Interreg

Co-funded by the European Union

Italy – Croatia

BIOPRESSADRIA

INTERREG ITALY-CROATIA PROGRAMME 2021 – 2027

Deliverable D.1.1.2

Report on characterization of habitat quality and pressures in pilot areas

Version: 1.0 (August 2026)

Interreg Co-funded by the European Union

Italy – Croatia

BIOPRESSADRIA

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1. Introduction and report context

1.1 Objectives of deliverable D.1.1.2 and cross-border cooperation

The main objective of Deliverable D.1.1.2 "Report on characterization of habitat quality and pressures in pilot areas" is to provide a comprehensive, data-driven assessment of the ecological status and anthropogenic pressures affecting selected coastal and marine ecosystems across the Adriatic Sea. Developed under Work Package 1 (WP1) of the BIOPRESSADRIA project, this report represents the direct operational deployment of the standardized methodological protocols established in Deliverable D.1.1.1.

Marine and coastal habitats within the Interreg Italy-Croatia cooperation area face intense and seasonal anthropogenic stress, primarily driven by nautical tourism, anchoring, and seaside recreation. To effectively mitigate these impacts, a coordinated cross-border approach is essential. Marine ecosystems, such as seagrass meadows, do not follow administrative borders; thus, protecting them requires synchronized monitoring tools and common diagnostic standards.

Deliverable D.1.1.2 fulfills this requirement by transitioning from theoretical protocols to empirical field results across five distinct geographic contexts in Italy and Croatia. To achieve this, the project implemented a flexible yet standardized set of methodologies. Rather than executing a rigid, identical set of surveys across all locations, the monitoring actions were tailored to the specific ecological and morphological features of each site. Crucially, to ensure a robust cross-border comparison, every specific monitoring technique was executed in at least one Italian and one Croatian pilot site. For instance, while the active bioacoustic monitoring of nektonic fauna was specifically conducted in Panzano Bay and the Kornati archipelago, the underwater *SCARS* protocol for anchor damage assessment was jointly deployed across Panzano, Kornati, and Badija.

Similarly, the distinct monitoring activities conducted in Porto Cesareo do not represent an exception to the project's standards, but rather a deliberate and necessary adaptation of the shared methodological framework to the site's unique environmental characteristics. This intrinsic adaptability ensures that all local assessments remain firmly aligned with the project's overarching goal: reducing the impact of coastal tourism and preserving biodiversity.

Ultimately, through this cross-border operational deployment, this report:

- **Formulates a standardized ecological baseline** for each pilot site, respecting local specificities.
- **Quantifies the spatial distribution and severity of pressures**, such as anchor-scarring, tourist trampling, and vessel congestion.

- **Delivers the critical empirical foundation** required to design, justify, and implement targeted conservation policies, eco-mooring installations, and spatial zoning plans in the subsequent phases of the project (WP2).

Beyond its technical scope, the data presented in this report acts as a fundamental knowledge tool for the stakeholder consultation process envisioned within WP1.1. By bridging the gap between empirical monitoring and collaborative governance, this deliverable ensures that the findings serve as a shared basis for co-designing effective management measures, ultimately fostering the long-term recovery and protection of the ecosystem value of the pilot areas.

1.2 Framework of the Adriatic cooperation area (Italy - Croatia)

The Adriatic Sea is a unique and highly vulnerable semi-enclosed basin within the Mediterranean. It is characterized by stark environmental gradients, ranging from the shallow, nutrient-rich, sediment-dominated waters of the Northern Adriatic to the deep, oligotrophic, rocky-island systems of the Dalmatian coast. At the same time, both the Italian and Croatian coastlines share an exceptional wealth of biodiversity, hosting critical ecological networks under the European Natura 2000 network, alongside an ever-growing socio-economic reliance on maritime tourism.

The BIOPRESSADRIA project targets five strategic pilot areas chosen to reflect this geographical and ecological diversity, providing a comprehensive cross-section of the cooperation area:

1. **Panzano Bay (Monfalcone, Italy):** Located in the northernmost tip of the Adriatic, this shallow estuarine environment represents a high-energy socio-economic context where marine seagrass habitats coexist with major commercial shipping routes, industrial ports, and dense local recreational boating.
2. **Marine Protected Area (MPA) Porto Cesareo (Lecce, Italy):** Situated along the Ionian-Adriatic transition zone, this site features highly dynamic coastal landscapes characterized by delicate sandy beaches, priority dune systems, and vast *Posidonia oceanica* meadows exposed to massive summer tourist influxes.
3. **Kornati National Park (Croatia):** A pristine archipelago in the central Adriatic, serving as an international hotspot for nautical tourism. Despite its protected status, it experiences intense seasonal anchoring pressure from yachts and recreational vessels within its sheltered bays.
4. **Pakleni Islands (Croatia):** Located off the coast of Hvar, these islands represent a highly prominent tourism destination facing extreme, unregulated seasonal anchoring, making them an ideal site to study damage to marine seagrass meadows.
5. **Natura 2000 Sites of the Dubrovnik-Neretva County – Badija Island (Korčula, Croatia):** Positioned in the southern Adriatic, this site highlights the ecological vulnerability of small-

island marine environments, where dense *Posidonia* beds are subjected to concentrated nautical mooring and localized organic pollution.

Working across these diverse coastal environments helps partners exchange practical solutions. The protection strategies tested in these sites could also offer useful insights for similar coastal areas in the region.



Figure 1 Project pilot sites: in Italy, Panzano Bay, MPA Porto Cesareo and, in Croatia, Kornati National Park, Pakleni Islands, and the area around Badija island off Korčula.

1.3 Summary of applied monitoring protocols

This report builds on the integrated monitoring methodologies defined in Deliverable D.1.1.1 to ensure data comparability across the five pilot sites. Rather than relying on isolated local approaches, project partners selected and applied appropriate techniques from a shared toolkit. Depending on site characteristics, these methods included satellite remote sensing, aerial photogrammetry, hydroacoustic technologies, or direct underwater scientific diving surveys.

Table 1 Methodological Matrix Applied in Pilot Areas (as defined in D.1.1.1)

Target Habitat / Pressure	Applied Methodology	Key Indicators & Parameters Captured
Marine Seagrass Meadows *(Posidonia oceanica, Cymodocea nodosa)*	• Diver-led quadrat sampling • Underwater video-transects • Side Scan Sonar (SSS) imaging	• Shoot density (shoots/m²) • Conservation Index (C.I.) • Meadow boudaries and fragmentation level
Nautical Tourism & Pressures	• Satellite imagery • In-situ visual boat counts	• Instantaneous and seasonal boat density • Vessel size distribution • Anchor spatial overlay on seagrass beds
Seabed Damage Assessment	• SCUBA visual validation • High-resolution seafloor mapping	• Frequency and length of anchor scars (scars) • Scar Damage Class ranking (Scales 1 to 5)
Dune Systems & Coastal Pressures	• UAV (Drone) Photogrammetry • RTK-GPS topographical tracking	• 3D digital surface models & volume tracking • Informal pedestrian path mapping • Dune vegetation loss/fragmentation
Nektonic Fauna & Mooring Noise	• Active bioacoustics • Underwater hydrophone arrays	• Fish school abundance and biomass tracking • Anthropogenic ambient noise profiles

1.4 Role of monitoring in assessing Pilot Action effectiveness

The monitoring activities presented in this report establish the ecological and pressure baseline against which the effectiveness of the WP2 Pilot Actions can be assessed during and beyond project implementation. Habitat quality indicators and pressure-monitoring results therefore provide an operational basis for evaluating management outcomes, supporting adaptive management and informing the design or refinement of future mitigation measures.

2. Integrated analytical methodological framework

This chapter explains the common methods used in all project areas so that data from Italian and Croatian partners can be easily compared. All field activities and data analysis followed the shared guidelines established in Deliverable D.1.1.1. The approach combines satellite and drone data with direct underwater checks to get a complete picture of the health of marine habitats and the impact of human activities.

2.1 Quality indicators for biological targets (marine seagrass and dune systems)

The biological status and structural health of target marine habitats, specifically focusing on seagrass meadows, were evaluated through a standardized sampling methodology. Monitoring activities included non-destructive sampling on the seabed to calculate shoot density, which serves as a primary indicator of ecosystem health. This metric was combined with a standardized classification scale to assess patch continuity and identify fragmented areas. To overcome local monitoring constraints, spatial mapping was supported by underwater observations to capture structural transitions across different zones. For the coastal and dune interface, fieldwork focused on tracking habitat vulnerability and assessing the impact of informal pedestrian paths created by summer beachgoers, integrating these data layers within a GIS environment to evaluate localized environmental pressure.

2.2 Quantification of pressures from recreational boating

The seasonal pressure from nautical tourism and recreational boating was mapped and quantified using an integrated approach that combines satellite remote sensing and GIS spatial analysis. High-resolution satellite images were collected during peak summer periods to automatically detect and map vessel positions across the study areas. These data were then processed to calculate vessel density and identify the main anchoring zones. Finally, the resulting density maps were overlaid onto updated seagrass cartography within a GIS environment. This spatial analysis allowed for the precise identification of the sensitive marine habitats directly exposed to environmental pressure from boating activities.

2.3 Calculation criteria for conservation indices and anchor damage classes

To translate field observations into clear management tools, the project framework evaluates both the ecological status of the seabed and the physical pressure caused by boating. The impact of traditional anchoring systems is classified using a standardized damage scale. This categorization



assesses the severity and frequency of physical scars on the seafloor, ranging from healthy, untouched meadows to areas with severe rhizome exposure and sediment erosion.
Concurrently, the overall health of the marine environment is evaluated using specific conservation indices. These indices integrate core ecological indicators of seagrass meadows with localized data on anchoring pressure. By combining data on structural habitat damage with vessel distribution patterns, the final framework calculates a composite diagnostic score. This index provides an objective assessment of ecosystem health, enabling consistent comparisons across different Adriatic pilot sites regardless of local geographical variation.

3. Characterization of pilot sites: habitat quality and existing pressures

3.1 Pilot Site 1: Panzano Bay (Monfalcone, Italy)

3.1.1 Geographical and morphological framework of the area of interest

Panzano Bay is a shallow and sheltered embayment of the Adriatic Sea (Friuli Venezia Giulia), located in the northeastern part of the Gulf of Trieste, limited to the south-west by Punta Sdobba, at the mouth of the Isonzo River. Here, *Cymodocea nodosa* and other marine seagrasses species with similar environmental requirements (*Zostera noltei*, *Z. marina* and species of the *Ruppia* genus) take advantage of the conditions of substantial naturalness of the coastal shallows, which present considerable bathymetric variability with an alternation of tidal flats and shoals even at a reasonable distance from the shoreline.

Administratively belonging to the Municipality of Monfalcone (Friuli Venezia Giulia), the pilot area features a coastline stretch extending approximately 13.7 km and encompasses a total marine surface of around 1,650 hectares. The boundaries of this marine zone were defined with a wide buffer margin to envelope the entire area where the presence of marine seagrass meadows has been historically recorded (Figure 2).

The bay is characterized by a high bathymetric variability, displaying a dynamic landscape where tidal flats and shallow shoals alternate even at a considerable distance from the shoreline. This specific morphology is preserved over time due to the protection offered by the local coastal arc, which reduces wave exposure and favors the active sedimentation of sandy materials, creating stable sandbank structures that support target benthic ecosystems.

This natural framework directly interfaces with an urban center of over 30 thousand inhabitants, characterized by heavy industrialization, extensive cargo handling piers, a thermoelectric power plant, and major commercial shipbuilding yards. Despite these conflicting spatial uses, the stretch of coast retains a high level of naturalness, allowing approximately 44% of Monfalcone's marine and coastal wetland environments to be preserved under the European Natura 2000 network. The pilot site directly intersects two major protected areas:

- The Special Area of Conservation (SAC) **IT3330007 "Cavana di Monfalcone"**, which covers 133 hectares (12% marine) in a transition zone between flat land and the sea, fed by a complex system of spring canals.
- The SAC/SPA **IT3330005 "Foce dell'Isonzo - Isola della Cona"**, which extends over 2,668 hectares (40% marine) along the final stretch of the Isonzo River and largely coincides with the "**Foce dell'Isonzo Regional Nature Reserve"**.

Within the marine sectors of these protected areas, two primary Annex I target habitats are conserved. **Habitat 1110** (Sandbanks which are slightly covered by shallow sea water all the time) represents the permanently submerged environment, occupying 15 hectares within the Cavana site and more than 1,200 hectares within the "Foce dell'Isonzo" site. **Habitat 1140** (Mudflats and sandflats not covered by seawater at low tide) represents the intertidal areas, covering 3 hectares in Cavana and nearly 70 hectares in the "Foce dell'Isonzo" sector. The overall conservation status, structural function, and global conservation value of Habitat 1110 are officially evaluated as "Excellent", while Habitat 1140 maintains an evaluation of "Good".

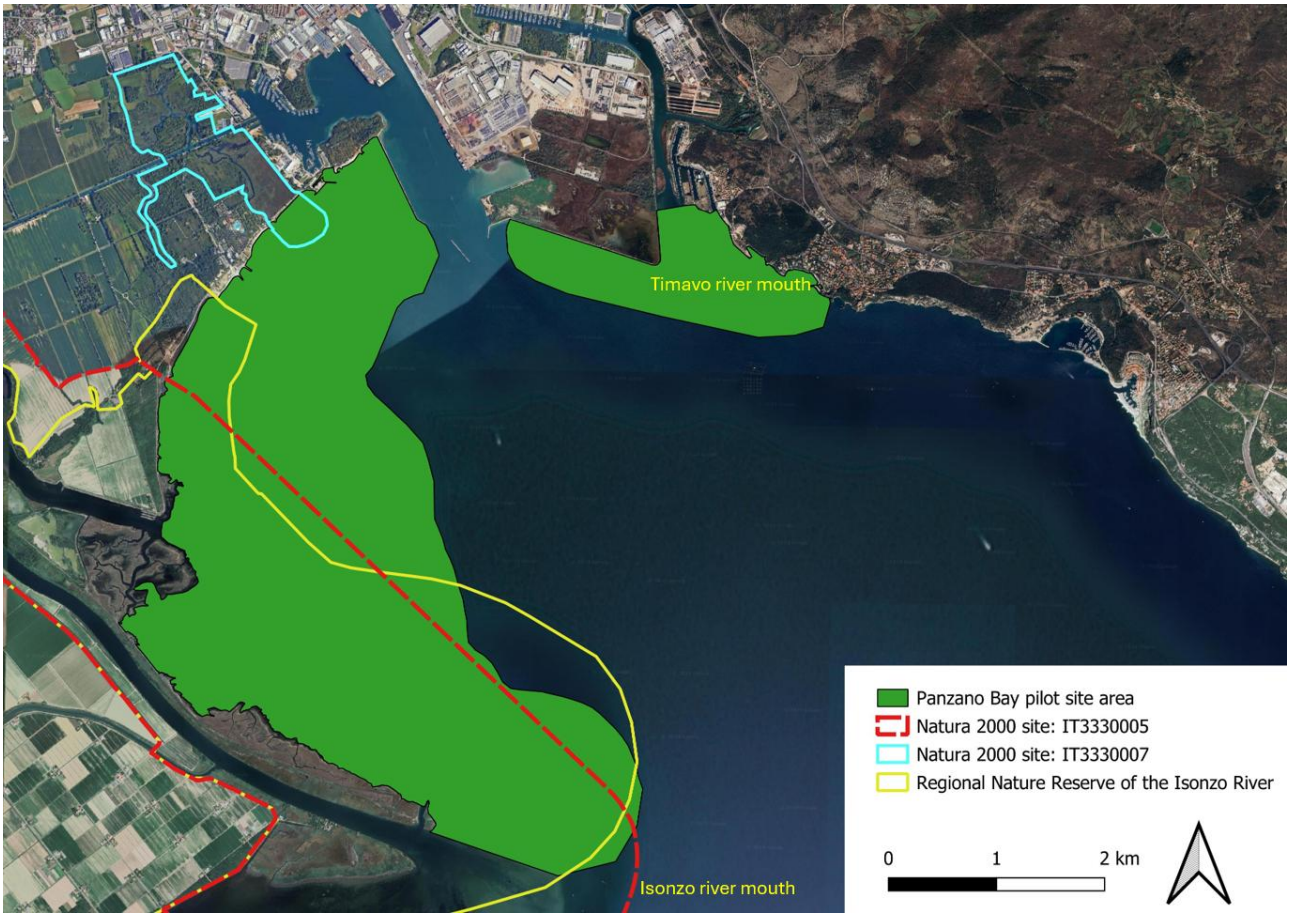


Figure 2 Geographical framework of the Bay of Panzano with references to Natura 2000 sites and regional reserves

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3.1.2 Main users of the area

Panzano Bay is a popular destination for recreational boaters from spring to autumn. During weekends, the bay hosts hundreds of small boats that anchor in shallow waters, alongside medium-sized vessels that moor in deeper zones. The bay is mostly frequented for daily trips. However, in 2021, the installation of an ecological buoy field through the previous INTERREG SASPAS project[1] provided boaters with a sustainable mooring option, reducing the need to anchor directly on the seagrass meadows.

Coastal tourism is primarily driven by local or regional visitors due to the absence of large-scale resort infrastructures. The local beaches cater well to water sports, offering active rentals for kitesurfing and windsurfing. Finally, small-scale commercial cruise traffic operating along the "Monfalcone–Grado–Trieste–Koper" route remains minimal and does not exert significant environmental pressure on the target marine habitats.

3.1.3 Existing pressures

As noted earlier, the environmental impact of boating tourism is mostly driven by the large number of small recreational boats. Local infrastructure includes numerous marinas and nautical clubs maintaining a collective capacity of approximately 3,500 to 4,000 leisure berths, contrasting with a minor commercial fleet dedicated to local fishing and aquaculture. Vessel density is visually concentrated in immediate coastal sectors and adjacent beach zones. During the peak summer season, an average of 500 boats routinely concentrate across five primary zones[2] (Figure 3). These vessels consistently measure under 10 meters in length due to bathymetric constraints, with small grapnel or umbrella anchors representing the predominant anchoring methods.

Anthropogenic disturbances in the area are primarily associated with localized recreational water sports, including diving and small-scale boating. While the bay is highly popular for kitesurfing, tracking data confirms this activity exerts no significant impact on the target seagrass meadows or adjacent benthic habitats. Similarly, recreational diving activity remains exceptionally low; although a few diving schools operate within the wider region, systematic monitoring indicates that their presence within the specific project boundaries is entirely sporadic and negligible.

[1] SASPAS, Project: *Safe Anchoring and Seagrass Protection in the Adriatic Sea*. 2014-2020 Interreg V-A Italy – Croatia CBC Programme. Priority Axis: Environment and cultural heritage.

[2] Geographically, these anchorage zones span from the northern canal outlets and port infrastructures of Monfalcone, extend along the shallow tidal flats of the western coastline, and reach across to the southeastern entrance facing the open sea.

Table 2 Panzano Bay: list of possible drivers and pressures (SASPAS, 2020[3]).

BAY OF PANZANO					
DRIVERS	PRESSURES	STATE			
		Water column	Seagrass meadows	*Pinna nobilis*	Benthos
TRANSPORTATION AND SERVICE CORRIDORS	***D03 shipping lanes, ports, marine constructions***				
	D03.01 port areas				
	D03.01.02 piers/tourist harbours or recreational piers	X	X	X	X
BIOLOGICAL RESOURCE USE OTHER THAN AGRICULTURE & FORESTRY	***F01 marine and Freshwater Aquaculture***				
	F01.01 intensive fish farming, intensification			X	X
	F01.02 suspension culture	X	X	X	X
	F02 fishing and harvesting aquatic ressources				
	F02.03 leisure fishing				
	F02.03.03 spear-fishing		X	X	X
HUMAN INTRUSIONS AND DISTURBANCES	***G01 outdoor sports and leisure activities, recreational activities***				
	G01.07 scubadiving, snorkeling		X	X	X
	G05 other human intrusions and disturbances				
	G05.03 penetration/disturbance belowsurface of the seabed		X	X	X
POLLUTION	***H03 marine water pollution***				
	H03.02 toxicchemical dischargefrom material dumped at sea				
	H03.02.01 non-synthetic compound contamination				X
	H03.02.04 introduction of other substance (e.g. liquid, gas)	X	X	X	X
INVASIVE, OTHER PROBLEMATIC SPECIES	***I01 invasive non-native species***	X	X	X	X
NATURAL SYSTEM MODIFICATIONS	***J02 human induced changes in hydraulic conditions***				
	J02.12 dykes, embankments, artificial beaches, general	X	X	X	X
	J02.12.01 sea defense or coast protection works, tidal barrages	X	X	X	X
NATURAL BIOTIC AND ABIOTIC PROCESSES (WITHOUT CATASTROPHES)	***K01 abiotic (slow) natural processes***				
	K01.02 silting up	X	X	X	X
	K02 biocenotic evolution, succession				
	K02.01 species composition change (succession)	X	X	X	X
	K02.02 accumulation of organic material	X	X	X	X
	K02.03 eutrophication (natural)	X	X	X	X
	K03 interspecific faunal relations				
	K03.03 introduction of deisease (microbial pathogens)			X	X
	K04 interspecific floral relations				
	K04.05 damage by herbivores (including game species)		X		X

Additional localized pressures stem from commercial aquaculture and artisanal fishing activities within the bay (Figure 4). A single designated zone is dedicated to co-located mariculture, encompassing approximately 400 mussel cultivation longlines and 63 floating finfish pens. This facility covers a total surface area of 370,000 square meters, generating an average annual yield of 1,200 tonnes of mussels, while fish production maintains a secondary local scale.

Commercial fishing is restricted to small-scale artisanal operations using passive gears, primarily gillnets. The shallow intertidal and subtidal zones containing the seagrass meadows are also frequented by recreational spearfishermen (estimated at 30 individuals operating roughly 15 days per year). This specific harvesting modality exerts no substantial pressure on the benthic ecosystems, as it relies entirely on the natural sheltering function of the meadows. Lastly, a single professional fisher holds local authorization for scuba-assisted harvesting, with activities strictly limited to specific mollusc species.

[3] SASPAS, 2020. Act 3.2 - DRIVERS AND PRESSURES IDENTIFICATION AND ASSESSMENT. FINAL REPORT.



Figure 3 Port/harbours distribution and pleasure boats density areas in Panzano Bay (from webgis.saspas.eu, modified).

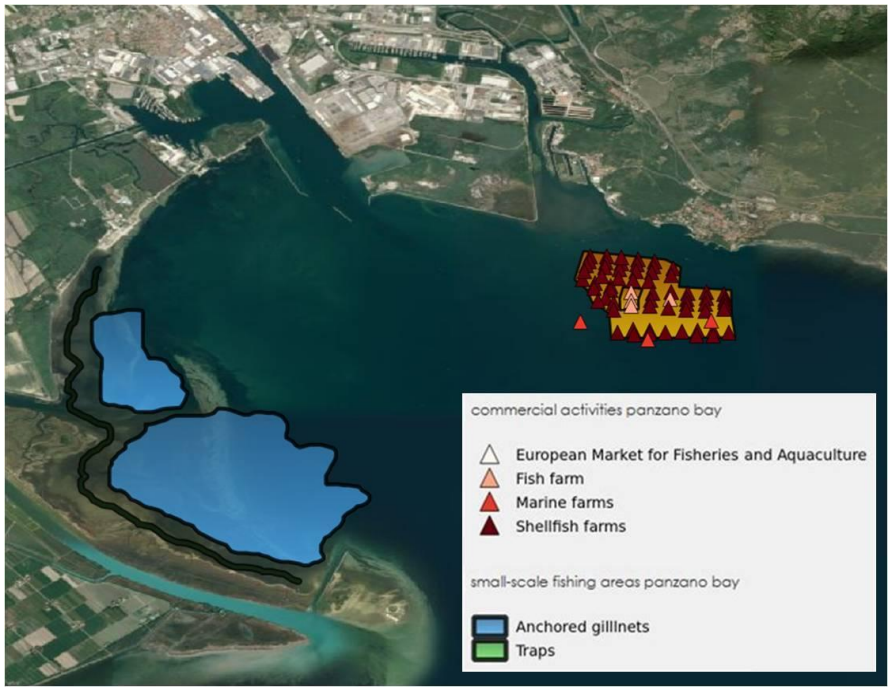


Figure 4 Mussel and fish farming, and small-scale fishing areas distribution in Panzano Bay (from webgis.saspas.eu, modified).

Potential pollution in Panzano Bay is closely linked to seasonal rainfall, which changes the quality and volume of freshwater flowing into the sea (Figure 5). The main sources of pollution include the Isonzo River and its connected channels (the Valentinis and Brancolo canals), agricultural runoff from the Brancolo land reclamation area, and urban stormwater. Additionally, local industrial and municipal sites, such as the Monfalcone port area, the thermoelectric power plant, cargo piers, and the Staranzano wastewater treatment plant, add to the pollution through sewer overflows and underwater pipes. This issue becomes worse during heavy rains and bad weather; strong southern winds combined with high tides often block the natural flow and mixing of river and sea water, trapping the pollutants inside the bay.

