Furthermore, we can also find many passerines with the same ecological relationship as Savi's warbler, Reed Bunting, Bearded Reedling, and Reed Warbler.

8.3. Threats to biodiversity

The Venice lagoon ecosystem has been subjected to multiple severe human-induced pressures over the past decades. Significant impacts stem from a large human population and its diverse activities, including substantial nutrient inputs from agriculture and industrial processes (Occhipinti-Ambrogi and Savini, 2003). The Porto Marghera industrial complex has significantly contributed to environmental contamination, particularly through heavy metals and other pollutants. Extensive hydraulic engineering projects, notably the excavation of deep channels, have fundamentally reshaped the lagoon's hydrological dynamics. These alterations have had a profound impact on the distribution patterns of both pollutants and nutrients throughout the ecosystem.

Aquaculture and fishing activities, particularly mechanical clam fishing of the introduced *Ruditapes philippinarum* (which arrived in 1983, Cesari and Pellizzato, 1985a), have dramatically transformed the ecosystem by spreading nutrients (Sfriso *et al*. 2003) and pollutants (Masiol *et al*. 2014), increasing sedimentation rates up to 16 times, and affecting water turbidity and sediment characteristics (Sfriso *et al*. 2005; Pranovi and Giovanardi 2004). Increases in turbidity can impact the survival of the phytobenthos, particularly affecting sensitive species, such as seagrasses, consequently further degrading the integrity of the benthic compartments (Sfriso *et al*., 2017). Moreover, seagrass loss may result in a decline in nursery habitats crucial for many species, including commercially important fish species, potentially leading to significant economic impacts on fisheries operating in these areas (Solidoro *et al*., 2010).

Additional environmental stressors include widespread erosion of tidal forms, accelerated by faster currents, motor-boat waves, sea-level rise, groundwater abstraction, and the recent installation of storm-surge barriers (MoSe implementation 2021). These cumulative pressures have led to significant biodiversity loss, disrupted macrophyte growth, and profound changes to benthic macrofauna, fundamentally compromising the lagoon's ecological integrity.

Additionally, climate change impacts are already noticeable in this area, manifesting as frequent heat waves, increased salinity in several farming sites, and changes in primary production (Soulíe et al., 2023). These events may directly affect filter feeding organisms, as observed in recent years with the Manila clam *Ruditapes philippinarum*, which experienced a dramatic decrease in natural stocks and annual production

(Milan *et al.*, 2023). Although the International Union for Conservation of Nature (IUCN) – Red List stands as a global reference for threatened species, it predominantly features terrestrial organisms, with limited occurrence of macroalgae and halophytes, leaving many categorized as non-evaluated (NE) (IUCN, 2024).Considering vegetal species documented in the Venice Lagoon, only some halophytes and all seagrasses are included in the list, with many designated as Low-Concern (LC). Many of the bird breeding aquatic species have a restricted areal distribution linked to wetlands, or small populations, whose survival is threatened (Campostrini and Dabalà, 2017). Among the species of conservation interest, included in the Birds Directive (Annex I), are *Charadrius alexandrinus, Sternula albifrons, Sterna hirundo, Sterna sandvicensis, Circus aeruginosus, Circus pygargus, Circus cyaneus, Recurvirostra avosetta, Himantopus himantopus, Botaurus stellaris, Ixobrychus minutus, Egretta garzetta, Ardea alba, Ardea purpure*a.

The area hosts several IUCN list fish species such as the critically endangered *Anguilla anguilla* and the vulnerable *Pagrus pagrus* and *Scophthalmus maximus.* Four species are of EU importance, included in the Habitat Directive: *Alosa fallax, Aphanius fasciatus, Knipowitschia panizzae, Pomatoschistus canestrinii.* (REST-COAST)

8.4. Non-Indigenous Species of the Venice Lagoon (NIS)

Venice Lagoon is a known hotspot of non-indigenous species (NIS) introductions within the Mediterranean Sea, harboring at least 34.6% of the total NIS found in the Mediterranean basin (Manghisi *et al.*, 2011) and hosting all the most important vectors of introduction of marine NIS—shipping, recreational boating, shellfish culture and live seafood trade.

It has been shown that about 20 edible species of exotic origin are regularly traded live for fish markets and processed near the lagoon canals, and might be accidentally released in the wild. Other non-commercial NIS, such as macroalgae used as packaging material for bivalves sold in the fish market, are also likely to be accidentally released in the lagoon waters (Sfriso and Marchini, 2014).

Human pressure and climate change altering the environmental dynamics of this ecosystem, pose a serious threat to the specialized native flora and fauna, consequently increasing the vulnerability of the Lagoon to biological invasions.

NIS pose a dual threat: they can lead to the extinction of native, vulnerable species, while also disrupting entire ecosystems by altering biogeochemical cycles and trophic chains, with consequential impacts on human well-being (Katsanevakis et al., 2014; Gallardo et al., 2016; Cuthbert et al., 2021; Sfriso et al., 2023). 71 non-indigenous species were censused in 2015 by Marchini and colleagues, mainly arrived through ballast waters (Galil *et al.*, 2014). Of those 29 are macroalgae, 13 molluscs, 13 crustaceans, 4 annelid worms, 4 cnidarians, 4 tunicates, 3 bryozoans, and 1 pycnogonid.

In 2023 Sfriso et al., identified 33 NI seaweed species and 2 halophytic species.
Only 3 NIS were intentionally introduced for culture purposes: the Manila clam *R. philippinarum*, the Pacific oyster *C. gigas*, and the rock oyster *Saccostrea glomerata* (Gould 1850).
Recently (since 2014–2016) the local artisanal fishery has suffered the strong negative impact of the invasive ctenophora *M. leidyi*, a plausible responsible for the reduction of landings of some main fishing target species, such as *Z. ophiocephalus* and *S. officinalis*, due to mechanical or trophic reasons or a combination of them. This situation could bring to the total loss of this traditional type of fishing in this lagoon, thus impacting both the local economy and the Venetian cultural heritage. (Piccardi *et al*., 2024)

The blue crab (*Callinectes sapidus*), a non-indigenous species, has become a significant biological and economic concern in the Venice Lagoon. First reported in 1943, likely introduced via ship ballast water, it only established widespread populations along the Veneto coast by 2010. Recent years have seen an alarming increase in its numbers. As a generalist and omnivore, the blue crab significantly impacts local flora and fauna, notably reducing populations of the commercially important native green crab, *Carcinus aestuarii*. However, the most severe economic damage is to bivalve aquaculture, particularly clam farms, where the blue crab preys on young and newly seeded clams, causing substantial losses. According to Fedagripesca, a prominent fishing industry association, the blue crab invasion has inflicted approximately €100 million in economic damage throughout Italy. In the Po Delta region, the impact has been particularly severe, with the species decimating up to 90% of juvenile clam populations.

8.5. Aquaculture in the Venice Lagoon: Current Practices and Economic Significance

8.5.1. Shellfish farming

The Venice Lagoon has historically been a crucial center for shellfish aquaculture in Europe, particularly for clam production (Boscolo-Brusa` *et al*. 2013), with 4,500 hectares dedicated to shellfish farms managed by 497 licensed operators, of which 253 are in the Chioggia basin (Marchini et al., 2015). The primary species cultivated is the Indo-Pacific Manila clam *(R. philippinarum*), which reached peak production of approximately 40,000 tons annually between 1995 and 2000 (Sfriso *et al*. 2014). However, due to overexploitation through indiscriminate harvesting of natural beds, illegal collecting, use of high-impact harvest gear, poor programming schedules, and inadequate management of nursery areas, production dramatically declined to around 2,000 tons by 2012. Recent data shows a continuing decline, with 2020 farming production estimated at 1,698 tons, representing a 21.3% decrease from 2019, plus an additional 527 tons from fishing in free-access areas. Since the late 1990s, local authorities have implemented regulations for clam culture activities, focusing on wild spat harvesting and seeding in licensed areas (Orel *et al*. 2000). However, the availability and quality of wild *R. philippinarum* stocks remain limiting factors for the industry's development. Farmers increasingly rely on imported seeds, with over 451,000 kg of Manila clam seeds imported from foreign hatcheries in 2013 (Marchini et al., 2015).