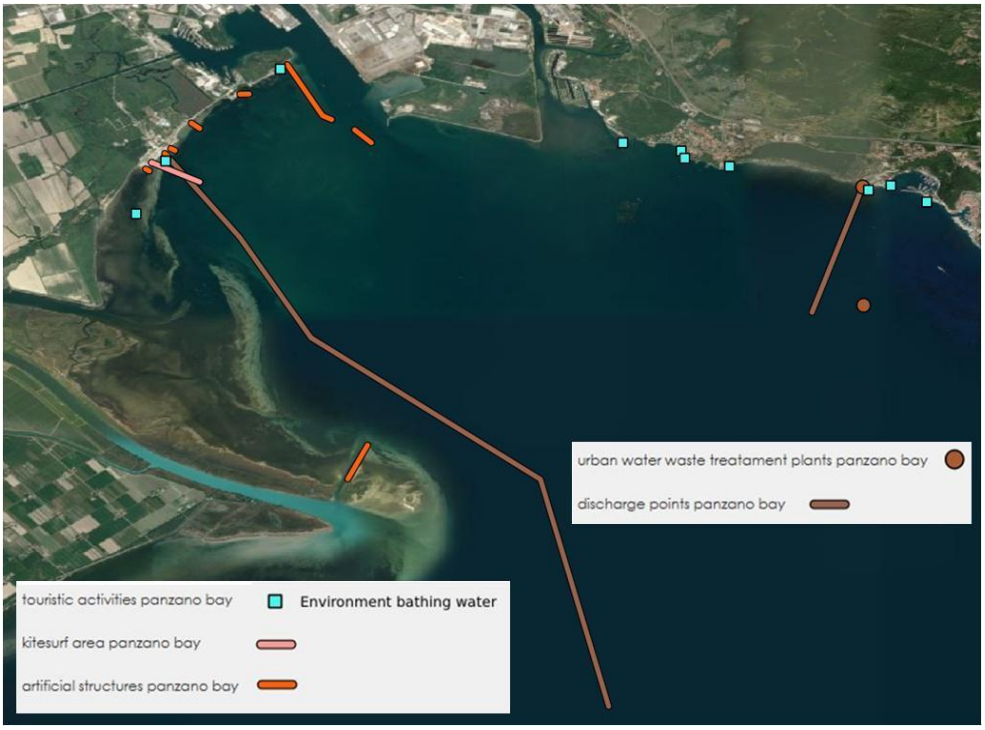


Figure 5 Bathing water, kitesurf areas, artificial structures, urban water treatment plant and discharge points distribution in Panzano Bay (from webgis.saspas.eu, modified).

Over the past decades, numerous records of invasive alien species, including algae, molluscs, crustaceans, and fish, have been documented in the Upper Adriatic and its lagoons. In accordance with the Marine Strategy Framework Directive (2008/56/EC), these species are carefully monitored for potential ecosystem impacts. Currently, they do not appear to exert significant pressure or cause targeted impacts on the presence and distribution of marine seagrass meadows within the pilot area. Specifically, recent observations of non-native or expanding species include the Atlantic blue crab

(*Callinectes sapidus*), the squirrelfish (*Holocentrus ascensionis*), and the grey triggerfish (*Balistes capriscus*).

3.1.4 Target habitats and pressure impact evaluation

Target Habitats and Seagrass Distribution

Considering the Natura 2000 Network, both habitats present (1110 and 1140) are characterized by a vast presence of marine seagrasses, spread through different vegetal associations. The main associations include *Cymodocea nodosa*, which colonizes different sedimentary categories, from well sorted fine sands to muddy sands and of *Zostera noltei* association, often mixed with *Ruppia* spp., whose distribution is related to bathymetry, distance from freshwater inputs (Isonzo river) and sea exposure.

In September 2024, in the framework of BIOPRESSADRIA project, field activities were carried out to update marine seagrasses distribution in Panzano Bay. Meadow contours and specific points corresponding to interesting information were georeferenced using a satellite detector connected to a field terminal that allowed the detected point to be verified directly on a cartographic support. The markers contained information related to the species, the coverage classes (scale from 1 to 4), the typology (continuous, discontinuous, punctiform and mixed) and other field data. Once the acquisition of the 2024 campaign markers was completed, all the field data were screened by comparing them with recent satellite photographs and the previous 2015 mapping, to identify modifications. For the first time, this mapping provides a precise characterization of the bay's biodiversity and identifies how seabed morphology, sediment types, and salinity gradients influence species distribution.

The 2024 mapping of the project's pilot area highlighted marine seagrass meadows extension of about 772 ha: pure meadows of *Cymodocea nodosa* (421.2 ha), *Zostera noltei* (147 ha), *Ruppia* spp. (99.4 ha) and mixed meadows of *Z. noltei-C. nodosa* (31.5 ha) and *Z. noltei- Ruppia* spp. (72.5 ha) (Figure 5 and Table 3).

The vegetation showed a high differentiation in species presence (*C. nodosa*, *Z. noltei*, and species of the genus *Ruppia*), in the range of cover values (three classes were present, from 6-50% of class 2 to 75-100% of class 4) and in the different species composition, often forming mixed meadows with various degrees of coverage (*Z. noltei-C. nodosa* and *Z. noltei-Ruppia* spp.).

In the marine area of the Panzano Bay, marine seagrasses are present almost exclusively in the western sector and partly in the north, on seabed with a maximum depth of approximately 4-5 m.

In the northern sector of the bay, between Panzano beach and Marina Julia, *C. nodosa* meadows are present from the coastline to the depth of approximately 2-3 m. In the central and southern sector

up to the mouth of the Isonzo, this species colonizes the purely marine seabed, from the sandy banks towards the marine side up to depths of about 5 m. On the seabed behind the sandy banks of the central-southern sector of the bay, where depths are shallower and there are also variations in the typology and morphology of the seabed and there is also fresh water, an alternation of several species was found.

In the central-southern sector on the marine side and the sandy banks, first *C. nodosa* on the frankly sandy seabed and then *Z. noltei* with various degrees of coverage were found towards the coastline (central sector).

Further south, in an area where waters arrive from the mouth of the Isonzo river, *Ruppia* spp. is widespread with extensive meadows and a high degree of coverage; towards the coastline the *Ruppia* meadows are pure while slightly further offshore and, on the sandbars, there are mixed meadows with *Z. noltei*. In the northern sector of the bay, significant meadows, in terms of extension and degree of coverage (about 20 ha), are present but only in the medium-low seabed at the mouth of the Timavo river.

Table 3 Coverage values by classes and total, in the Panzano Bay in 2015 and 2024.

	2024 MAPPING		2015 MAPPING	
SPECIES	**COVERAGE CLASSES**	**ha**	**COVERAGE CLASSES**	**ha**
Cymodocea nodosa	2 3 4	61.5 95.1 264.6	2 3 4	5.2 632.3 118.9
Ruppia spp.	2 3	5.2 94.3	-	-
Zostera noltei	2 3 4	8.6 70.6 67.9	-	-
Z. noltei - C. nodosa	2 3	6.2 25.4	-	-
Z. noltei - Ruppia spp.	3	72.5	-	-
TOTAL		**771.7**		**756.3**

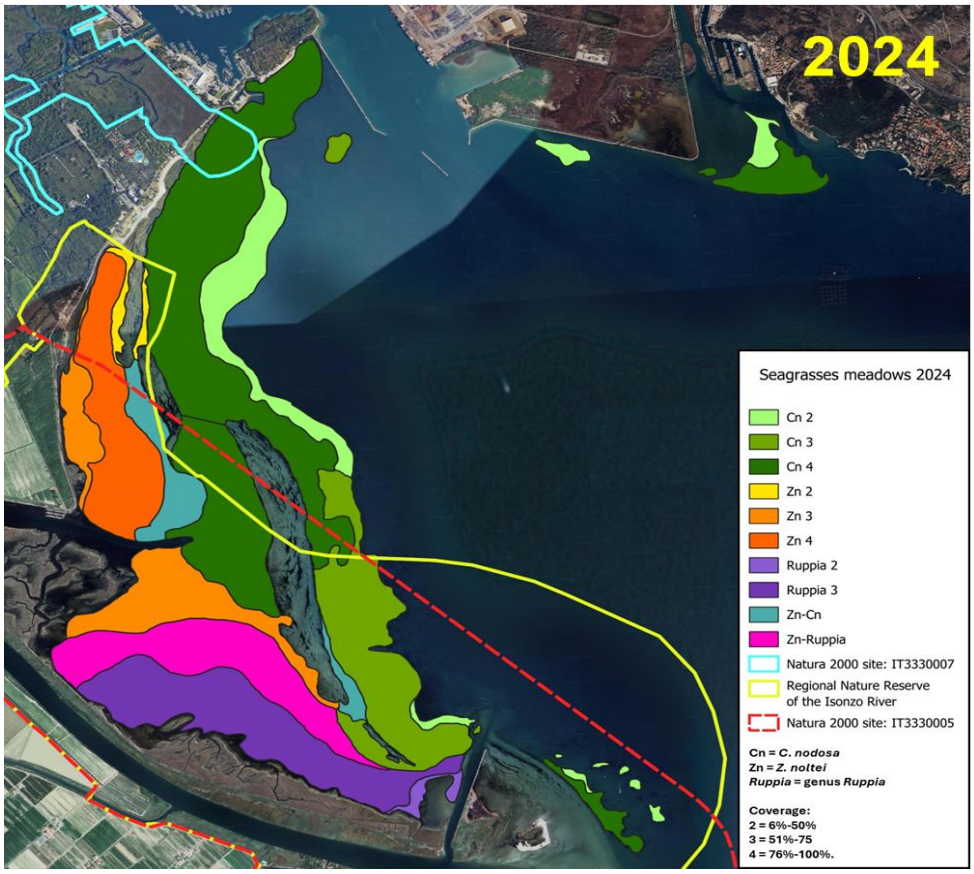


Figure 6 Marine seagrasses distribution in Panzano Bay in 2024.

The previous survey, carried out in 2015 in the same area, reported an extension of 756.3 ha of seagrasses. However, it focused on undifferentiated meadows and attributed them exclusively to the species *Cymodocea nodosa* (Figure 7 and Table 3). Although the maps are substantially similar, a comparison between the 2015 and 2024 surveys highlights some differences:

- the 2024 survey was performed with accurate species discrimination, which revealed a remarkable biodiversity, with species alternating on the seabed in relation to the morphology of the sites, the type of sediments and the salinity of the water;

- the 2024 survey shows a greater extension of the meadows on the medium-shallow seabed at the mouth of the Timavo river.

In both surveys, however, the seagrass meadows in the areas of the SAC – "Cavana di Monfalcone", the SAC – "Foce dell'Isonzo - Isola della Cona" and the Regional Nature Reserve of the Foce dell'Isonzo are similar in extension.

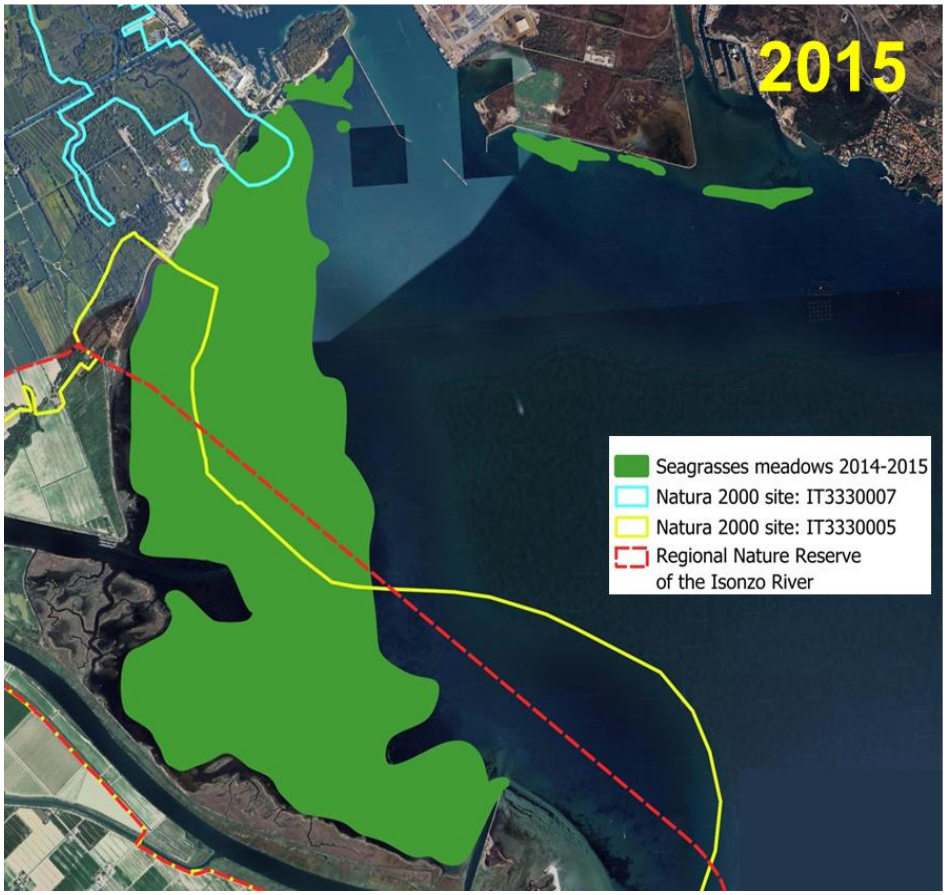


Figure 7 Marine seagrasses distribution in Panzano Bay in 2015.

The 2024 mapping provides a significantly defined assessment compared to the 2015 survey, which relied on less differentiated data (attributing 750 ha solely to *C. nodosa*). The updated results reveal a higher level of biodiversity, showing that species distribution is closely correlated with subtle environmental gradients. Notably, an expansion of seagrass beds was observed in medium-shallow zones near the Timavo River mouth, a dynamic which was not captured in previous surveys.

It is important to note that the lower *C. nodosa* coverage recorded in 2024 does not reflect an ecological decline, but rather a more accurate taxonomic differentiation between pure and mixed meadows previously aggregated under a single category. According to Gianni et al. (2025)[4], Panzano Bay remains a resilient environment for *C. nodosa*: the influx of freshwater and nutrients from the

[4] Gianni, F., Falace, A., Orlando-Bonaca, M., Ciriaco, S., Ivajnšič, D., Kaleb, S., Lipej, L., Mavrič, B., Querin, S., & Bandelj, V., 2025. Environmental alterations and sea warming drive seagrass meadow decline in urbanized coastal areas of the northern Adriatic Sea. Estuarine, Coastal and Shelf Science. https://doi.org/10.1016/j.ecss.2025.109563

Isonzo River maintains conditions favorable for seagrass growth, enhancing primary productivity and mitigating stressors.

Furthermore, while other areas of the Gulf of Trieste experienced severe seagrass losses (up to 89% between 2014 and 2018), Panzano Bay has shown no significant decline, with meadows remaining extensive and continuous throughout this period. The stability of the Special Areas of Conservation, specifically "Cavana di Monfalcone" and "Foce dell'Isonzo – Isola della Cona," underscores the ecological importance of this coastal sector and validates the effectiveness of current monitoring efforts.

Seagrass Monitoring Stations and Structural Parameters

The first in-situ monitoring activities were carried out in September 2024, at the same time as the seagrass mapping campaign. The main objective was to collect baseline data on the health of the meadows across the sampling stations. The number of monitoring stations was defined considering the general characteristics of the surveyed area (i.e., extension and homogeneity) and previously conducted research and monitoring campaigns in the area. The monitoring team measured specific structural parameters, including shoot density (shoots/m²) and percentage coverage (Figure 8).



Figure 8 In-situ monitoring operations in 2024 using sampling quadrats to evaluate shoot density.

Below are a summary table (Table 4) describing the monitoring stations and the main parameters assessed during the campaigns, and a figure (Figure 9) showing the location of the monitoring stations describing the monitoring sites and the main parameters assessed during the campaigns.

Table 4 Overview of monitoring stations and main parameters (surveys 2024 and 2025).

Station	Location Description	Target Species & Main Parameters	Observed Impacts
1	Eastern sector of the bay; located in shallow waters near the artificial breakwaters and the anthropized coastline, east of the main access channel.	*Cymodocea nodosa* meadow: **Coverage:** 95–100% **Shoot density:** 650–700 shoots/m^2	Near-total absence of meadow damage (occasional small unvegetated patches observed).
2	Northern sector, inner bay; positioned in the sheltered area at the entrance of Monfalcone's navigation channels and marinas, close to the port infrastructure.	*Cymodocea nodosa* meadow: **Coverage:** 95–100% **Shoot density:** 650–700 shoots/m^2	Near-total absence of meadow damage (occasional small unvegetated patches observed).
3	Central sector of the bay; situated along the eastern edge of the main tidal sandbank.	*Cymodocea nodosa* meadow: **Coverage:** 95–100% **Shoot density:** 750–800 shoots/m^2	Presence of limited anchor scars.
4	Southern sector, outer bay; located at the southern tip of the sandbank system (near the lagoon inlet.	*Cymodocea nodosa* meadow: **Coverage:** 95–100% **Shoot density:** 750–800 shoots/m^2	Presence of limited anchor scars.

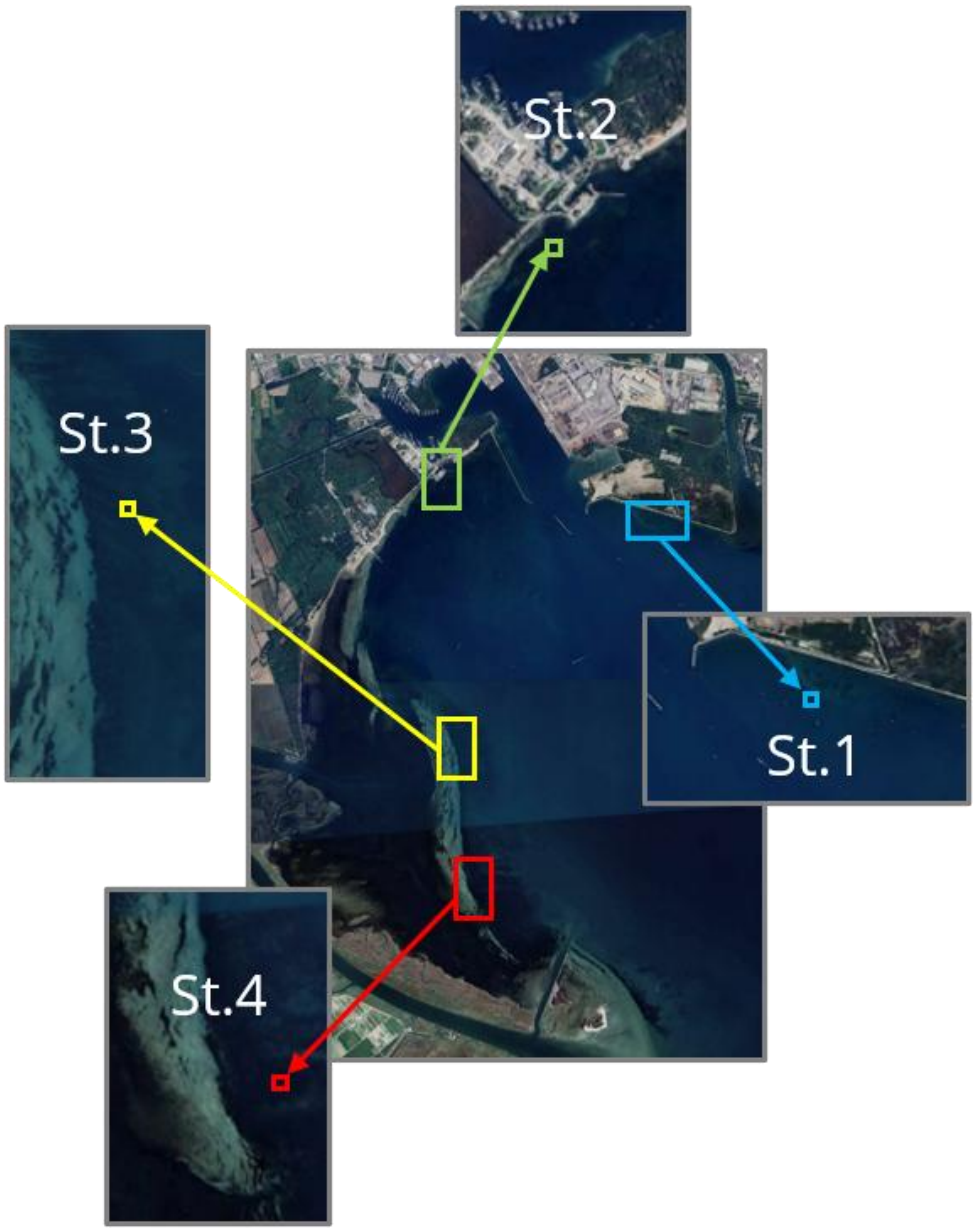


Figure 9 Satellite map illustrating the location and distribution of the four monitoring stations (St.1, 2, 3, and 4).

In July 2025, the monitoring activities were extended. Considering the localized density and degradation patterns observed at these sampling stations during the previous year, the monitoring team extended the investigation to search for, map, and quantify similar anchor scars and mooring-induced clearings in the immediate vicinity and neighboring sectors (Refer to the following section 3.1.4.2, subsection "*Underwater Monitoring of Anchoring Damage*").

Pressures and Impact Monitoring

This section outlines the monitoring of anthropogenic pressures and the biological response to mitigation efforts. By combining habitat distribution data, satellite-derived nautical pressure analysis, and bioacoustic monitoring, this section provides an assessment of the ecosystem's status and the effectiveness of current management strategies.

Data related to disturbances on marine seagrass meadows caused by leisure activities carried out in Panzano Bay or by other factors have historically been very scarce. In particular, the effective pressure of recreational boating and frequent anchoring had never been considered and analysed. There is no continuous monitoring aimed at controlling specific phenomena of damage and disappearance of seagrass meadows, since the existing literature has generally interpreted these disturbances only in terms of medium- and long-term regressive dynamics of the area as a whole.

The monitoring of maritime traffic is carried out by the Port Authority of Monfalcone (Capitaneria di Porto) through a Vessel Traffic System (VTS); however, this system mainly records commercial traffic and no information is available online for the recreational sector, with the exception of some port throughput statistics reported in Table 5.

Table 5 *Port of Monfalcone throughput statistics (https://www.adspmao.it/it/i-porti-del-sistema/monfalcone/statistiche).*

Autorità di Sistema Portuale del Mare Adriatico Orientale
Porti di Trieste e Monfalcone

PORT OF MONFALCONE
THROUGHPUT STATISTICS - ESPO

TIME PERIOD GOING FROM	01/01/2022 to 31/12/2022			01/01/2023 to 31/12/2023			Difference	
	IN	OUT	TOTAL	IN	OUT	TOTAL	TOTAL	%
TOTAL THROUGHPUT (Ton.)	**3.318.775**	**525.714**	**3.844.489**	**3.079.148**	**750.573**	**3.829.721**	**-14.768**	**-0,38%**
LIQUID BULK	**0**	**0**	**0**	**0**	**0**	**0**	**0**	
Crude oil	0	0	0	0	0	0	**0**	
Refined (petroleum) products	0	0	0	0	0	0	**0**	
Gaseus, liquified or compressed petroleum products and natural gas	0	0	0	0	0	0	**0**	
Chemical products	0	0	0	0	0	0	**0**	
Other liquid bulk	0	0	0	0	0	0	**0**	
DRY BULK	**2.716.147**	**380.975**	**3.097.122**	**2.492.141**	**519.984**	**3.012.125**	**-84.997**	**-2,74%**
Cereals	52.014	0	52.014	18.078	22.000	40.078	**-11.936**	**-22,95%**
Foodstuff/Fodder/Oil seeds	0	0	0	0	0	0	**0**	
Coal and lignite	314.918	0	314.918	134.031	0	134.031	**-180.887**	**-57,44%**
Ores/cement/lime/plasters	255.685	0	255.685	51.424	0	51.424	**-204.261**	**-79,89%**
Metallurgical products	2.078.234	380.975	2.459.209	2.250.528	497.984	2.748.512	**289.303**	**+11,76%**
Chemical products	15.296	0	15.296	38.080	0	38.080	**22.784**	**+148,95%**
Other dry bulk	0	0	0	0	0	0	**0**	
GENERAL CARGO	**602.628**	**144.739**	**747.367**	**587.007**	**230.589**	**817.596**	**70.229**	**+9,40%**
Containerized (including Ro-Ro containers)								
Ro-Ro (excluding Ro-Ro containers)	48.622	113.993	162.615	63.379	139.156	202.535	**39.920**	**+24,55%**
Other general cargo	554.006	30.746	584.752	523.628	91.433	615.061	**30.309**	**+5,18%**
ADDITIONAL INFORMATION								
NUMBER OF CALLS		**330**			**388**		**58**	**+17,58%**
GROSS TONNAGE		**9.268.601**			**9.447.625**		**179.024**	**+1,93%**
NUMBER OF LOCAL AND FERRY PASSENGERS	**19**	**10**	**29**	**5**	**32**	**37**	**8**	**+27,59%**
Local (< 20 miles journey)	0	0	0	0	0	0	**0**	
Ferry passengers	19	10	29	5	32	37	**8**	**+27,59%**
CRUISE PASSENGERS		**95.599**			**92.045**		**-3.554**	**-3,72%**
Home Port	35.019	36.907	71.926	31.116	32.340	63.456	**-8.470**	**-11,78%**
Transits			23.673			28.589	**4.916**	**+20,77%**
NUMBER OF CONTAINERS (in TEUs)	**873**	**1.088**	**1.961**	**231**	**190**	**421**	**-1.540**	**-78,53%**
Hinterland	873	1.088	1.961	231	190	421	**-1.540**	**-78,53%**
Empty	872	6	878	231	0	231	**-647**	**-73,69%**
Full	1	1.082	1.083	0	190	190	**-893**	**-82,46%**
Transshipped	0	0	0	0	0	0	**0**	
Empty	0	0	0	0	0	0	**0**	
Full	0	0	0	0	0	0	**0**	
NUMBER OF VEHICLES	**32.556**	**51.110**	**83.666**	**44.687**	**64.500**	**109.187**	**25.521**	**+30,50%**
Number of Ro-Ro units	0	0	0	0	0	0	**0**	
Number of private vehicles	0	0	0	0	0	0	**0**	
Number of commercial vehicles	32.556	51.110	83.666	44.687	64.500	109.187	**25.521**	**+30,50%**

Regarding leisure boat traffic, no historical information was available on the spatial and temporal distribution of recreational vessels within the bay, although qualitative observations indicated that the very shallow colonized bottoms represented the main target sites disturbed by anchoring. Preliminary observations on this phenomenon were carried out during the SASPAS project, highlighting the need for a more detailed assessment.

To address this knowledge gap, within the BIOPRESSADRIA project, a multi-tier monitoring framework designed to evaluate the pressures exerted by recreational boating and the resulting ecological response was implemented and integrated. This approach combines three complementary investigative phases: satellite-based traffic analysis to quantify anthropic pressure, underwater SCARS mapping to assess physical habitat damage, and high-resolution bioacoustic monitoring to evaluate the functional response of the marine community. These phases are detailed below.

Satellite-based assessment of recreational boating pressure (Vessel Detection)

Objectives

The large spatial extent of the BIOPRESSADRIA pilot area makes conventional field surveys insufficient to comprehensively describe recreational boating activity throughout the summer season. To overcome this limitation, a satellite-based monitoring approach was implemented to reconstruct the spatial and temporal distribution of recreational boating within approximately 20 km² of Panzano Bay (Monfalcone) (Figure 10). The study area was selected to include the sectors most intensively used by recreational vessels, the BIOPRESSADRIA experimental monitoring sites and the main seagrass meadows, allowing boating pressure to be analysed in relation to sensitive habitats and ongoing ecological monitoring activities.

The analysis covered five consecutive summer seasons (2021–2025) using high-resolution PlanetScope imagery acquired between June and September. After quality filtering, 815 satellite scenes were retained from the original archive, providing a unique temporal dataset with sufficient frequency to investigate both seasonal and short-term variations in recreational boating. Compared with traditional surveys, this approach allowed repeated observations over the whole study area, making it possible to identify recurrent spatial patterns and quantify their temporal variability.

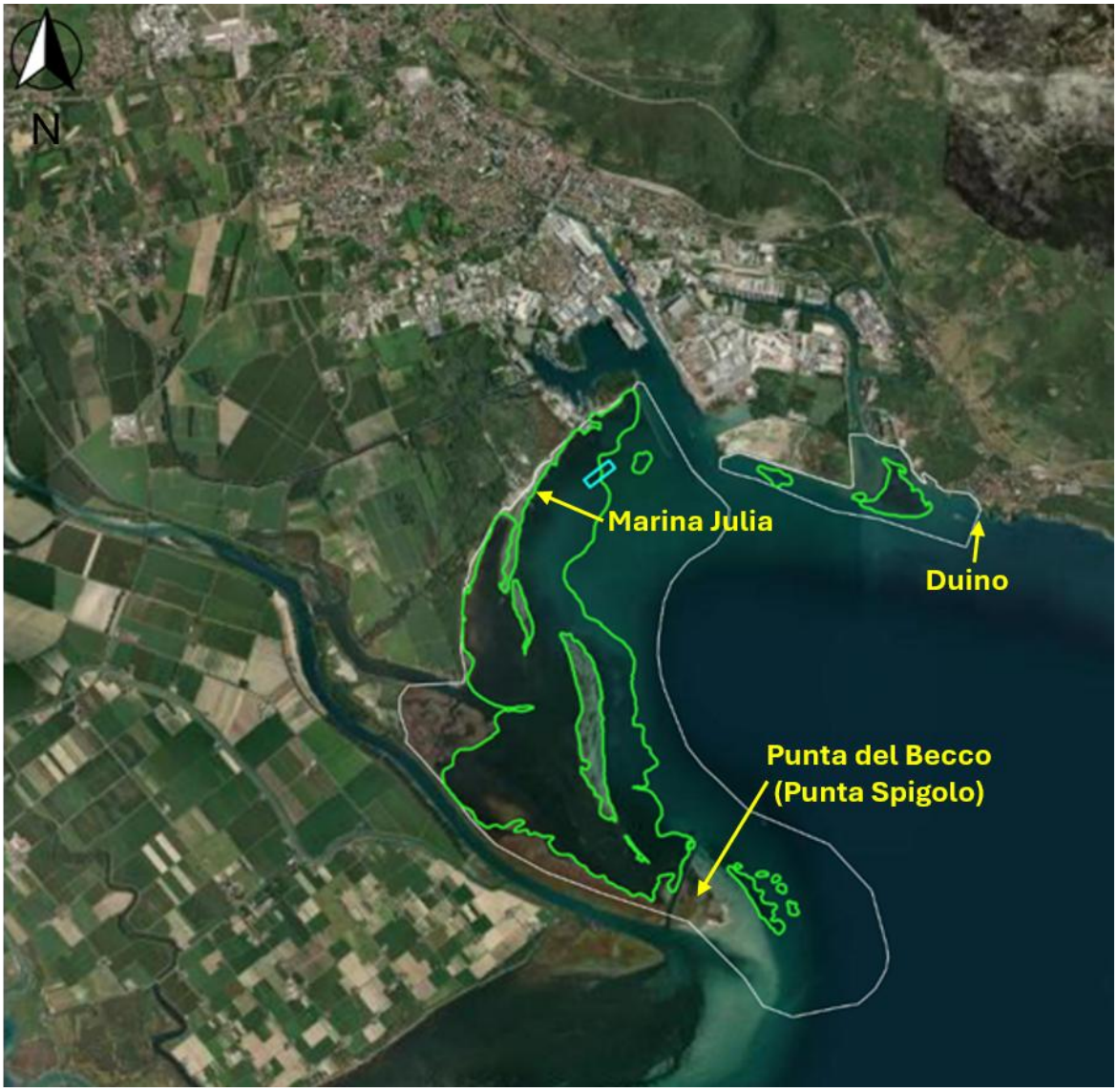


Figure 10 Study area within Panzano Bay. The white polygon delineates the study area, while seagrass habitats are outlined in green (2024 distribution). The Biopressadria buoy area is highlighted in cyan. Background imagery is from high-resolution satellite data.

The main characteristics of the monitoring programme and the principal findings are summarized in Table 6, providing an overview of the satellite dataset and the most relevant outcomes discussed in the following sections.

Table 6 Summary of the satellite monitoring dataset and key findings.

Indicator	Value
Study period	2021–2025
Summer months analysed	June–September
Study area	~20 km²
Satellite scenes analysed	815
Main seasonal peak	July–August
Dominant boating behaviour	Stationary (anchored) boats
Main hotspot areas	Western bay, Duino, Panzano Basin entrance, Monfalcone harbour channel
Habitats most exposed	Margins of seagrass meadows and adjacent sandy substrates

Seasonal dynamics of boating activity

The satellite observations revealed a well-defined seasonal cycle of recreational boating. Boat activity increased progressively from June, generally reached its highest intensity during July and August, and declined during September. Although some differences were observed among individual years, the overall seasonal pattern remained consistent throughout the five-year monitoring period, confirming the strong concentration of recreational use during the central part of the summer season.

The availability of frequent satellite acquisitions also highlighted a marked intra-weekly variability. Boat densities recorded during weekends, and holiday periods were substantially higher than those observed during weekdays, indicating that the greatest pressure on coastal habitats occurs during relatively short periods of peak recreational use. Consequently, monthly averages should be interpreted with caution, as they partially smooth these peaks and may underestimate the actual pressure experienced by sensitive habitats during the busiest days of the season. These results demonstrate the importance of high-frequency observations for accurately describing boating dynamics and identifying periods of maximum environmental pressure.



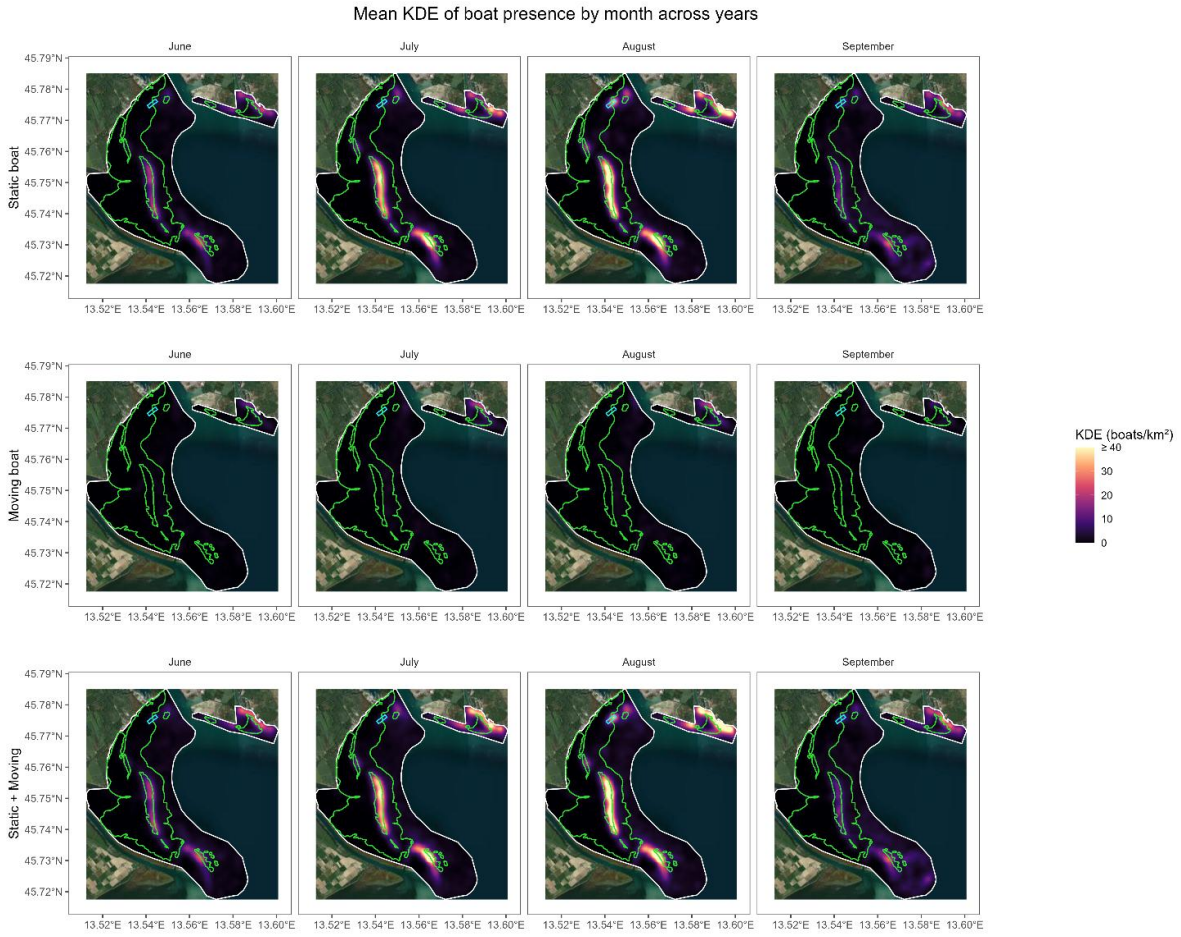


Figure 11 Average recreational boating density in Panzano Bay during the 2021–2025 summer seasons, showing stationary vessels, moving vessels and their combined distribution. The figure highlights the recurrent boating hotspots identified throughout the study period.

Spatial distribution and recurrent hotspots

Despite the temporal variability in boating intensity, the spatial distribution of recreational vessels proved remarkably stable throughout the study period. Rather than being evenly distributed across the bay, boating activity consistently concentrated within a limited number of recurrent hotspots that were observed every year.

The most intensively used areas include the shallow western sector between Punta del Becco (Punta Spigolo) and Marina Julia, the offshore waters of Duino, the entrance to the Panzano Basin and the area immediately west of the Monfalcone harbour channel, close to the BIOPRESSADRIA buoy field (Figure 10). These sectors are characterized by sheltered conditions and convenient access from navigation routes, making them preferred locations for anchoring and recreational use. The

persistence of these hotspots throughout five consecutive summers indicates that they represent stable patterns of space use rather than isolated events.

The analysis further showed that stationary vessels were consistently more abundant than moving boats, indicating that anchoring and recreational stops represent the dominant component of boating pressure within the study area. This finding is particularly relevant because anchoring is one of the principal mechanisms through which recreational boating can affect shallow benthic habitats.

In synthesis, the analysis identified four primary recurrent hotspots where recreational boating consistently concentrates. These areas represent stable patterns of space use rather than transient events and include:

- The shallow western sector between Punta del Becco (Punta Spigolo) and Marina Julia.
- The offshore waters of Duino.
- The transition zone at the entrance of the Panzano Basin.
- The area immediately to the west of the Monfalcone harbour channel, near the BIOPRESSADRIA buoy field.

While the total study area covers 20 km², the intense pressure is spatially concentrated, with 0.41 km² of these hotspots located over seagrass meadows and 1.61 km² over non-vegetated substrates. This underscores that boating pressure is not uniform, but rather focused on specific, persistent locations.

Relationship with seagrass habitats

A major objective of the analysis was to evaluate the interaction between recreational boating and seagrass meadows. Average boat densities were consistently higher over unvegetated substrates than within vegetated habitats throughout the monitoring period, suggesting that recreational boaters generally prefer sandy bottoms for anchoring. Nevertheless, the analysis clearly demonstrated that seagrass habitats are also regularly exposed to boating activity (Figure 12).



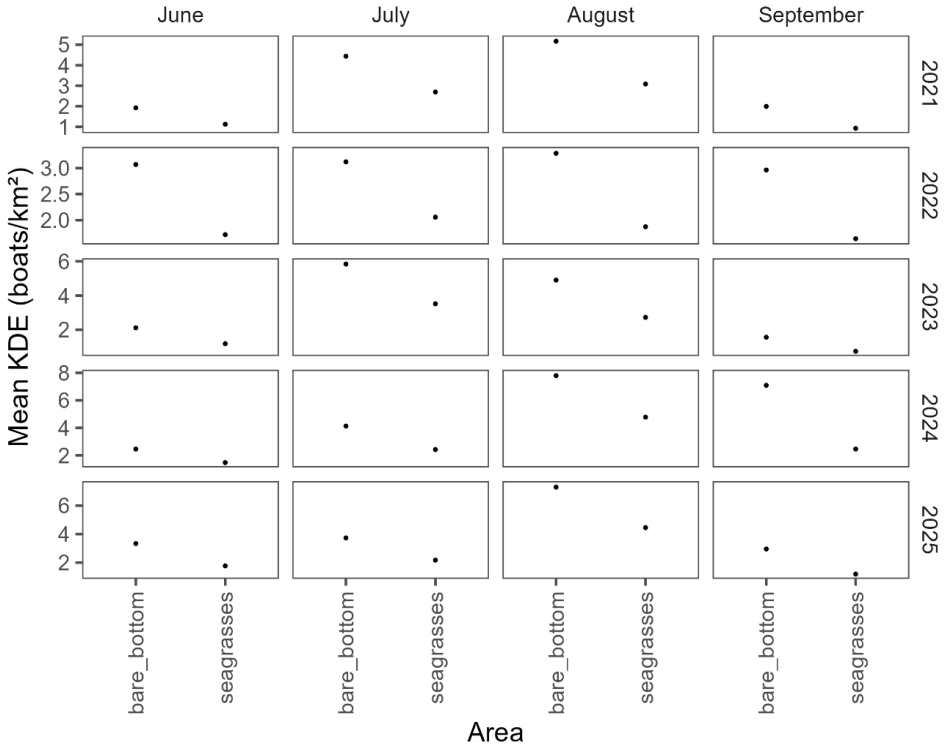


Figure 12 Mean boat density (KDE, boats km $^{-2}$) in bare substrates and seagrass habitats across months (June–September) and years (2021–2025). Results show consistent differences between habitat types, with higher densities generally observed in bare areas compared to seagrass meadows, and clear seasonal variability across summer months.

Boat presence was repeatedly detected within seagrass meadows, while visual inspection of high-resolution imagery showed that vessels frequently anchor immediately along the margins of vegetated patches. Although this behavior may partially reduce direct disturbance, several examples of boats positioned directly above seagrass meadows were also identified, confirming that localized anchoring pressure still occurs within these sensitive habitats.

The hotspot analysis further highlighted that only a relatively small proportion of the study area concentrates the highest levels of boating activity. However, several of these hotspot areas overlap with or occur immediately adjacent to seagrass meadows. Within these hotspots, boat densities over vegetated habitats were only slightly lower than those observed over neighboring unvegetated areas, whereas seagrass meadows located outside hotspot areas experienced consistently low boating pressure. These findings indicate that the ecological risk associated with recreational boating is highly concentrated spatially rather than uniformly distributed across the bay.

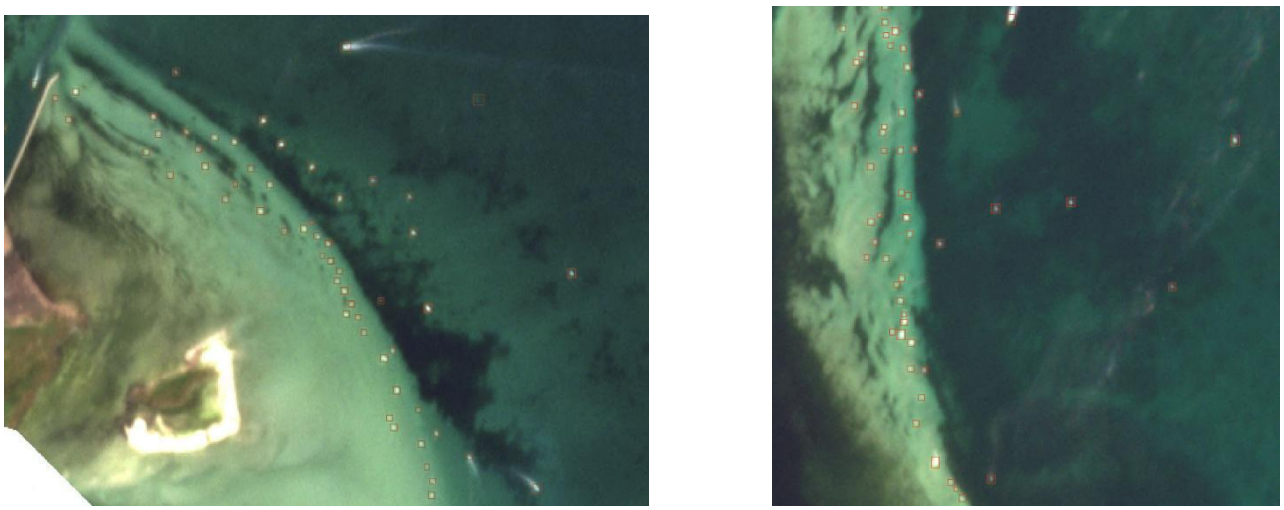


Figure 13 Examples of the spatial relationship between recreational boats and seagrass meadows. Boats generally concentrate along the meadow margins, although direct presence over vegetated habitats is also observed.

Implications for coastal management

The satellite-based assessment provides a much more comprehensive description of recreational boating than previously available datasets. The identified hotspots indicate a broader spatial extent of boating activity than previously recognised and demonstrate that several areas of intensive use occur within or immediately adjacent to Natura 2000 sites, regional protected areas and mapped seagrass habitats.

The BIOPRESSADRIA buoy area, although not corresponding to the highest boat densities recorded in the bay, consistently exhibited values above the average observed across the study area, confirming its role as a recurrent area of recreational boating and supporting its suitability for integrated ecological monitoring.

Overall, the results demonstrate that high-frequency satellite observations provide an effective tool for identifying persistent hotspots of recreational boating, quantifying seasonal and interannual variability, and evaluating potential interactions with sensitive coastal habitats. The generated density maps therefore represent a valuable decision-support product for future management actions aimed at reducing anchoring impacts while preserving the ecological integrity of Panzano Bay.

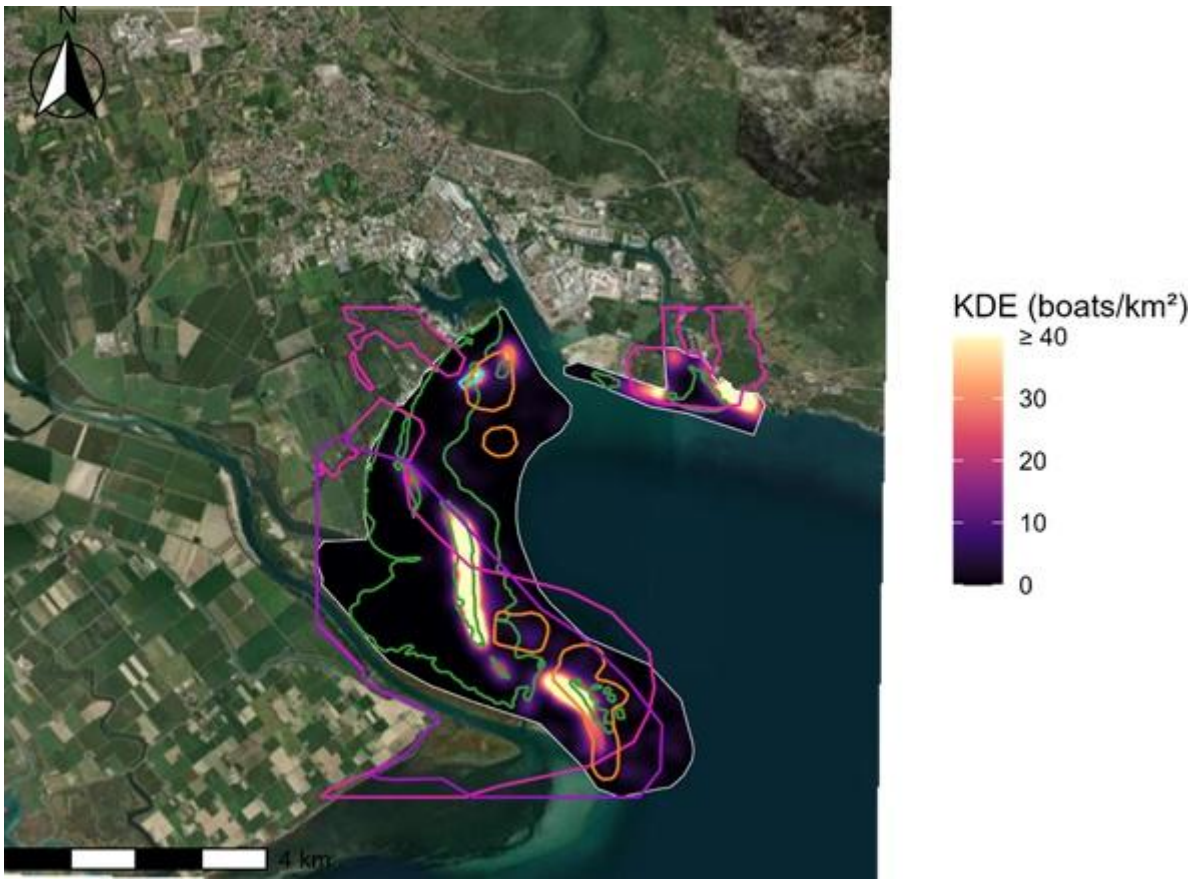


Figure 14 *Recreational boating density overlaid with seagrass meadows and protected areas, highlighting the spatial overlap between boating hotspots and environmentally sensitive habitats*.