Beyond clam farming, the Venice Lagoon is also significant for mussel and oyster cultivation. The Mediterranean mussel (*Mytilus galloprovincialis*) is particularly important, with the lagoon contributing 25% of the Veneto region's total mussel production, generating approximately 3,000 tons and 2.2 million euros in revenue (Osservatorio Socio Economico Della Pesca e dell'Acquacoltura, 2021). The region also exports mollusk juveniles to other Italian farming sites, especially in Liguria and Sardinia in the Western Mediterranean (Prioli 2008).

8.5.2. Fish farming

Aquaculture in the Veneto region is uniquely defined by "Vallicoltura", a centuries-old extensive farming method employed in the brackish coastal lagoons. This time-honored practice adheres to a natural cycle comprising three primary stages:

Mounting (*Montata*): During spring, juvenile fish naturally migrate from the sea into the lagoon's valleys through specially designed sluice gates. However, due to pollution and unpredictable weather patterns affecting natural repopulation and reducing overall yields, this process is now augmented with artificial seeding.

Growing (*Allevamento*): The juveniles are initially placed in special ponds called "seragi" for controlled feeding and monitoring, before being released into the valleys where they grow from spring to autumn feeding on natural pastures.

Descent (*Discesa*): From September to January, fish instinctively return to the sea as lagoon waters cool, a process managed by lowering water levels and introducing warmer seawater. Fish move towards the exit canal and remain imprisoned in special traps (lavorieri) or directed to winter holding ponds if of too small size (Atlante della Laguna di Venezia).

Farmed species included euryhaline species such as European eel (*Anguilla anguilla*), flathead grey mullet (*Mugil cephalus*), european seabass (*Dicentrarchus labrax*) and gilthead seabream (*Sparus aurata*) (Istituto Veneto).

8.6. Tourism in the Venice Lagoon: Impacts, Challenges, and Sustainable Practices

The UNESCO World Heritage site "Venice and its Lagoon" fascinates people; it is one of the most popular Italian tourist cities and one of the top tourist destinations in the world. Venice recorded roughly 5.5 million arrivals in 2019, but only 53,000 people live in the historic part of the city.
Overtourism represents a significant problem for Venice inhabitants with overcrowding, steep prices and lack of housing possibilities at reasonable rates (there is an unfair competition, as yearly rentals are in the same market as the short-term ones): Venice central neighborhoods are experiencing a continuous de-population phenomenon, with people moving toward the inland area; in fact, starting from the mid-1960, the population has decreased from 100'000 to roughly 58'000. In addition to the stress imposed on the citizens, and the growing costs for the public finances, tourism causes also negative environmental effects such as air emissions, solid waste, sewage releases, and visual pollution. Overtourism is generating budget issues for the city finances, with always increasing upkeep and maintenance costs: 80% of Venice visitors are not staying overnight in the Lagoon and are spending only between 5 and 15 EUR in the city. In 2023, Venice registered more than 38 million touristic presences (accounting for more than half of the overall number for Veneto Region, totaling more than 71 million), official data for 2024 are currently not available but the number is expected to grow.

The Venice Lagoon has seen a significant increase in nautical infrastructure, with the number of marinas and yacht clubs growing from 24 in 2000 to over 30 today. Luxury yachting is actively promoted, evidenced by the installation of dedicated berths for yachts and mega-yachts in some of Venice's most picturesque locations (Porto di Venezia 2014).
In response to years of public protest, large cruise ships (exceeding 25,000 tons) have been prohibited from traversing the San Marco basin and Giudecca Channel since 2021. While new routes for these massive vessels are being developed and tested within the Lagoon, concerns persist. Although these ships no longer directly threaten Venice's central architectural heritage, their presence continues to pose significant risks to the Lagoon's fragile ecosystem.

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