Underwater Monitoring of Anchoring Damage (SCARS Protocol)

Following the identification of areas characterized by the highest recreational boating density (see Figure 14), field activities focused on the application of the "Anchoring Scars Monitoring Protocol" to assess whether the estimated anchoring pressure resulted in detectable physical impacts on the seabed.

Panzano Bay was selected as the BIOPRESSADRIA pilot site for a low-pressure environment, providing the opportunity to validate the SCARS protocol under environmental conditions significantly different from those of the Croatian pilot sites, such as Kornati N.P. and the islands around Korčula, where boating pressure is considerably higher.

The underwater surveys were conducted by the scientific diving team in selected monitoring areas, focusing on priority zones potentially exposed to higher anchoring pressure rather than covering the entire bay. These sites (Site 1 and Site 2, Figure 16) were identified through analyses of boating

density and field observations. The 2024 seagrass distribution map provided the spatial baseline for site selection. Particular attention was devoted to the monospecific *Cymodocea nodosa* meadows, which represent the dominant seagrass habitat in the northern Adriatic Sea and cover approximately 420 ha of the roughly 770 ha of mapped seagrass habitats in Panzano Bay (September 2024).

The information collected during the field surveys was integrated into the SCARS assessment framework by combining data on meadow condition, scar characteristics and persistence, and local anchoring pressure. This approach allowed the evaluation of habitat conservation status while providing a comprehensive assessment of the observed impacts.

The monitoring activities followed the same operational workflow adopted at some Croatian pilot sites. This included the identification of potential anchoring scars, underwater verification by scientific divers, and GIS-based mapping of the impacted patches. However, the characteristics of the observed impacts differed substantially from those recorded in higher-pressure areas.

Most of the detected scars were shallow and superficial, showing little or no rhizome exposure, limited canopy disturbance and low persistence over time. These features made the scars difficult to identify using aerial imagery alone, confirming the importance of underwater surveys for the accurate detection and verification of low-intensity anchoring impacts.

The GIS analysis enabled the delineation of impacted patches within the monitoring area and their classification according to the Scar Damage Class (S.C.) index. The resulting maps provided a clear representation of both the spatial distribution and the relative severity of the observed impacts Figure 16).



Figure 15 Examples of Cymodocea nodosa "scars" in Panzano Bay.

Overall, the application of the SCARS protocol showed that the current level of recreational anchoring does not produce significant mechanical degradation of the *Cymodocea nodosa* meadow. The observed impacts were generally limited to superficial disturbances and showed a high recovery potential, confirming the resilience of this habitat under the current pressure conditions.

At the same time, the pilot application demonstrated that the SCARS protocol is able to detect, classify and map even low-intensity anchoring impacts, providing a reliable baseline for future monitoring activities. The results support the use of the protocol as a standardized tool for assessing anchoring impacts and for supporting evidence-based management of seagrass habitats in low-pressure coastal environments.

Application of the SCARS Assessment Protocol

The Panzano Bay pilot site provided the opportunity to apply the SCARS assessment Protocol by integrating the results of underwater surveys, spatial analysis and habitat descriptors into a standardized assessment of anchoring impacts on *Cymodocea nodosa* meadows.

The information collected during the SCARS surveys was evaluated using the Integrated Scoring Matrix, which combines Degradation Risk (DR), Recovery Potential (RP) and Anchoring Pressure (AP). By bringing these three components together, the matrix provides an overall assessment of habitat condition and supports the interpretation of the observed anchoring impacts (Figure 17).

The analysis was performed separately for the two monitoring sites identified within the SCARS survey area (Site 1 and Site 2, Figure 16), which correspond to the specific areas where the monitoring stations (St. 3 and St. 4 – see Figure 9) are located. These two sites were selected because field monitoring activities confirmed the presence of actual anchoring scars (see Table 4). On the contrary, the areas hosting the remaining monitoring stations (St.1 and St.2) were excluded from this specific in-depth assessment, as the surveys did not detect unvegetated patches that could be unequivocally attributed to anchoring impacts. Although both analyzed sites are located within the same seagrass meadow system (*C. nodosa* meadows), they differ in their exposure to recreational boating and local environmental conditions, allowing a comparison of the relative contribution of anchoring pressure and natural factors to meadow condition.

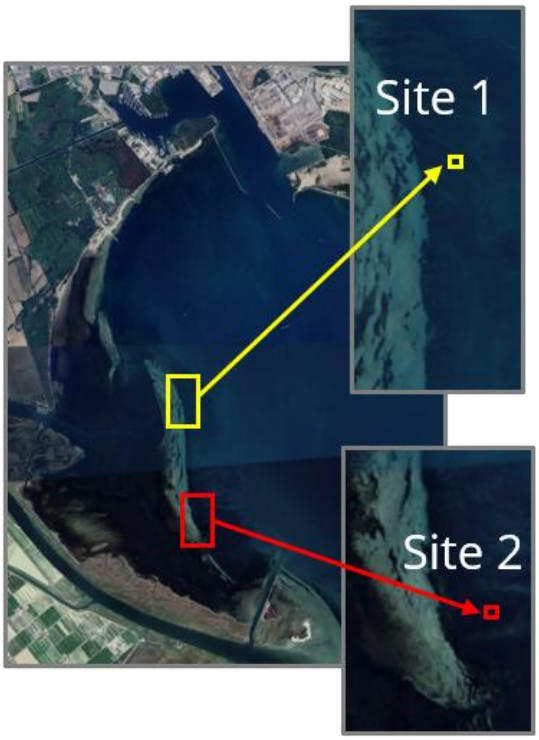
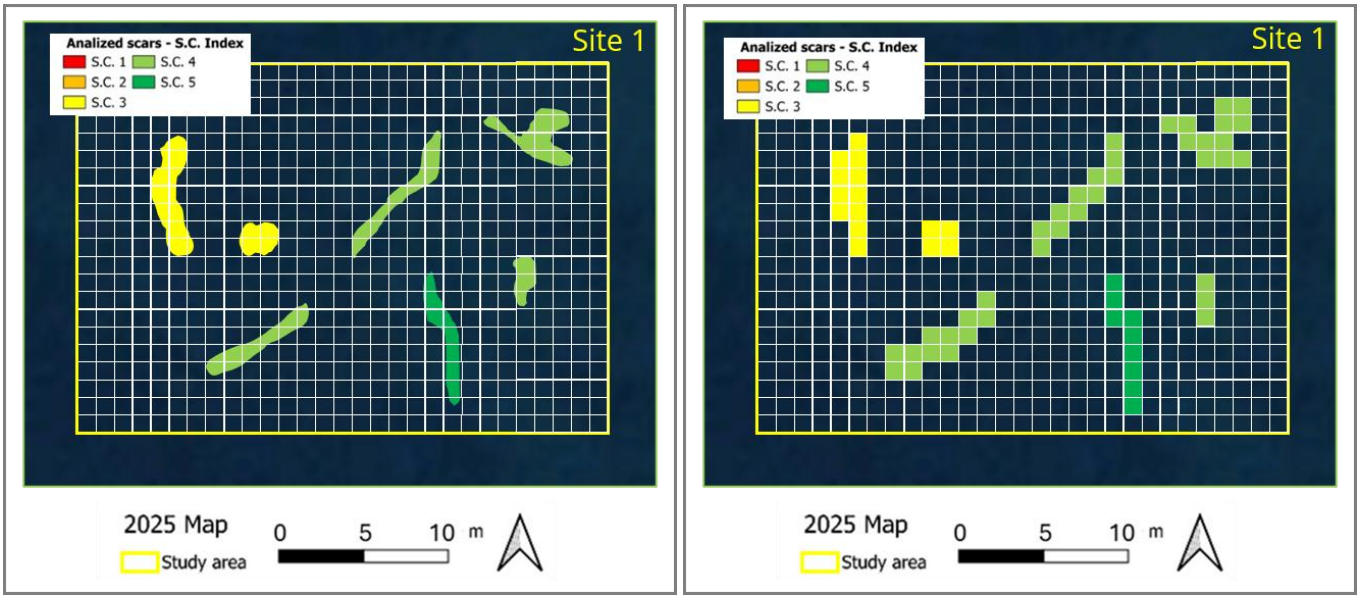


Figure 16 Monitoring area in Panzano Bay: localization of Site 1 and Site 2.



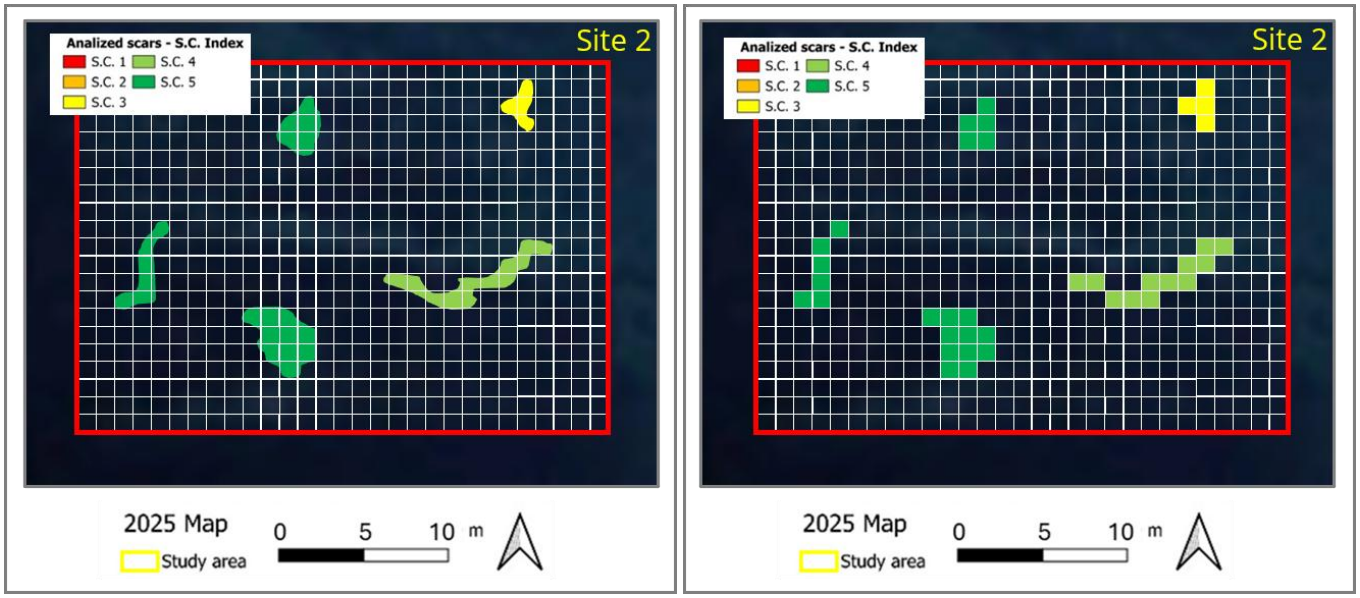


Figure 17 Monitoring area in Panzano Bay and GIS-based delineation of monitored impacted patches (highlighted in yellow and green) within the working perimeter in Site 1 and Site 2. Scars polygons are classified and color-coded according to their corresponding S.C. index values.

Table 7 Integrated Scoring Matrix (Site 1 and Site 2).

	DR	RP	AP	Total	Interpretation
Site 1	3	2	3	8	Moderate impact; localized anchoring effects with high recovery capacity.
Site 2	2	1	3	6	Low–moderate impact; mixed natural and anthropogenic pressures with a very high recovery capacity.

Site 1, located in the central–southern sector of Panzano Bay, is characterized by moderate recreational boating and mooring activities. SCARS observations indicate localized anchoring impacts, resulting in a moderate Degradation Risk (DR = 3) and moderate Anchoring Pressure (AP = 3). Despite these pressures, the continuity of the *Cymodocea nodosa* meadow indicates a high capacity for natural recovery (RP = 2), suggesting that the observed disturbances remain largely reversible under current environmental conditions. The resulting total score (6) classifies Site 1 as a low-to-moderately impacted area.

Site 2, located near the southern entrance of the bay, is influenced by stronger hydrodynamic conditions, sediment resuspension associated with freshwater inputs from the Isonzo River, and

episodic recreational boating activity. Although the site experiences a similar level of anchoring pressure (AP = 3) and low Degradation Risk (DR = 2), it exhibits a very high capacity for natural recovery (RP = 1), reflecting the resilience of the *Cymodocea nodosa* meadow under the current environmental conditions. The resulting total score (6) places Site 2 within the low-impact class.

When compared, Site 1 and Site 2 exhibit slightly different pressure–response patterns. Both sites are characterized by low degradation risk and moderate anchoring pressure; however, Site 2 shows a higher recovery capacity (RP = 1) than Site 1 (RP = 2), indicating a greater potential for natural recovery despite being exposed to stronger hydrodynamic processes and sediment resuspension. Overall, both sites remain in favourable ecological condition, with only limited evidence of anchoring-related disturbance under the current pressure regime.

These differences are summarised in in Figure 18, where each site is represented according to its position in the DR–RP space, with "bubble size" proportional to Anchoring Pressure (AP) and color indicating overall ecological condition.

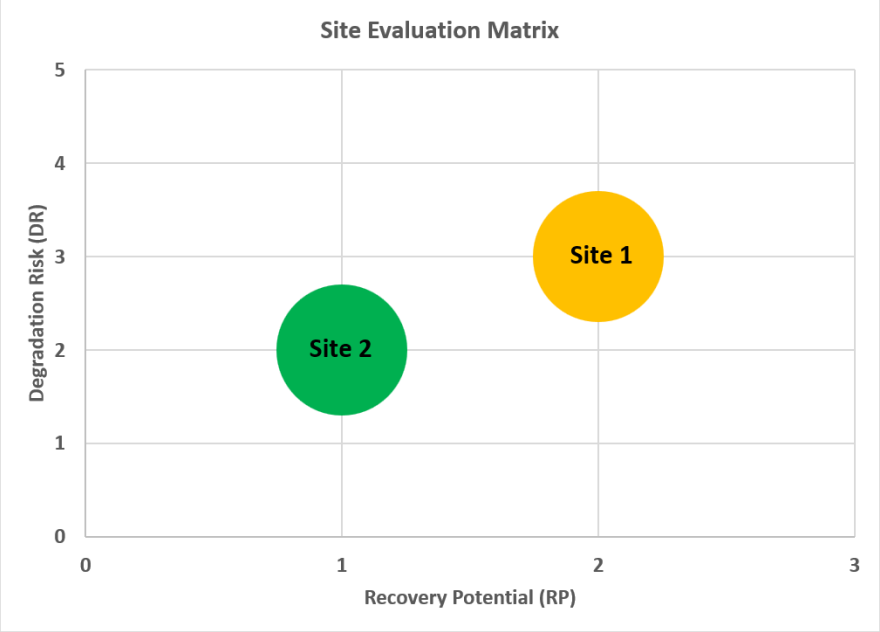


Figure 18 Bubble plot of Site 1 and Site 2 showing DR, RP, and AP (bubble size). Bubble color indicates the overall ecological condition associated with the presence and severity of anchoring scars (green = stable; orange = moderate; red = critical).

Overall, the Integrated Scoring Matrix proved effective in summarizing differences in degradation risk and recovery potential between the monitored sites. The framework provides a practical and transferable tool for supporting future monitoring and adaptive management of *Cymodocea nodosa* meadows under low to moderate anchoring pressure.

Bioacoustic Assessment of Nektonic Fauna

Objectives

The experimental eco-mooring buoy field established in Panzano Bay represents one of the key management measures implemented to reduce the impacts of recreational anchoring on seagrass meadows. While the primary objective of this infrastructure is to prevent direct damage to benthic habitats by providing environmentally sustainable mooring points, the BIOPRESSADRIA project also investigated its potential ecological role in supporting marine communities. To this end, an active bioacoustic monitoring campaign (3 surveys conducted between 2024 and 2025) was carried out to assess the abundance, biomass and spatial distribution of nektonic organisms within the managed area, providing an ecological indicator of the biological response associated with the eco-mooring field.

Table 8 summarizes the main characteristics of the monitoring program together with the principal findings discussed in the following sections.

Table 8 Summary of the bioacoustic monitoring program and key findings.

Indicator	Value
Study site	Panzano Bay eco-mooring field (Monfalcone)
Monitoring period	Late summer / Early fall - 2024 Late spring / Early summer - 2025 Late summer / Early fall - 2025
Survey method	Active hydroacoustic monitoring
Survey design	Repeated transects across the buoy field
Water depth	~5.5 m
Estimated fish biomass	115–225 kg ha^{-1}
Main ecological response	High nekton biomass with marked temporal variability
Management implication	Eco-mooring field represents a managed area regularly used by fish communities.

Study area and monitoring approach

The study focused exclusively on the experimental buoy field located in the western sector of Panzano Bay (Monfalcone), originally established under the Interreg SASPAS project and subsequently maintained within BIOPRESSADRIA. The mooring field occupies an area of approximately 500 × 250 m, lying on shallow bottoms at an average depth of about 5.5 m, approximately 500 m from the shoreline and close to the entrance of the Port of Monfalcone. Unlike the other pilot sites investigated within the project, the Panzano buoy field is relatively isolated from



natural rocky reefs and other structured habitats, providing an opportunity to evaluate the ecological response of fish communities within a managed coastal area characterised primarily by marine seagrass meadows and soft-bottom habitats.

The survey was conducted using active hydroacoustic techniques, allowing the systematic assessment of nekton communities throughout the entire water column without disturbing marine organisms or damaging sensitive habitats. Repeated survey transects were performed across the buoy field to obtain spatially representative estimates of fish abundance, biomass, and body size distribution (Figure 19).

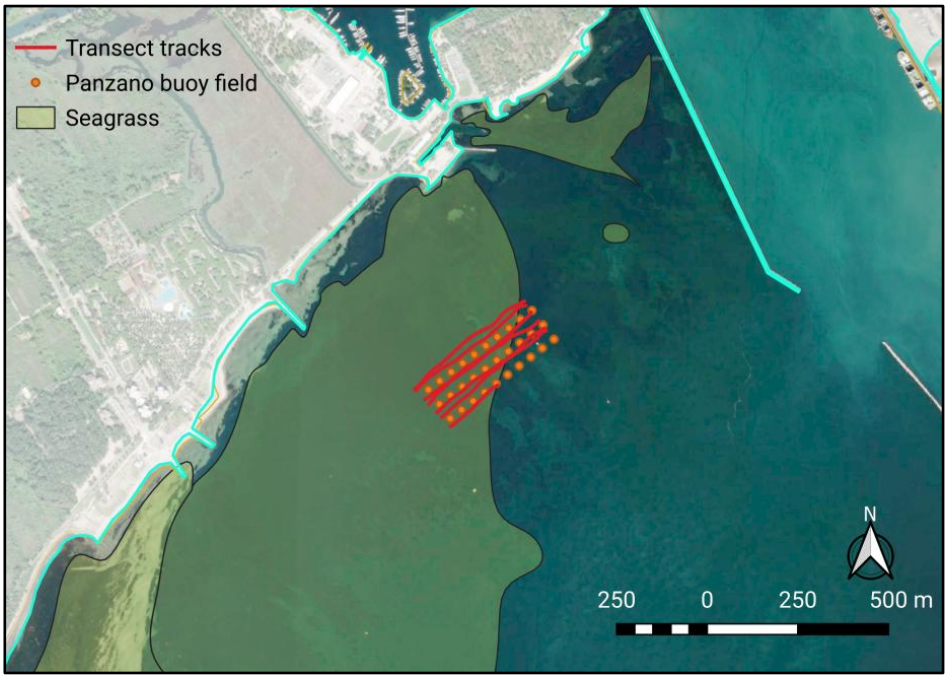


Figure 19 Positioning of the pilot site within the Bay of Panzano (Monfalcone). The transects, highlighted in red, were mapped within the buoy field marked in orange.

Fish biomass and community response

The bioacoustic surveys revealed that the eco-mooring field supports relatively high nekton biomass, with peak values reaching 225 kg ha^{-1} during the monitoring period. These estimates are comparable to those observed in the Croatian pilot site (Kornati NP) where the strongest ecological response to mooring buoy installations was recorded, indicating that the Panzano buoy field also represents a habitat regularly used by fish communities. However, unlike the Croatian site, the temporal variability in Panzano was extremely pronounced: while high biomass was recorded in summer 2024 and

autumn 2025 (115–225 kg ha^{-1}), the survey conducted in late spring 2025 showed a near-total absence of nekton (0.01 kg ha^{-1}). This significant fluctuation, ranging from near-zero to 35,636 fish/ha, highlights that as a "mature-isolated" system, situated distant from natural reef structures, Panzano exhibits unique aggregation dynamics, likely modulated by its higher trophic status and environmental isolation rather than remaining constant over time (Figure 20).

Beyond overall biomass, the surveys also documented changes in the size structure of the detected organisms. Compared with the first monitoring campaign, the average body length of fish increased substantially, shifting from 5.7 (±1.3) cm in 2024 to 13.2 (±0.6) cm in autumn 2025, indicating a shift from assemblages dominated by smaller individuals towards communities including larger specimens.

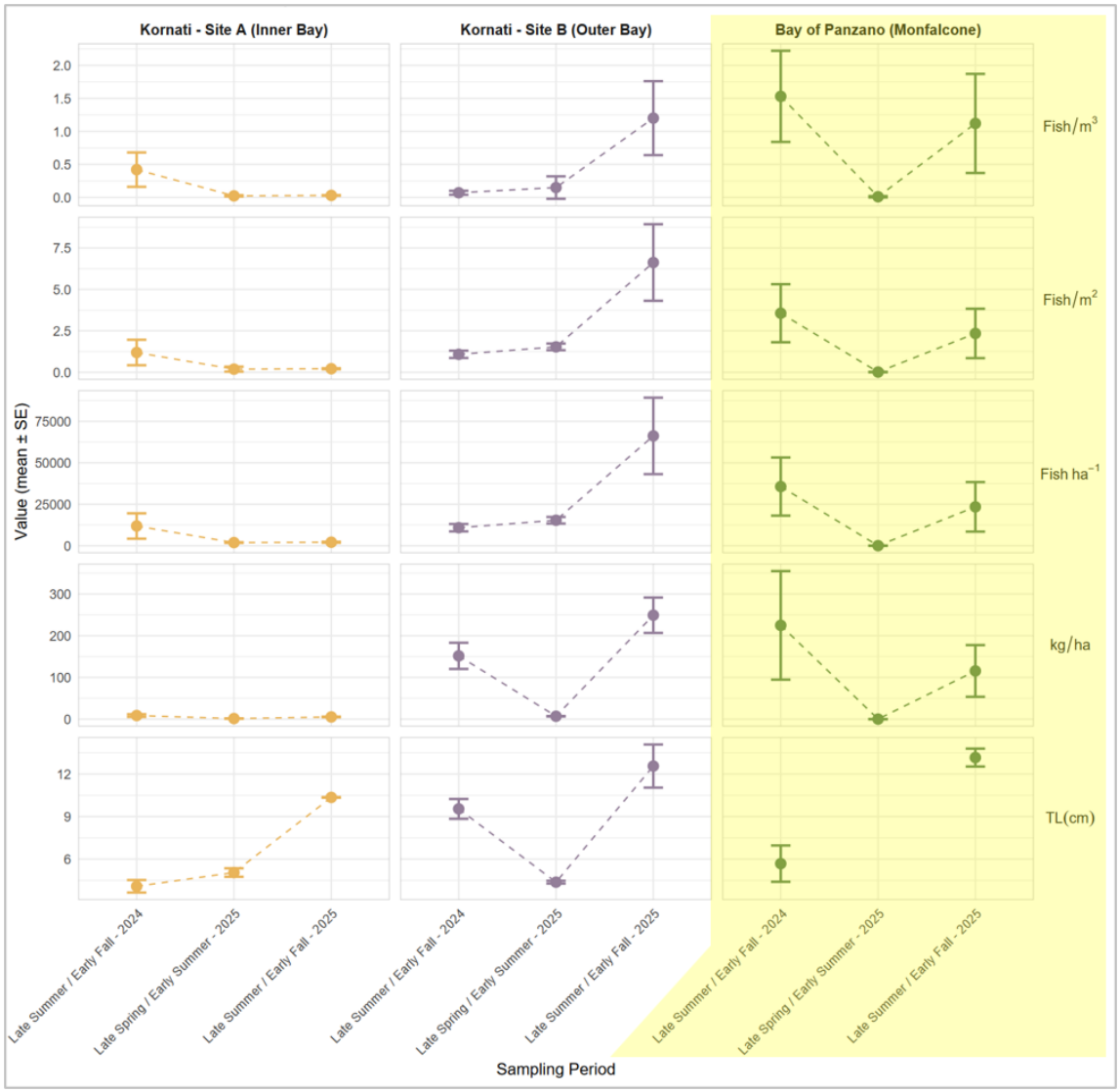


Figure 20 Temporal trends from the three acoustic surveys conducted at the study sites (Panzano Bay site is highlighted in yellow). Reported metrics include fish density, total length, and biomass per unit area.

Ecological interpretation

The results indicate that the ecological functioning of eco-mooring systems cannot be interpreted independently of the surrounding environmental context. In Panzano Bay, the buoy field appears capable of supporting substantial nekton biomass, but the observed temporal variability suggests that fish distribution is also influenced by seasonal dynamics, habitat characteristics and anthropogenic disturbance. Field observations carried out during the monitoring campaign indicated lower recreational boating activity during the autumn survey period, raising the possibility that reduced human disturbance may contribute, together with the presence of the eco-mooring infrastructure, to the increased use of the area by marine fauna. Nevertheless, the results suggest that this hypothesis requires further investigation through integrated long-term monitoring combining biological indicators with quantitative assessments of boating pressure.

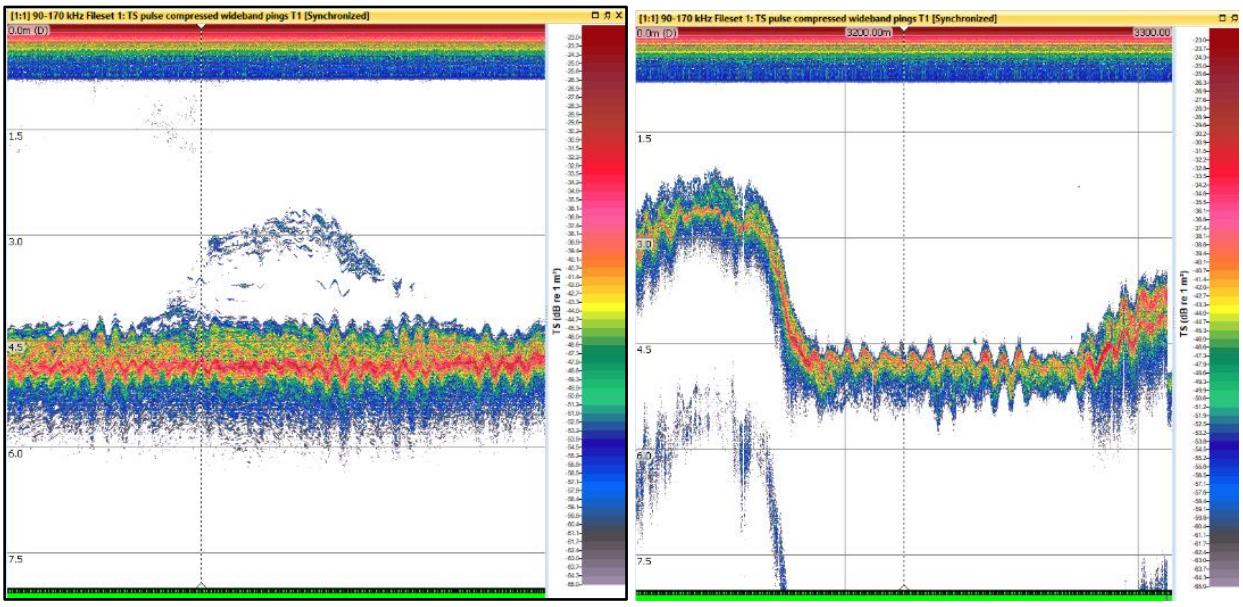


Figure 21 In the image on the left, a portion of an echogram, recorded in the buoy field of the Bay of Panzano. In its centre, some traces generated by a small aggregation of fish can be seen, located near the seabed (red band at approximately 4.5 meters depth). In the image on the right, a Portion of an echogram related to the northernmost area of the buoy field.

Management implications

Overall, bioacoustic assessment demonstrates the value of non-invasive acoustic monitoring as a tool for evaluating the ecological performance of coastal management measures. For the Panzano pilot site, the results provide evidence that the eco-mooring field is actively used by nekton communities and contributes to a broader understanding of the ecological effects associated with environmentally sustainable mooring systems. Although the available data do not allow definitive conclusions regarding a fish aggregation effect, they indicate that the managed area can support

relatively high fish biomass and highlight the importance of integrating habitat conservation, boating management and ecological monitoring within future coastal management strategies.

3.1.5 Implications for Pilot Actions and future monitoring

The monitoring results provide the ecological and pressure baseline required to support and periodically reassess the management measures implemented in Panzano Bay under WP2. In this pilot site, anchoring impacts appear generally localised and the seagrass system remains relatively stable and resilient; consequently, the principal management objective is not the remediation of a severely degraded habitat, but the prevention of further disturbance and the long-term maintenance of ecological functionality. Repeated habitat mapping, pressure assessment and monitoring of anchoring traces will allow future changes to be detected and will provide the evidence needed to refine zoning, mooring management and other mitigation measures through an adaptive approach.

3.2 Pilot Site 2: National Park Kornati (Croatia)

3.2.1 Geographical and morphological framework of the area of interest

The Kornati archipelago is situated in the Croatian part of the Adriatic Sea, in the Central Dalmatia region, to the west of City of Šibenik in Šibenik-Knin County (https://www.sibensko-kninska-zupanija.hr) and local self-government unit - Municipality of Murter-Kornati (https://murter.hr/). The Kornati archipelago, as a separate and unique island group, stretches over an area of approximately 320 km² and includes 149 islands, islets and reefs that are permanently or occasionally above sea level. Four chains of islands are classified into two groups:

- The Upper Kornati (Gornji Kornati) – the Sit and Žut island chains with a total of 51 land units
- The Lower Kornati (Donji Kornati) – the Kornati and open sea or Piškera island chain with a total of 98 land units.

Kornati National Park encompasses the majority of the Lower Kornati, while the Upper Kornati are protected under the important landscape category and are under the management of the Public Institution for the Management of Protected Natural Values of Šibenik-Knin County (https://priroda-skz.hr/).
Kornati National Park is managed by the Kornati National Park Public Institution, established by the Government of the Republic of Croatia in 1982, two years after it declared the area a national park (www.np-kornati.hr). The Public Institution manages the protection, maintenance and promotion of Kornati National Park with the objective of protecting, restoring and preserving the original state of the natural environment, ensuring the unimpeded occurrence of natural processes and the

sustainable utilisation of natural resources. The Public Institution oversees the conditions and undertakes measures to protect the natural environment in the territory of Kornati National Park under the Law on Nature Protection[5] (Official Gazette 80/13, 15/18, 14/19, 127/19, 155/23) and related regulations.

The Kornati National Park consists of 89 islands, islets, and reefs, covering an area of approximately 217 km^2 (21,700 ha). This unique marine environment features a rugged landscape dominated by limestone formations, cliffs and karst phenomena. The largest island, Kornat, stands as the focal point of the park and reaches a height of 237 meters. The terrestrial and marine ecosystems of Kornati National Park are home to a wide range of biodiversity, including endemic plant species and diverse marine life. The entire National Park area is also part of Natura 2000, a network of nature protection areas in the territory of the European Union. The management of a NATURA 2000 area must ensure long-term survival of target species and habitat types in a certain area. It includes two designated Natura 2000 sites:

- HR1000035 – Kornati National Park and Telašćica Nature Park - Special Protection Area (SPA) under the EU Birds Directive, designated for the conservation of vulnerable and migratory wild bird species and their habitats.
- HR4000001 – Kornati National Park - Special Area of Conservation (SAC-s) – designated to protect and preserve habitats and species listed under the EU Habitats Directive.

All conservation measures, with specific activities and goals to preserve Natura 2000 habitats and species, are defined in the Management Plan of Kornati National Park (PU 6012), which should be implemented by the Public Institution of Kornati National Park during the period 2024–2033 (www.np-kornati.hr/images/plan_upravljanja/2023/PU6012_NP_Kornati.pdf).

One of the most important marine habitat in Kornati National Park is Posidonia beds (*Posidonia oceanicae*, code: 1120), a priority Natura 2000 habitat that stretches across most of the coastal belt of the Kornati Islands waters up to a depth of 30 metres. The *Posidonia oceanica* in the National Park area forms dense meadows that provide habitat, food, and protection for various marine species. To protect these valuable meadows, Kornati National Park Public Institution implements various conservation projects, including the Interreg project BIOPRESSADRIA (https://www.italy-croatia.eu/web/biopressadria).

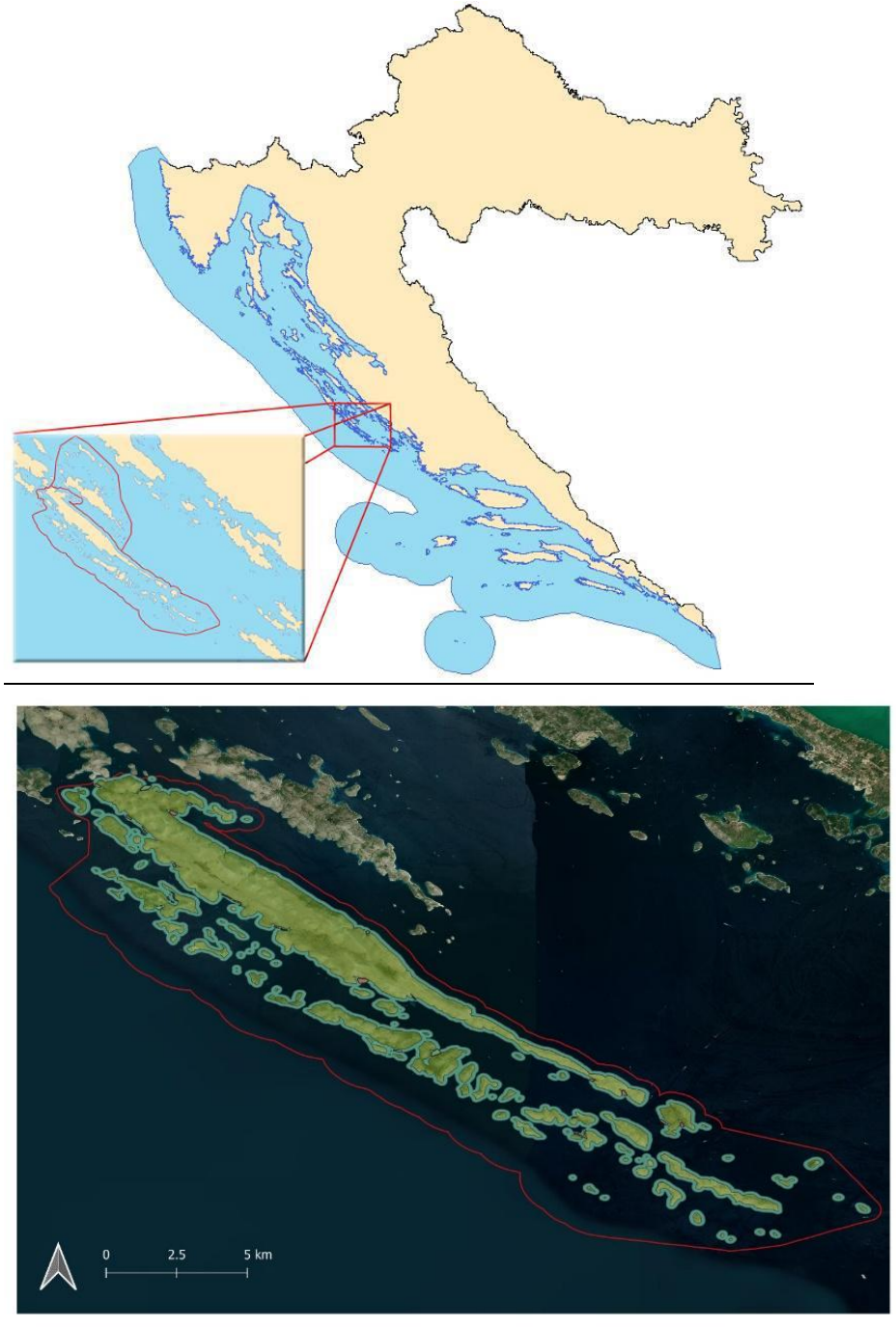


Figure 22 Location of the Kornati archipelago (a) and Kornati National Park area and borders.

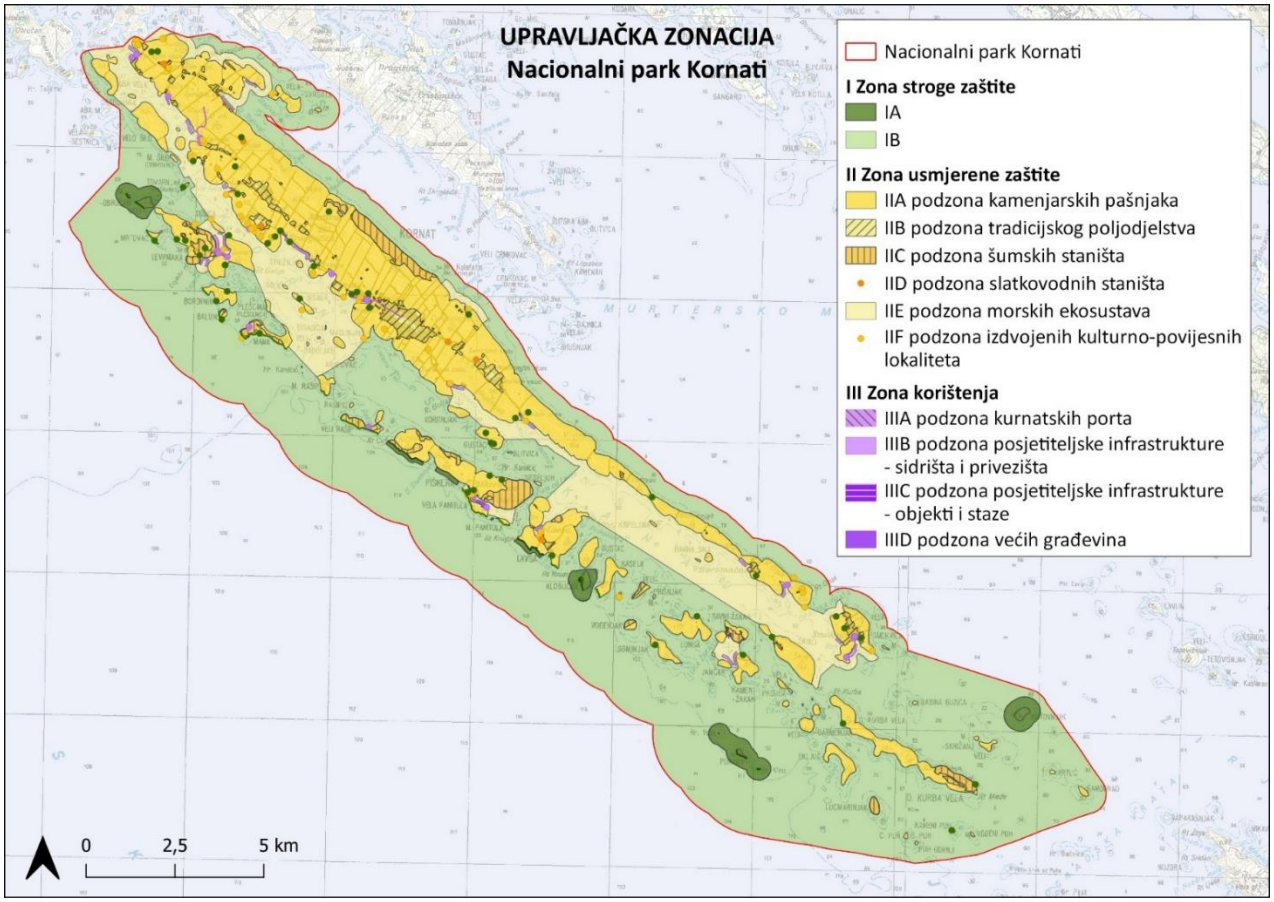


Figure 23 Management zonation of the Kornati National Park (green – strict protected zones, yellow – conservation zones, purple – usage zones).

3.2.2 Main users of the area

Residents and owners

The land area of Kornati National Park, with the exception of the coastal areas that have the status of maritime domain, is entirely privately owned by about 800 owners – Kurnatari, mostly residents of Murter, with a smaller portion from Betina, and an even smaller portion from Zaglav and Sali on Dugi Otok. The main traditional activities of the Kurnatari include sheep farming, olive cultivation, beekeeping, and fishing – mostly for personal use. All these activities are still significantly present in the area of the National Park, although they have been in rapid decline since the second half of the last century due to the aging of the last, so to speak, "pre-modern" generation. Today, fishing is only

allowed as recreational fishing. In the last 50 years, a significant tourism and hospitality industry has also developed in the park.

Nautical visitors

The most prominent tourist activity in the park area is nautical tourism. The attractiveness of the Kornati archipelago for sailing, the large number of sheltered bays suitable for anchoring, the growing number of organized moorings, the well-developed gastronomic offer, and several large marinas with extensive charter fleets along the coast from Zadar to Rogoznica contribute to the constant increase in the number of boaters and vessels. According to the statistics of the public institution on ticket sales in recent years, Kornati is visited annually by about 20,000 individual vessels. On an average day during the peak summer season (July and August), there are around 200 vessels in the park, with the maximum number in a day relatively often exceeding 300, and on exceptional days even 400 vessels—although, due to the methodology used to estimate numbers, it is certain that the actual figure is considerably (in some estimates even twice) higher. For example, in summer of 2025 the highest count of the vessels recognized in the analysis of the pressure of the nautical tourism was in August and it was 531. Boaters' visits are highly seasonal, with over 90% of visits occurring between June and September, and over 60% in the two peak months of July (26%) and August (36%). It is estimated that in recent years, around 125,000 visitors have visited the Park in this way.

Boating and overnight stays

With the exception of the strict protection zones, boating is permitted in the entire area of Kornati National Park. Anchorage and overnight stays are permitted in the following inlets: Stiniva, Stival, Tomasovac – Suha punta, Šipnate, Lučica, Kravljačica, Strižnja, Vrulje, Gujak, Opat, Smokvica, Ravni Žakan, Lavsa, Piškera – Vela Panitula and at Anica cove on Levrnaci, Podbižanj and Koromašna. There are currently 164 ecological mooring buoys that provide visitors with safe mooring, enable the control of visitor numbers and movements, and contribute to the conservation of valuable marine habitats in anchoring areas (https://www.np-kornati.hr/index.php?option=com_content&view=article&id=432&Itemid=414&lang=en).

Boat excursions

Boat-owners and/or travel agencies that organize excursions in Kornati National Park must have a signed contract to work with the Public Institution. Visitors, who wish to visit Kornati National Park by excursion boat, have at their disposal boats of various types and capacities, with various harbors of departure. In 2022, around 40 boat operators offered group day trips from nearby coastal destinations (from Zadar to Primošten), using approximately 60 boats with a total capacity of around 2,300 passengers. The boats vary in type and capacity, ranging from smaller fast boats with a capacity of 10-15 people (57%), to medium-sized boats with a capacity of 20-60 people (23%), larger boats with a capacity of 60-100 people (12%), and large excursion boats with a capacity of 100-200 people (8%).

It is estimated that around 52,000 visitors participated in group day trips to the park in 2022, through approximately 1,100 excursions/arrivals of excursion boats of various sizes. In addition, around 20 so-called mini cruise ships for multi-day cruises regularly dock in the park, with a capacity of about 36 guests. There were about 40 such arrivals in 2022, with around 1,300 guests. It can be roughly estimated that during the peak season, the Park is visited daily by 15-20 excursion boats of various sizes, with a total of about 500 visitors.

Diving and snorkelling

The underwater area of the Kornati is one of the more attractive diving destinations in the Adriatic, especially the reefs that steeply descend into the depths from the open sea side of the island chain, featuring appealing coral communities. There are nine zones in which diving visits are permitted in Kornati National Park: Kornat (Opat – Tanka Prisliga), Samograd, Oključ, Mala Panitula, Vela Panitula, Rašip, Kasela, Mana and Borovnik. Diving visits using scuba diving gear is only permitted through organized programs and under the guidance of a diving center that has signed an agreement with the Public Institution for this activity. In the past five years, around ten diving centers from the surrounding area have offered guided diving services at the nine currently designated diving zones/locations in the park (with a peak of 13 in 2018 and a low of 8 in 2022). Approximately 100 guided diving visits are conducted annually, with a total of around 1,000 divers, of which more than two-thirds come from the two largest diving canters. Diving is permitted to a maximum depth of 40 meters, only during the day, and must comply with all regulations to avoid damaging sensitive marine habitats and associated species.

Permits are not required for snorkeling and swimming, but it may only be done within swimming zones – a distance of up to 50 meters from the shoreline (except in strict protection zones).

Restaurants and Taverns

In the Park area, during the season from April to October, around 20 hospitality establishments (taverns/restaurants) operate, mostly "family-run businesses" that have often developed as an additional activity on larger traditional estates, with still active sheep farming and olive cultivation. A number of Kornati taverns have successfully positioned themselves as a quality and recognizable gastronomic destination in restored and partially adapted, yet still distinctly "Kurnatari modest" facilities. It is very important that better communication is established with the owners of restaurants and taverns, including providing education on the values of the area, that they be provided a support in adapting to the minimal technical conditions, that they be offered the possibility of participating in creating a range of products and in their branding and joint promotion.

3.2.3 *Existing pressures*

Protecting and managing Kornati National Park presents many challenges, the biggest of which is reducing the impact of various anthropogenic pressures. Because the Park covers a large area and consists of numerous islands, islets and reefs surrounded by the sea, it is difficult to monitor the entire Park, enforce protection measures, and ensure that visitors follow the rules.

The **existing pressures** affecting Kornati National Park include the increased nautical tourism, growing number of boats and visitors, free anchoring, marine and coastal litter, illegal fishing, noise from vessels, limited monitoring and enforcement, the spread of invasive species, and the effects of climate change. Together, these pressures can have negative impacts on the Park ecosystems and biodiversity and may reduce their resilience over time. Protecting the Park therefore requires effective management, regular monitoring, cooperation between different stakeholders and raising awareness among visitors about the importance of conserving this unique area.

The increasing growth of **nautical tourism** is one of the main pressures affecting Kornati National Park. During the tourist season, a large number of recreational boats, yachts, and charter vessels visit the Park every day. This increased traffic can disturb marine biodiversity, generate underwater and surface noise, and contribute to **water pollution** through fuel leaks, wastewater discharge and litter. The Park experiences a significant rise in nautical tourism, with around 20,000 individual vessels visiting annually. This influx leads to congestion, particularly during peak months, with hundreds of boats often present simultaneously. **Excursion boats and day trips** represent another important source of pressure on Kornati National Park, as they bring large numbers of visitors to the same locations within a short period of time, especially during the summer season.

Excursion boats and organized day trips are another important source of pressure on Kornati National Park. Approximately 52,000 visitors participate in group day trips to the Park each year, facilitated by around 40 boat operators. Most of these visits take place during the summer season, when many people visit the same locations at the same time, increasing pressure on the Park natural environment. At the same time, intensive boat traffic generates **underwater noise** and increases the **risk of pollution** from wastewater and other boat-related waste, although the overall extent of these impacts is not regularly monitored. The biggest pressure on marine habitats, especially *Posidonia oceanica* meadows, is **free anchoring.** This pressure has serious consequences, including habitat loss, reduced biodiversity, and the overall degradation of the marine ecosystem. In many cases, the damage is irreversible, and restoring some habitats can take a long time. To completely ban free anchoring and protect marine habitats in Kornati National Park, ecological moorings have been installed in recent years to reduce damage to *Posidonia oceanica* meadows and preserve sensitive marine ecosystems. While **diving using scuba diving** gear is regulated, the presence of diving centres and guided visits (around 100 annually) can still impact sensitive marine ecosystems. Although divers must follow strict rules, diving represents a less significant pressure compared to other human activities, but it can still contribute to some stress on vulnerable marine habitats. The



growth of **family-run taverns and restaurants** has turned the area into a gastronomic destination, increasing local activity and potentially impacting traditional practices like sheep farming and olive cultivation. All houses and restaurants in the Park rely on individual septic tanks which if not properly sealed or managed may cause **wastewater pollution**. Scale of wastewater pressure is not monitored. However, there are no major villages in the park, mainly small settlements in bays with several houses or restaurants. The increase in visitors and maritime activities also result in increased **marine litter**, especially in bays where boats are present, which poses a threat to marine life and habitats, impacting the ecological balance. Monitoring of marine litter in Kornati National Park was carried out within the framework of the ACT4LITTER project, which aimed to identify the main sources of marine litter and develop measures to reduce its impact. The results showed that plastic was the most common type of marine litter, followed by glass, metal, textiles and rubber, with waste originating from both land-based sources and maritime activities. A significant pressure is also caused by **illegal fishing**. Although traditional fishing is prohibited within the National Park, regulated recreational fishing is still allowed under specific rules and conditions. **Global climate changes** have also reflected on environmental changes in the marine environment. Rising sea temperatures, more frequent extreme weather events, and other climate-related changes can further affect marine habitats and the species that depend on them. Sea temperature changes and their impact on coraligenous communities have been monitored in Kornati National Park for many years. The results show negative effects, including tissue necrosis and mortality in sponges, scleractinian corals, and gorgonians. Climate change also accelerates the spread of **invasive marine species**. Rising sea temperatures and changes in salinity allow tropical species to colonize new areas, where they can outcompete native species and cause irreversible changes in ecosystems. Some of the invasive species recorded in Kornati National Park include the lionfish (*Pterois miles*), *Caulerpa cylindracea*, fireworm (*Hermodice carunculata*), *Stypopodium* sp., and other non-native species.

Habitats

The marine area of Kornati National Park is included in the Natura 2000 ecological network (site code: HR4000001), designated for the conservation of marine habitat types of European importance. The protected area encompasses approximately 3,000 hectares and includes three Annex I habitat types under the EU Habitats Directive: *Posidonia oceanica* seagrass beds (1120), reefs (1170), and submerged or partially submerged sea caves (8330).

These habitats represent key components of the Park's marine biodiversity, providing essential ecological functions such as nursery grounds, shelter, and feeding habitats for numerous marine species. Their protection contributes to maintaining the ecological integrity of the Adriatic Sea and supports the long-term conservation objectives of the Natura 2000 network.

Main focus in this project was protection of ***Posidonia oceanica* seagrass beds (1120)**, which is done by installing the ecological mooorings to prevent boaters from damaging the seagrass beds with their anchors. Habitat type Posidonia beds 1120 provides numerous ecological functions and ecosystem services. It supports exceptionally high biodiversity by offering feeding grounds, shelter, nursery

areas, and spawning habitats for hundreds of marine species. The dense root and rhizome system stabilizes sediments, reduces coastal erosion, improves water clarity by trapping suspended particles, and stores significant amounts of "blue carbon," making *Posidonia* meadows one of the most efficient long-term carbon storages in the Mediterranean. Because *Posidonia oceanica* grows extremely slowly (typically only a few centimetres of rhizome per year), damaged meadows may require decades or even centuries to recover, and in many cases recovery is incomplete. Consequently, Habitat 1120 is considered a conservation priority throughout the Mediterranean and is the focus of numerous restoration, monitoring, and sustainable management initiatives, including the installation of ecological mooring systems to prevent anchor damage. So, in this project by installing ecological moorings the main goal is to mitigate the effects of anchors on this valuable habitat type.

The **Reefs (1170)** are widely represented along the Croatian Adriatic coast including Kornati National Park. In Croatia, this habitat primarily consists of natural rocky reefs and coralligenous formations that extend from the shallow infralittoral zone to deeper circalittoral waters. These reefs are characterized by hard substrates, including bedrock, boulders and huge walls which provide a stable surface for the development of diverse benthic communities dominated by macroalgae, sponges, bryozoans, corals, gorgonians, and other sessile invertebrates. Mainly made out of karst, its structure provides lot of hiding/resting grounds for large number of fish species such as groupers, scorpion fish, breams etc.

Submerged or partly submerged sea caves (8830) are found along the Croatian Adriatic coast, these habitats are particularly associated with the extensive limestone and karst coastline. Sea caves vary from small cavities and tunnels to larger and more complex cave systems and are often closely connected with reefs (1170). They provide shelter, feeding areas and nursery habitats for numerous marine species icluding sponges, bryozoans, polychaete worms, and other sessile invertebrates. In Kornati National Park there are present vast number of caves but only small number of them are fully explored.

Large shallow inlets and bays (1160) as a habitat are present in Kornati national park in just two sites, Lavsa island and Šipnate bay on Kornat. These sheltered environments are protected from strong wave action and are characterized by a mosaic of sediments and substrates, including sand, mud, gravel, rocky bottoms, and seagrass meadows (*Cymodocea nodosa*).

Table 9 presents the marine habitat types recorded within the Natura 2000 site together with their conservation assessment, including representativity, relative surface, conservation status, and overall site value

Table 9 Marine habitat types recorded within the Natura 2000 site and assessment criteria.

ANNEX I HABITAT TYPE							SITE ASSESSMENT			
CODE	NAME	PF	NP	COVERS (ha)	CAVES (number)	DATA QUALITY	A|B|C|D	A|B|C|D		
							Representativity	Relative surface	Conservation	Global
1120*	Posidonia beds (*Posidonia oceanicae*)	1	0	2.100,00	_	P	B	C	B	B
1160	Large shallow inlets and bays	0	0	31,00	_	M	A	C	B	B
1170	Reefs	0	0	318,00	_	P	A	C	B	A
8830	Submerged or partly submerged sea caves	0	0	0,00	18	M	A	C	B	A

The assessment follows the Standard Data Form methodology for Natura 2000 sites
PF (Priority Form): Value "1" indicates the priority form of habitat types that may occur in both priority and non-priority forms (codes 6210, 7130, and 9430).
NP (Not Present): Value "1" indicates that the habitat type is no longer present within the site.
Caves: For habitat types 8310 and 8330, the number of caves is reported when surface area estimates are unavailable.
Data Quality: G – Good (survey-based data); M – Moderate (partially surveyed data with extrapolation); P – Poor (approximate estimation).
Representativity: A – Excellent; B – Good; C – Significant; D – Non-significant.
Relative Surface: A – More than 15% of the national distribution; B – 2–15%; C – Less than 2%.
Conservation Status: A – Excellent conservation; B – Good conservation; C – Average or reduced conservation.Global Assessment: A – Excellent value; B – Good value; C – Significant value for conservation.

3.2.4 Target habitats and pressure impact evaluation

Public Institution National Park Kornati activities within BIOPRESSADRIA are focused on *Posidonia oceanica* meadows and nautical tourism that are the main threat to this priority habitat type.
Evaluation of this pressure and its impact on *Posidonia oceanica* meadows was evaluated within the whole Park area.
Main project activities focused on mitigating nautical tourism pressures will focus on the area of Lojena bay and Anica Bay (Figure 24).

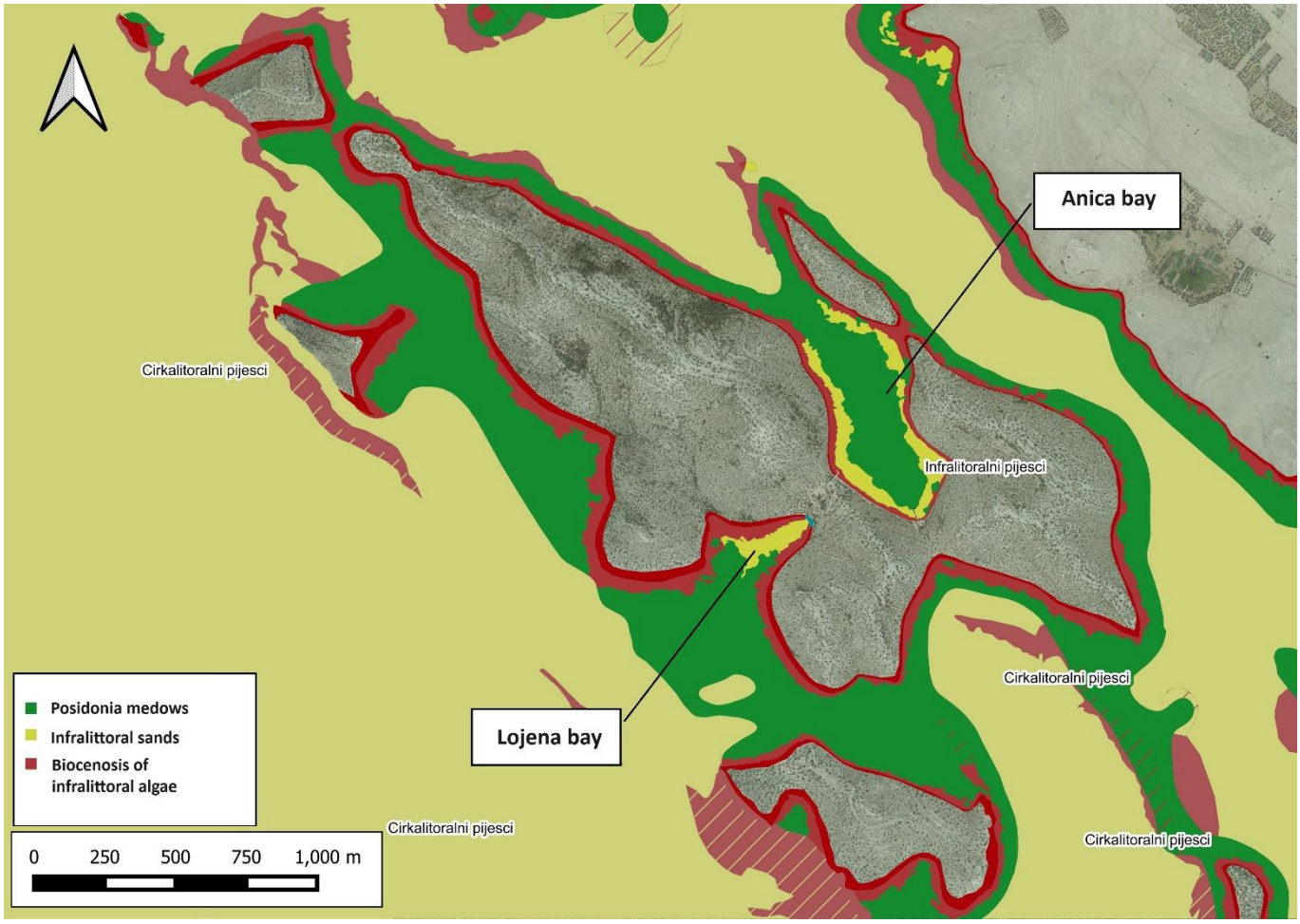


Figure 24 Pilot site for Biopressadria project and representation of marine habitat types.

This area is one of most attractive swimming area, due to beautiful Lojena bay which has also one of very few beaches in the park. It is very much visited by tourist that come by individual boats or

are brought by touring daily excursion boats ships (Figure 25). There is also one restaurant present in Anica bay “Konoba Levrnaka”.



Figure 25 Daily touring excursion boats in Anica bay.

Through BIOPRESSADRIA project, the Kornati National Park Public Institution installed new 19 ecological mooring buoys in two bays to reduce nautical pressure and protect marine habitats, especially sensitive *Posidonia oceanica* meadows. Figures 26 and 27 show the use of these buoys in both bays.



Figure 26 Use of ecological moorings in Anica bay.



Figure 27Use of ecological moorings in Lojena bay

Posidonia beds monitoring

A comprehensive monitoring of *Posidonia oceanica* meadows was carried out in Kornati National Park in June 2025 within the BIOPRESSADRIA project, following the same monitoring protocol and permanent monitoring sites established in 2023, allowing direct comparison of ecological status over

time. The survey covered five representative locations, including three sites historically exposed to intensive anchoring pressure (Kravljačica Bay, Vrulje Bay and Kameni Žakan) and two reference sites with negligible anchoring pressure (Borovik and Levrnaka – Prisliga Bay).

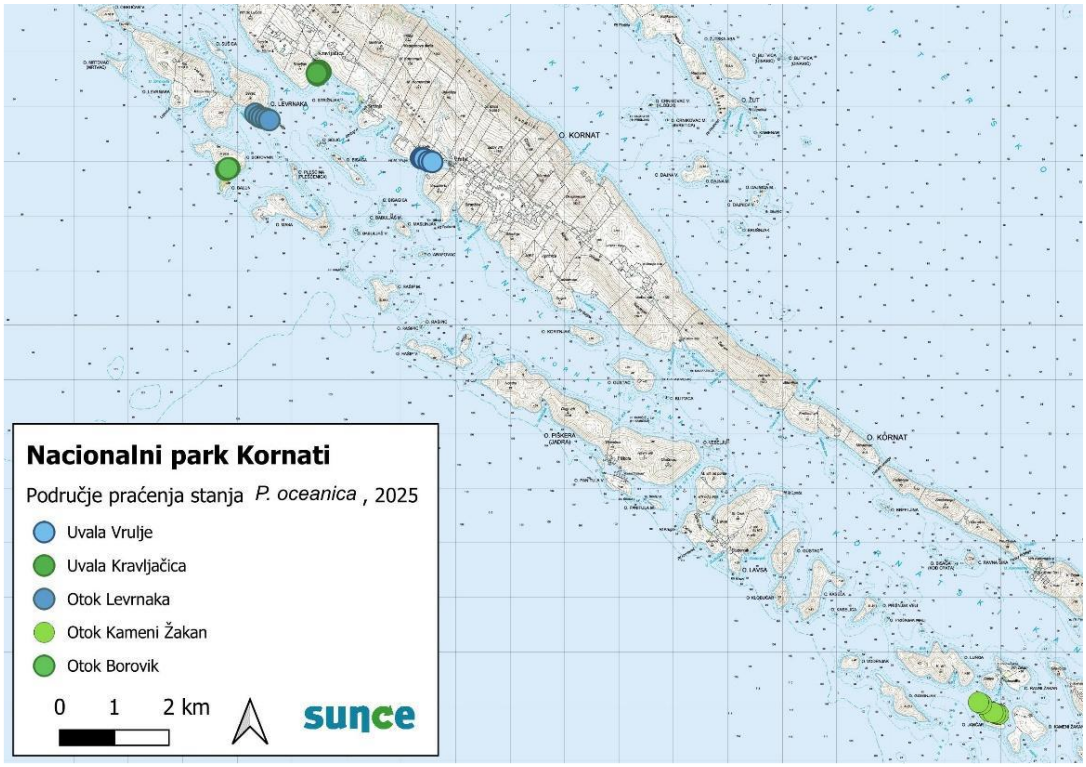


Figure 28 Sampling stations for Posidonia oceanica monitoring.

The monitoring confirms clear spatial differences in meadow condition. Reference meadows at Borovik and Levrnaka remain in good ecological condition, characterized by high shoot density, dense canopy and healthy meadow structure. In contrast, meadows exposed to long-term anchoring pressure show significantly lower shoot density and poorer conservation status. Among the monitored sites, Kravljačica represents the most degraded meadow, while Vrulje and Kameni Žakan remain in poor to moderate condition. These results confirm that anchoring continues to be the dominant local pressure affecting the conservation status of *Posidonia oceanica* within the Park.
The results are consistent with previous monitoring campaigns initiated in 2012 under the MedPAN South project and continued through the SASPAS project (2020–2021). Since 2023, five permanent monitoring sites have been established to enable long-term assessment using harmonised methodology. Comparison of the available time series indicates that reference sites have consistently maintained higher shoot densities and better ecological status, whereas meadows affected by

anchoring have shown little or no measurable recovery. The report notes that interpretation of long-term trends should consider methodological differences between early monitoring campaigns (2012–2021) and the standardized protocol adopted in 2023 and 2025.

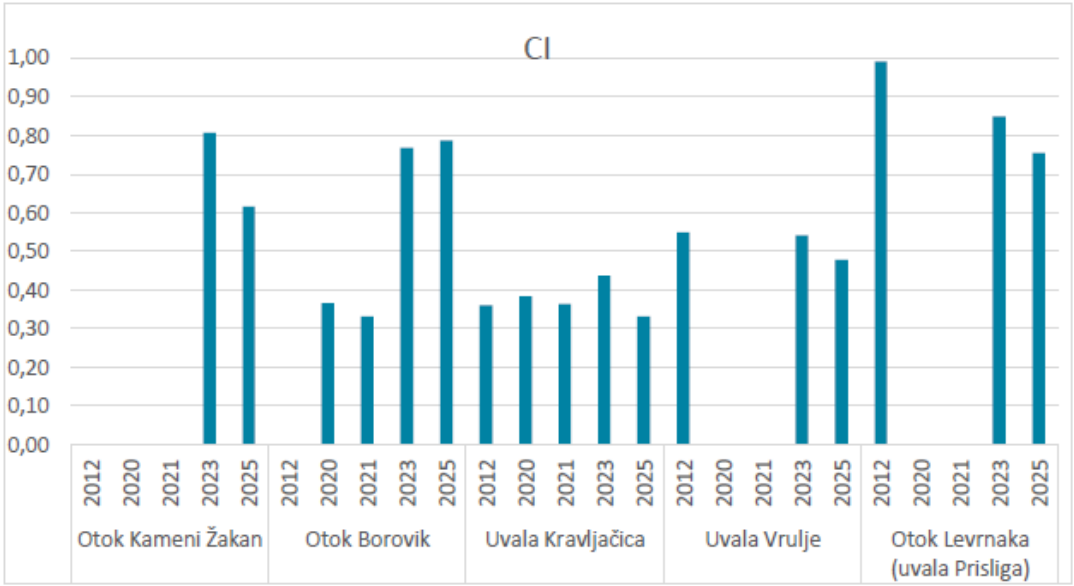


Figure 29 Conservation Index (CI) values for Posidonia oceanica meadows (2012. – 2025.).

Although environmentally friendly mooring systems have been installed at the monitored anchoring locations, the expected ecological recovery has not yet become evident. Satellite analyses carried out within the BIOPRESSADRIA project demonstrate a substantial increase in the use of ecological mooring buoys between 2023 and 2025, suggesting that the new infrastructure contributes to reducing additional mechanical damage. However, free anchoring still occurs, and due to the extremely slow growth and recovery rate of *Posidonia oceanica*, measurable ecological improvements are expected only over longer time scales.

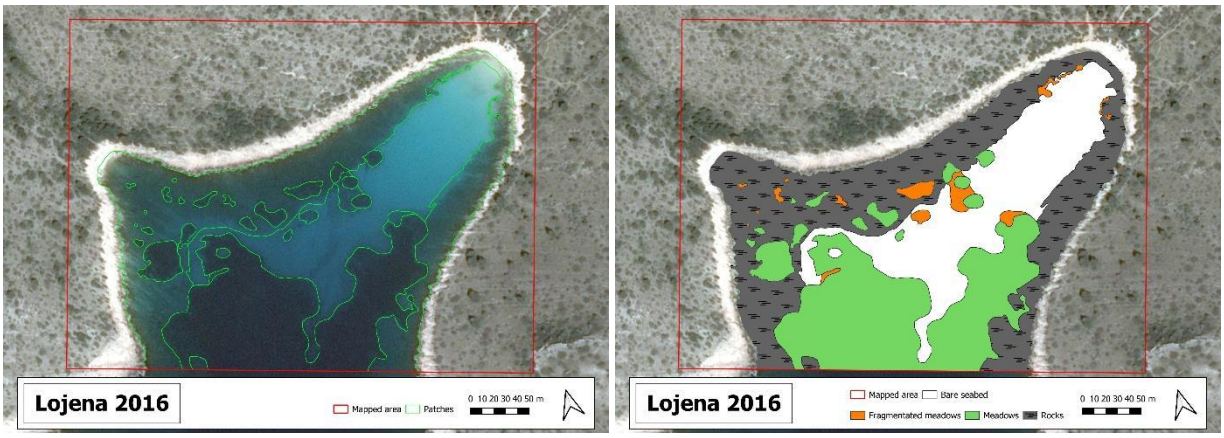
Overall, the 2025 monitoring confirms that *Posidonia oceanica* meadows in Kornati National Park remain an essential indicator of marine ecosystem health. The findings support the continuation of long-term ecological monitoring, expansion and effective use of environmentally friendly mooring systems, and implementation of additional management measures aimed at reducing anchoring pressure and ensuring the long-term conservation of this priority Mediterranean habitat.

Underwater Monitoring of Anchoring Damage (SCARS Protocol)

The SCARS protocol was applied in Lojena Bay to quantify the impact of recreational anchoring on *Posidonia oceanica* meadows. The investigation integrated desk analysis, using aerial imagery to identify potential scars, with direct underwater surveys, which were essential to distinguish anthropogenic disturbances from natural erosion dynamics.

Temporal Dynamics of Seagrass Meadows (2016–2023)

To better understand the current situation, satellite and aerial imagery from 2016 to 2023 were analyzed (Figure 30). This assessment focused on the temporal evolution of the *Posidonia oceanica* meadows, revealing a clear trend of habitat degradation. While the overall distribution of the meadow remained present, a progressive shift from dense, continuous meadows to fragmented areas was identified. Specifically, "fragmented meadows" increased from 1% (1,429.4 m²) in 2016 to 4% (4,251 m²) in 2023, while "continuous meadows" showed a parallel decrease from 16% (19,215.7 m²) to 14% (16,978 m²). This pattern of increasing fragmentation and loss of meadow continuity provides the necessary context to pinpoint the areas of highest anthropogenic stress and to focus the underwater surveys on these critical sites.



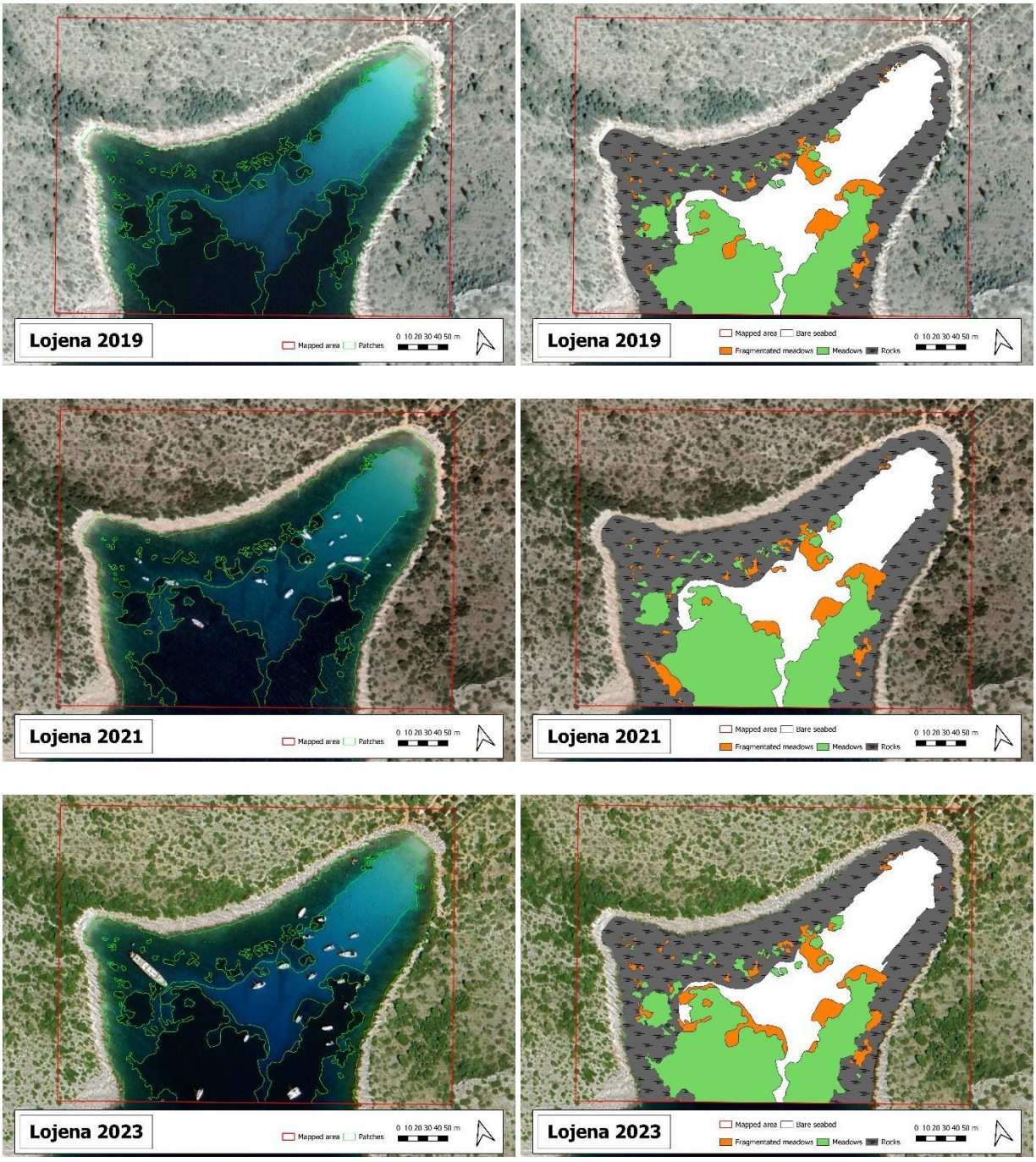


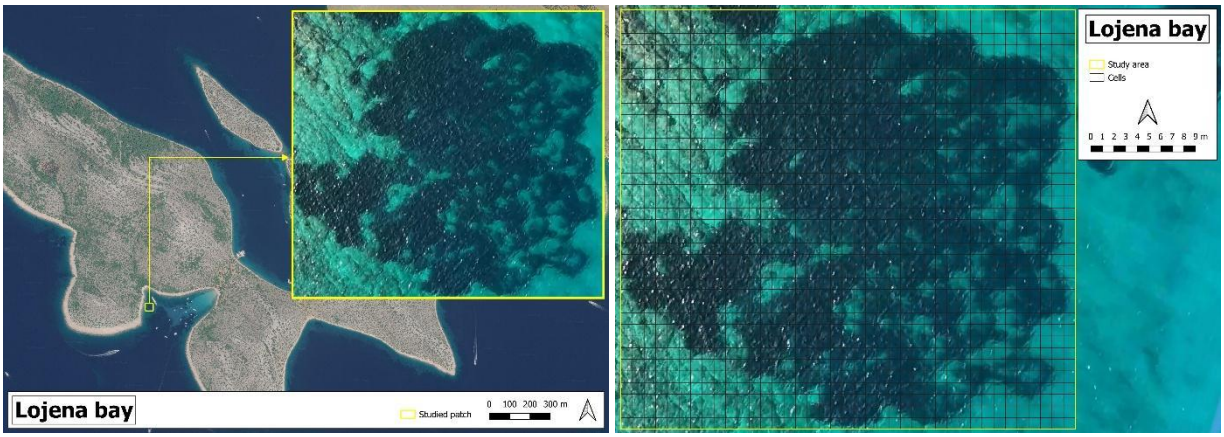
Figure 30 Monitoring of anchoring damage in Lojena Bay: temporal assessment of Posidonia oceanica coverage (2016–2023). The maps illustrate the progressive spatial evolution of the habitat, highlighting the shift from continuous meadows to fragmented areas due to anthropogenic pressure.

Application of the SCARS Assessment Protocol

Potential anchoring scars identified through GIS analysis of aerial imagery were validated by underwater surveys conducted by scientific divers, allowing natural unvegetated patches to be distinguished from anchoring-related disturbances. Field observations focused on scar morphology, rhizome and leaf condition, meadow continuity, and sediment characteristics, providing the information required to classify each scar according to the standardized Scar Damage Class (S.C.) system, an index that quantifies the severity of mechanical impacts on seagrass meadows based primarily on the extent of rhizome exposure and canopy loss.

The monitored sector covered approximately **1,405 m²**, including **780 m²** of vegetated meadow, **480 m²** of naturally unvegetated seabed and **145 m²** classified as potential anchoring scars from the preliminary GIS analysis. Underwater verification analyzed 3 scars, corresponding to **27%** of the mapped scar surface (Figure 31). The assessment confirmed that all monitored scars fall into **Scar Damage Class 1** (red), indicating critical mechanical disturbance and significant degradation of the meadow structure[6].

The spatial distribution of the scars indicates that anchoring impacts are not uniformly distributed across the bay but are concentrated within the sectors most frequently used by recreational vessels. Several scars displayed the typical elongated morphology associated with anchor dragging, whereas others showed more circular patterns compatible with repeated chain abrasion around the anchoring point.



[6] As it was not always possible to clearly distinguish, throughout the monitored area, whether bare seabed patches corresponded to natural sandy gaps, dead matte, or the direct result of seagrass removal caused by anchoring, the Conservation Index (C.I.) could not be calculated.

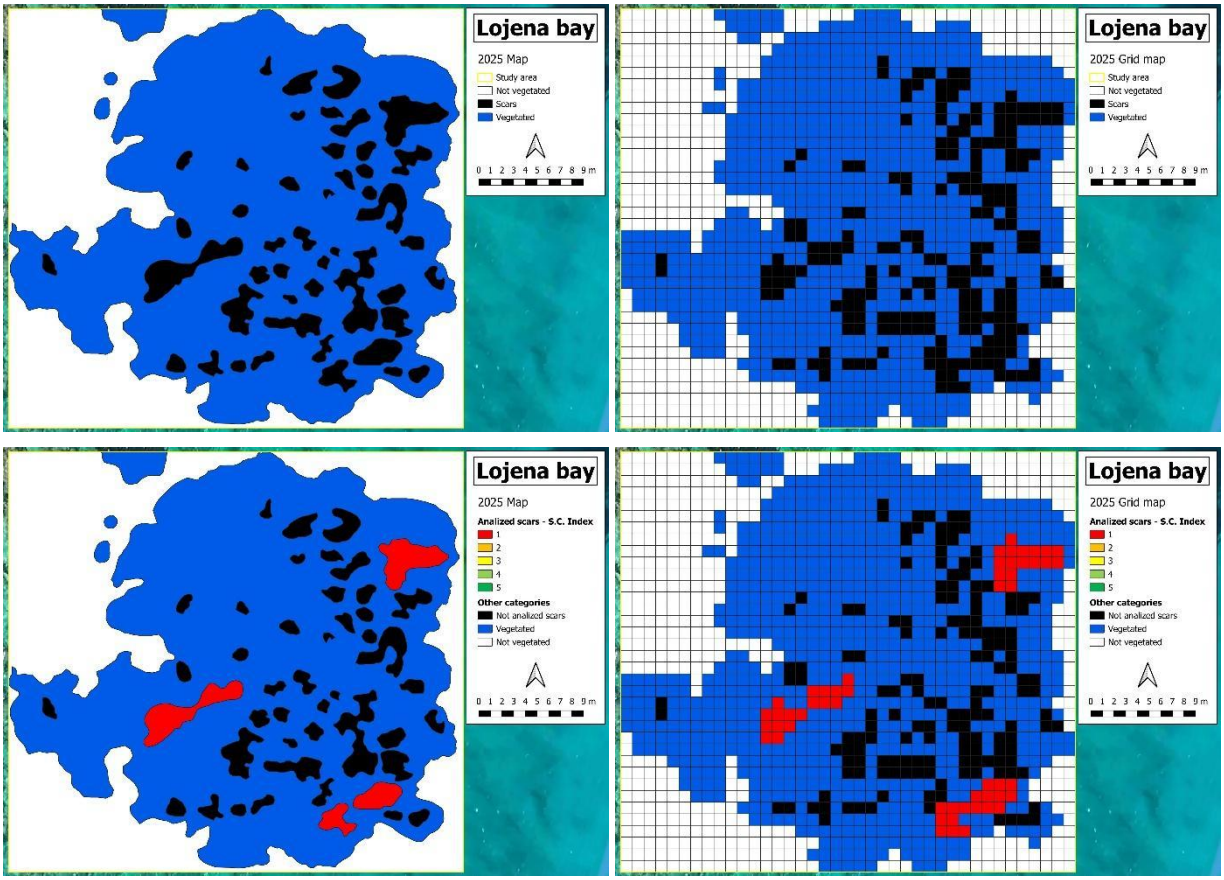


Figure 31 Monitoring of anchoring damage in the monitored area. The maps show the selection of the study area, the spatial distribution of the identified scars, and their classification using the Scar Damage Class (S.C.) index. Red areas represent S.C. 1, indicating the most severe level of mechanical damage.

The field observations highlighted that, within the monitored patch, the conservation status of the *Posidonia oceanica* meadow is characterized by a dual pattern. While extensive portions of the bed still retain high structural integrity, the overall patch exhibits widespread signs of physiological stress and degradation. Localized areas, beyond the clear evidence of mechanical disturbance associated with these severe scars (S.C.=1), display signs of decline, such as rhizome exposure, canopy fragmentation, and reduced shoot density. These widespread indicators of vulnerability across the entire patch suggest that the meadow is under significant pressure, warranting particular attention in future monitoring campaigns.

The information collected during the underwater surveys was integrated with the GIS mapping of anchoring scars to provide an overall evaluation of habitat condition following the SCARS assessment framework. The protocol combines direct observations of meadow condition with expert

interpretation of anchoring pressure, allowing ecological impacts to be evaluated using standardized criteria.

The assessment was based on the integrated interpretation of meadow conservation, scar severity and local boating pressure. According to the protocol, the monitored site was evaluated through the three complementary descriptors: Degradation Risk (DR), Recovery Potential (RP) and Anchoring Pressure (AP), which together provide an overall indication of the ecological condition of the meadow.

Table 10 Integrated Scoring Matrix.

	DR	RP	AP	Total	Interpretation
Lojena Bay (analyzed area)	4	5	5	14	High impact; management action needed to prevent further degradation and support recovery or protection (**Biopressadria pilot action 2: eco-mooring**)

The results indicate that anchoring constitutes an important, localized source of physical disturbance for the *Posidonia oceanica* meadow in Lojena Bay (Table 10). Although the impacts are concentrated within preferred anchoring areas rather than affecting the entire meadow, repeated mechanical disturbance may progressively reduce meadow continuity and increase habitat fragmentation if the current pressure persists.

The SCARS application therefore provides a quantitative baseline for future monitoring and offers a practical framework for evaluating the effectiveness of management actions, including anchoring regulation, installation of eco-mooring systems and periodic reassessment of scar evolution. Repeated surveys will make it possible to determine whether damaged patches remain stable, recover naturally or continue to expand under ongoing recreational pressure.

Satellite monitoring of anchoring pressure

An assessment of nautical tourism pressure within Kornati National Park was carried out as part of the BIOPRESSADRIA project to evaluate the intensity and spatial distribution of maritime activities during the peak tourist season of 2023 and 2025. The satellite monitoring campaign covered the period from 1 June to 30 September and included the analysis of vessel positions, patterns of spatial use, anchoring frequency, the use of existing mooring infrastructure, and the distribution of pressure across the most environmentally sensitive areas of the park.

The monitoring results provide a comprehensive overview of the spatial and temporal patterns of nautical activities, enabling the identification of areas experiencing the highest levels of visitor pressure. Particular attention was given to distinguishing between free anchoring and the use of organized moorings and ecological buoy fields, as the type of mooring practice plays a crucial role in mitigating impacts on sensitive marine habitats, especially *Posidonia oceanica* seagrass meadows.

The analysis confirms that nautical traffic within Kornati National Park is not evenly distributed across the protected area. Instead, vessel activity is consistently concentrated in a limited number of bays that represent the most attractive destinations for recreational boating. This spatial pattern remained stable and consisted throughout the 2023 and 2025 monitoring period.

One of the key outcomes of the monitoring campaign was the identification of spatially distinct anchoring hotspots, defined as areas where the highest concentration of vessels was consistently



recorded throughout the monitoring period. The density analysis of detected vessels revealed only minor variations in anchoring patterns between individual months, indicating stable and predictable spatial use by nautical visitors.
The most prominent anchoring hotspots were identified in the bays of Lojena, Žakan, Kameni Žakan, Smokvica, Anica, Gujak, Piškera, and Vrulje. These locations experienced consistently high levels of vessel activity throughout the peak tourist season, highlighting their importance as the primary destinations for recreational boating within Kornati National Park.

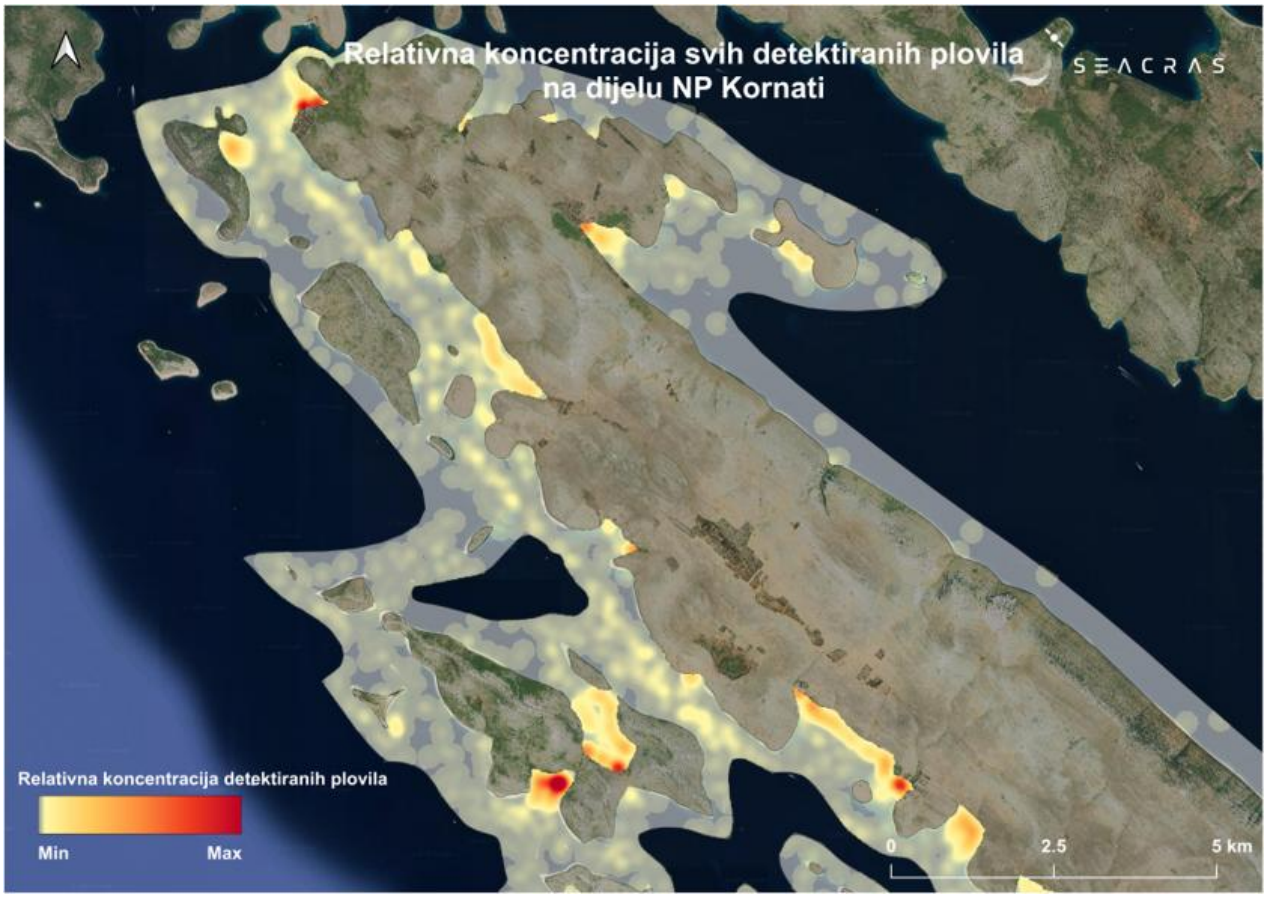


Figure 32 Heatmaps showing the pressure on various bays including Anica and Lojena bay on Levrnaka

The monitoring results confirmed that nautical traffic within Kornati National Park followed highly consistent spatial patterns throughout the period from June to September 2025. Vessel activity remained concentrated in a limited number of the most attractive bays, resulting in a markedly uneven distribution of pressure across the park, while large parts of the marine area experienced relatively low levels of use.

The analysis further demonstrated that the existing mooring infrastructure, particularly the system of ecological mooring buoys, plays a significant role in reducing free anchoring in locations where such facilities are available. However, during the peak tourist season, the available mooring capacity frequently reaches its limit, leading to an increase in free anchoring, including anchoring over *Posidonia oceanica* seagrass meadows. These findings underline the need for further development and optimization of mooring infrastructure at the most heavily used locations, while ensuring the protection of the Park's sensitive marine habitats and overall natural values.
Vessels up to 16 meters in length represented the dominant user group throughout the monitoring period. This indicates that future visitor management measures and infrastructure planning should primarily address the operational requirements and spatial distribution of this vessel category to improve both visitor management and environmental protection.

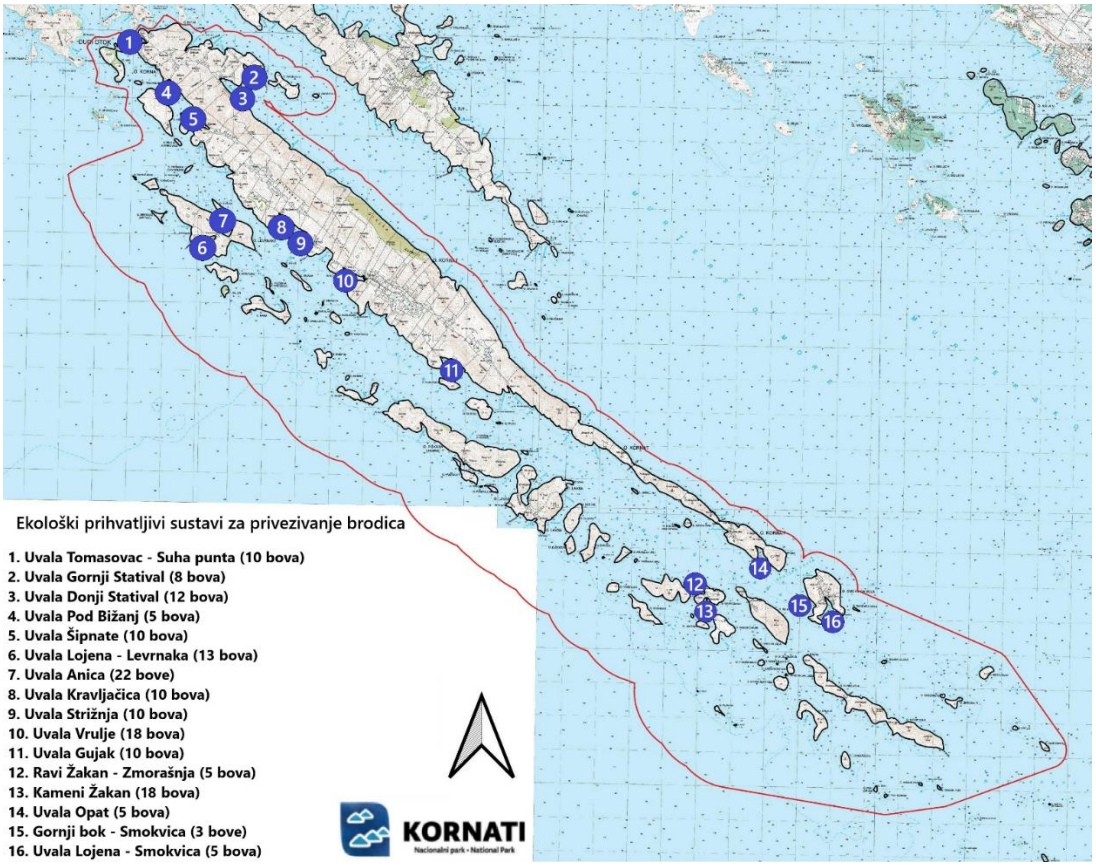


Figure 33 Map of all bays with ecological mooring systems in Kornati National Park.

In the area of the Kornati National Park, to date, environmentally friendly anchorages have been established at a total of 16 locations. At each of the anchorages, there is a certain number of buoys for mooring boats up to 16 meters in length.
The anchor systems are not placed in the usual way by tying them to concrete blocks, but by drilling through sand and sediment into the rocky substrate where the anchors are directly shot into the seabed. This "anchor" remains buried in the rock without significant damage to the seabed. During the installation and later exploitation of the anchorage, there is no contact with the vegetation cover, which is extremely important for the preservation of seagrass and why this anchor system is more environmentally friendly compared to the installation of concrete blocks.
Each anchorage consists of a circular sea space with an anchor life in the center, as well as with an anchor buoy with a final moored loop of anchor rope next to it.
It is important to emphasize that this solution was chosen to ensure that the anchor chain does not touch the seabed even during the lowest water level. The anchor mooring works in such a way that the vessel is moored with the bow to the anchor line and depending on the influence of the wind on the vessel, rotates around the anchor buoy. The Public Institution Kornati National Park has plans to extend number of buoys in the park and completely forbid free anchoring in order to ensure the full protection and conservation of valuable *Posidonia oceanica* meadows.



Figure 34 Ecological mooring system in use (buoy).

Lojena Bay – Spatial Analysis

Lojena Bay is one of the most frequently visited anchorage sites within Kornati National Park and was selected as a pilot area for the implementation of measures aimed at protecting marine habitats due to its intensive nautical use.

Particular attention is given to the conservation of *Posidonia oceanica* seagrass meadows, which represent one of the most valuable and ecologically significant habitat types in the Adriatic Sea.

To establish a baseline condition prior to the implementation of the planned management measures, a spatial analysis of boating activity within the bay was conducted. The analysis is based on vessel position and characteristics data collected during monitoring surveys carried out in 2023 and complemented with data collected in 2025. The datasets were processed within a GIS environment to assess the spatial distribution of vessels throughout the bay and their relationship with different seabed types, particularly areas covered by *Posidonia oceanica* meadows.

The total area covered by the analysis is 20.66 ha, of which 13.88 ha, approximately 67% of the bay, is occupied by *Posidonia oceanica* meadows. Due to the extensive presence of this sensitive habitat, understanding anchoring patterns within the bay is essential for planning and evaluating future anchoring management measures.



Figure 35 Lojena Bay study area and the distribution of Posidonia oceanica meadows

The results presented below provide an overview of vessel spatial distribution within Lojena Bay during the survey periods and identify areas subject to the highest anchoring pressure on the seabed and *Posidonia oceanica* meadows. These findings establish a baseline dataset for future monitoring and assessment of the effectiveness of the planned anchoring management measures in the bay.

2023 Anchoring Distribution

A total of 461 vessels were recorded at anchor within Lojena Bay during the 2023 monitoring period. The recorded vessel positions indicate intensive use of the sheltered inner part of the bay, where the majority of anchoring activity was concentrated. Only a limited number of vessels were observed in the outer and deeper sections of the study area.

The spatial distribution of vessels reveals a clear preference for the central and north-eastern sectors of the bay, corresponding to areas providing favourable anchoring conditions and protection from prevailing winds. Medium-sized vessels represented the dominant vessel category, while small

vessels were also frequently recorded. Large vessels accounted for only a small proportion of the observed anchoring activity.

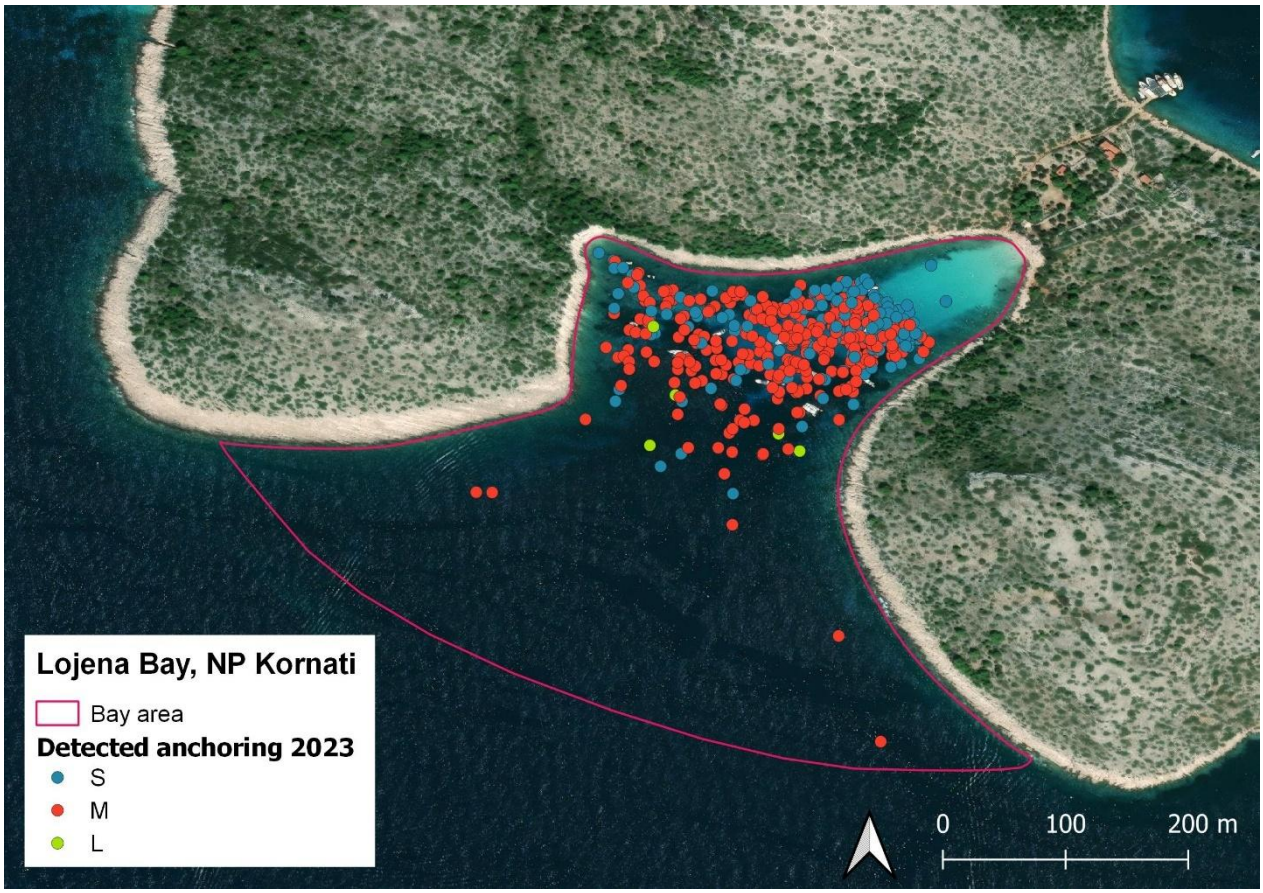


Figure 36 Spatial distribution of vessels recorded at anchor in Lojena Bay during the 2023 monitoring period

A spatial overlay analysis between vessel locations and the distribution of *Posidonia oceanica* meadows identified 107 vessels anchored within seagrass-covered areas, representing 23.2% of all recorded vessels in Lojena Bay during the 2023 monitoring period. Vessel locations within Posidonia habitats were predominantly concentrated in the central and inner sections of the bay, where the highest levels of anchoring activity were recorded. The results indicate a substantial spatial overlap between recreational anchoring activities and seagrass habitats, demonstrating that nearly one-quarter of all observed vessels were anchored within areas occupied by Posidonia.

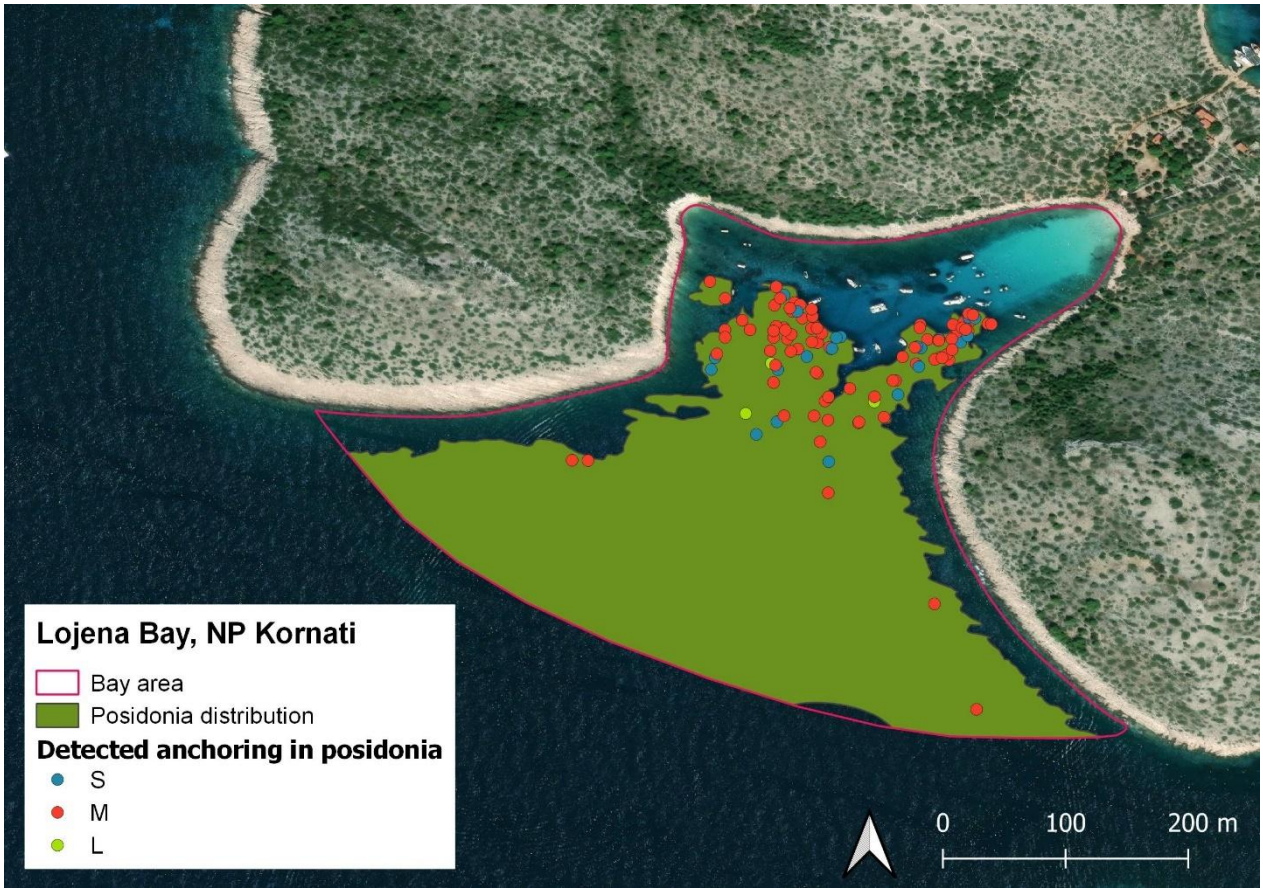


Figure 37 Distribution of vessels anchored within Posidonia oceanica meadows in Lojena Bay during the 2023 monitoring period (n = 107)

Table 11Number and percentage of vessels recorded within Posidonia oceanica meadows relative to the total number of vessels in each size category (2023).

Vessel size	Number	% from total detected vessels	In posidonia	% of category anchored in Posidonia
S	173	37.5%	23	13.3%
M	283	61.4%	81	28.6%
L	5	1,1%	3	60%
Total	**461**	**100%**	**107**	**23,2%**

Analysis by vessel size category revealed differences in anchoring patterns within *Posidonia oceanica* meadows. Medium-sized vessels accounted for the largest number of vessels anchored within seagrass habitats (81 vessels), followed by small vessels (23 vessels). Although only five large vessels were recorded during the monitoring period, three of them were located within Posidonia meadows. Overall, 13.3% of small vessels, 28.6% of medium-sized vessels and 60.0% of large vessels were recorded within areas covered by Posidonia oceanica.

2025 Anchoring Distribution

During 2025, 13 eco-mooring buoys were installed in Lojena Bay as a measure to reduce anchoring pressure on sensitive marine habitats. The eco-moorings were designed for vessels up to 16 m in length, while no eco-moorings were installed for vessels larger than 16 m. Vessel locations were derived from high-resolution satellite imagery acquired between June and September 2025 and analysed within a GIS environment.

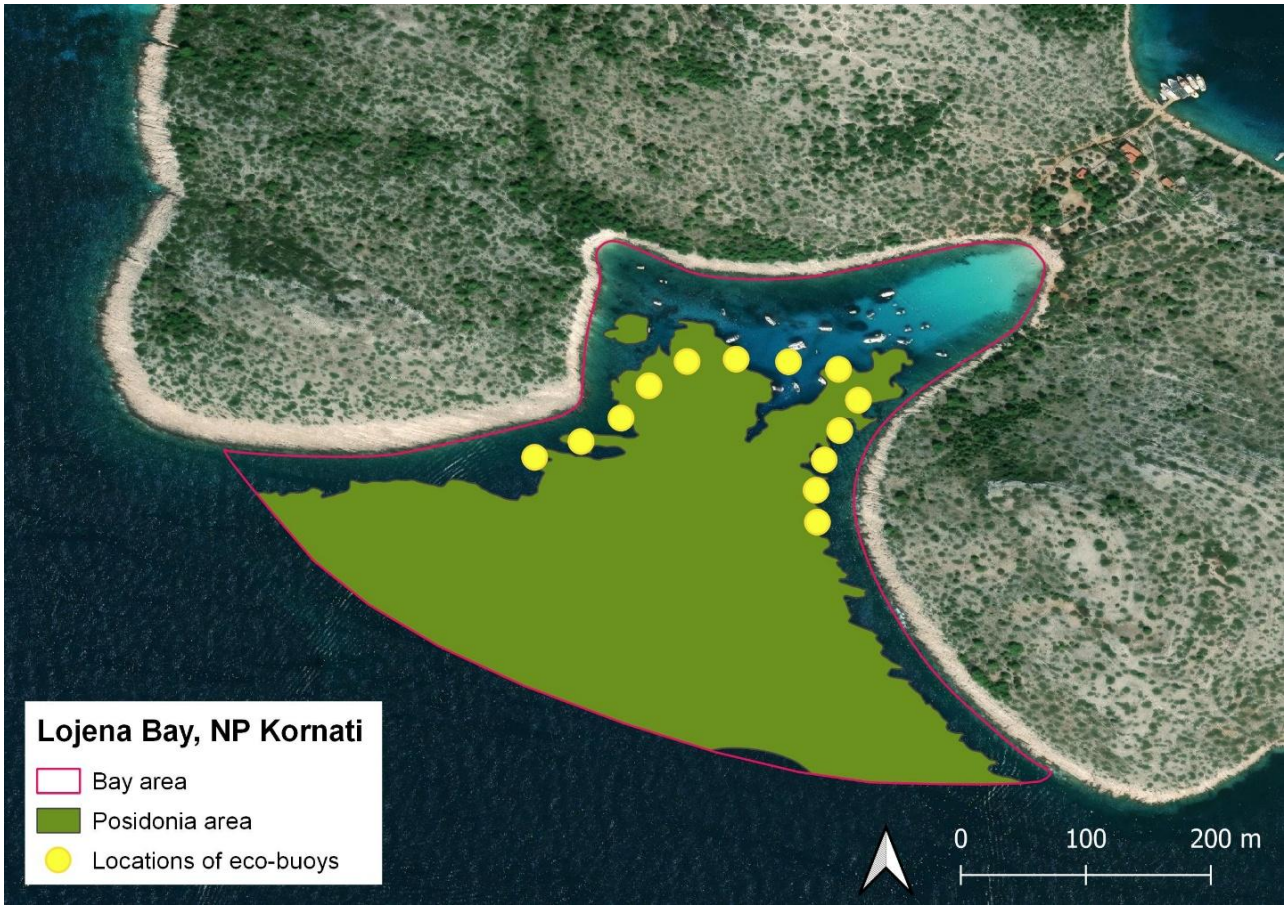


Figure 38 Distribution of eco-mooring buoys within Lojena Bay in relation to the extent of Posidonia oceanica meadows and the study area boundary

Compared to the 2023 baseline dataset, the 2025 analysis provided additional information on vessel operation type, allowing vessels to be classified according to anchoring, mooring and navigation activities. Vessel size categories were also defined differently. A total of 903 vessels were detected within Lojena Bay during the monitoring period. For the assessment of anchoring and mooring pressure, only vessels engaged in stationary activities were considered, namely vessels anchored with their own anchor, vessels moored to eco-mooring buoys, or vessels moored to other buoys. Vessels alongside coastal infrastructure and vessels in transit were excluded from this analysis.
A total of 903 vessels were detected within Lojena Bay during the monitoring period. Of these 555 vessels, 176 (31.7%) were shorter than 10 m, 275 (49.5%) were between 10 and 16 m, 103 (18.6%) were between 16 and 26 m, and 1 vessel (0.2%) exceeded 30 m. No vessels were recorded in the 26–30 m category. Vessels between 10 and 16 m represented the dominant size category, accounting for nearly half of all vessels associated with anchoring and mooring activities.

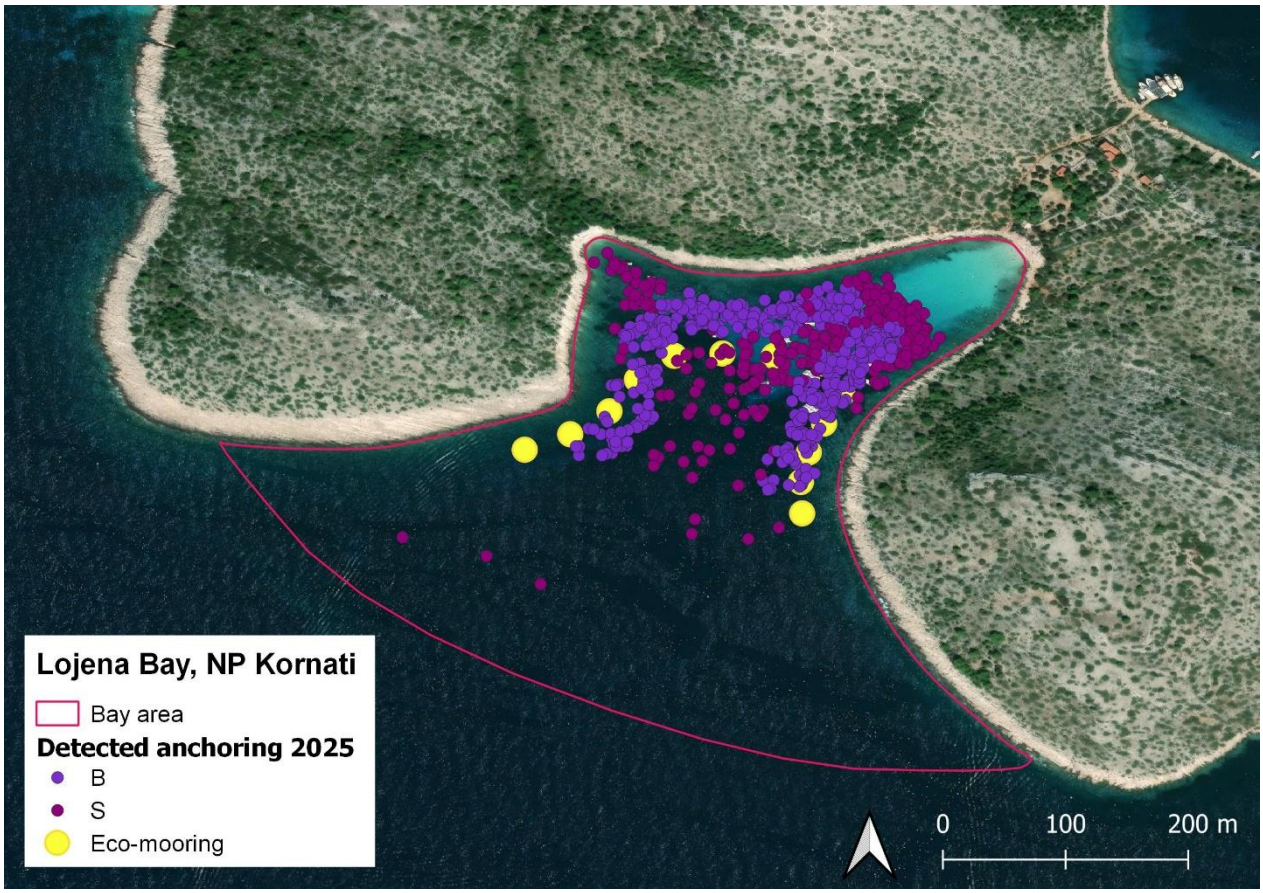


Figure 39 Spatial distribution of stationary vessels and eco-mooring locations in Lojena Bay during the 2025 monitoring period

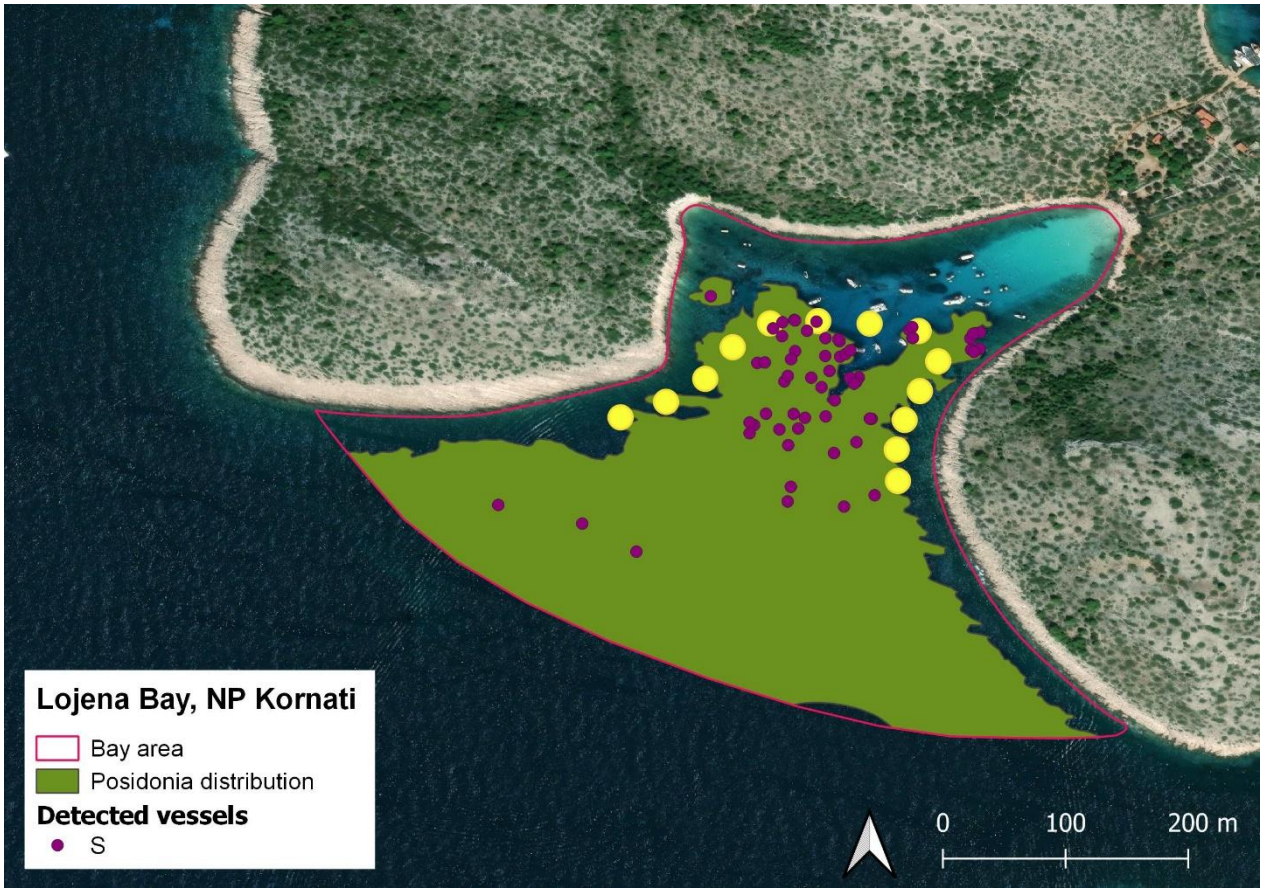


Figure 40 Distribution of freely anchored vessels recorded within Posidonia oceanica meadows in Lojena Bay during the 2025 monitoring period

Table 12 Distribution of vessels included in the anchoring and mooring analysis by vessel size category in Lojena Bay during the 2025 monitoring period (n = 555)

Vessel size	Number	% from total detected vessels	In posidonia	% of category anchored in Posidonia
<10 m	176	31.7%	15	8.5%
10-16 m	275	49.5%	26	9.5%
16-26 m	103	18.6%	18	17.5%
26-30 m		0.0%	0	0.0%
>30 m	1	0.2%	1	100%
Total	**555**	**100%**	**60**	**10.8%**

Comparison of the 2023 and 2025 datasets indicates a notable reduction in anchoring pressure on *Posidonia oceanica* meadows within Lojena Bay. While the total number of vessels associated with anchoring and mooring activities increased from 461 to 555, the number of vessels recorded within seagrass habitats decreased from 107 to 60. Consequently, the proportion of vessels located within Posidonia oceanica meadows declined from 23.2% to 10.8%. These results suggest that the installation of eco-mooring buoys contributed to a reduction in direct anchoring within sensitive seagrass habitats while maintaining the bay's capacity to accommodate nautical activities.

Table 13 Comparison of key indicators describing vessel distribution and overlap with Posidonia oceanica meadows in Lojena Bay in 2023 and 2025

Indicator	2023	2025
Total vessels in analysis	461	555
Vessels in Posidonia	107	60
% in Posidonia	23.2%	10.8%

Spatial analysis

Kernel Density Estimation (KDE) was applied to identify areas of concentrated vessel activity within Lojena Bay during the 2023 and 2025 monitoring periods.
Considering data from 2023, the analysis revealed a pronounced hotspot in the inner north-eastern section of the bay, indicating that this area was consistently preferred for anchoring by recreational vessels. Anchoring intensity gradually decreased towards the central and outer parts of the bay, where vessel detections were less frequent. The identified hotspot represents the area exposed to the highest anchoring pressure within the bay and largely coincides with the main anchorage area used by vessels during the monitoring period. As the survey was conducted prior to the installation of eco-mooring infrastructure, the hotspot provides a baseline representation of anchoring behaviour and serves as a reference for assessing subsequent changes in vessel distribution and habitat use.

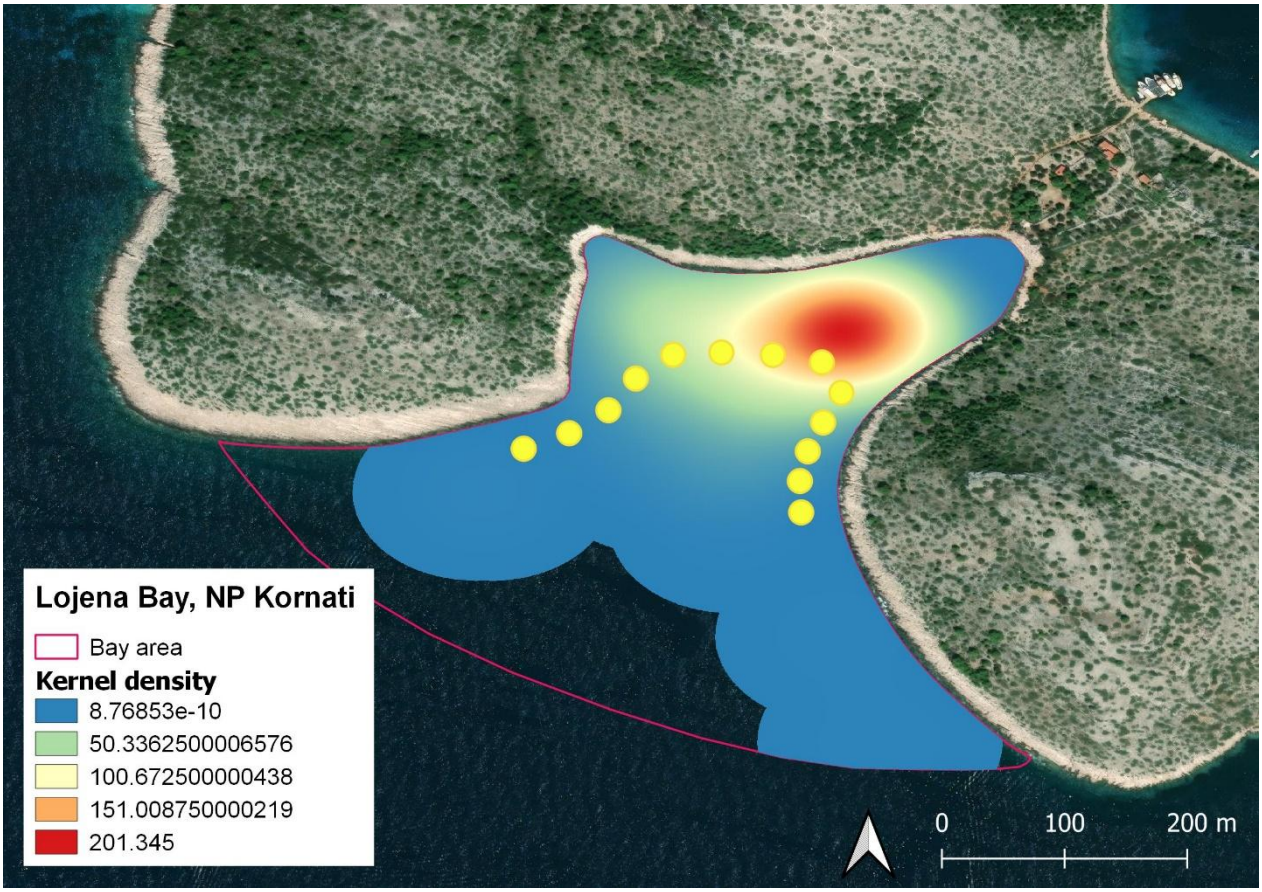


Figure 41 Kernel density estimation (KDE) of anchoring activity in Lojena Bay based on vessel locations recorded during the 2023 monitoring period. Eco-mooring locations installed in 2025 are shown for reference.

The analysis of data collected during 2025 revealed a distinct hotspot in the inner north-eastern section of the bay, indicating that vessel activity remained concentrated within the main sheltered anchorage area. Activity gradually decreased towards the central and outer sections of the bay, where vessel occurrences were less frequent. The identified hotspot corresponds to the area containing the installed eco-mooring system, suggesting that vessel activity became concentrated within the managed mooring zone.

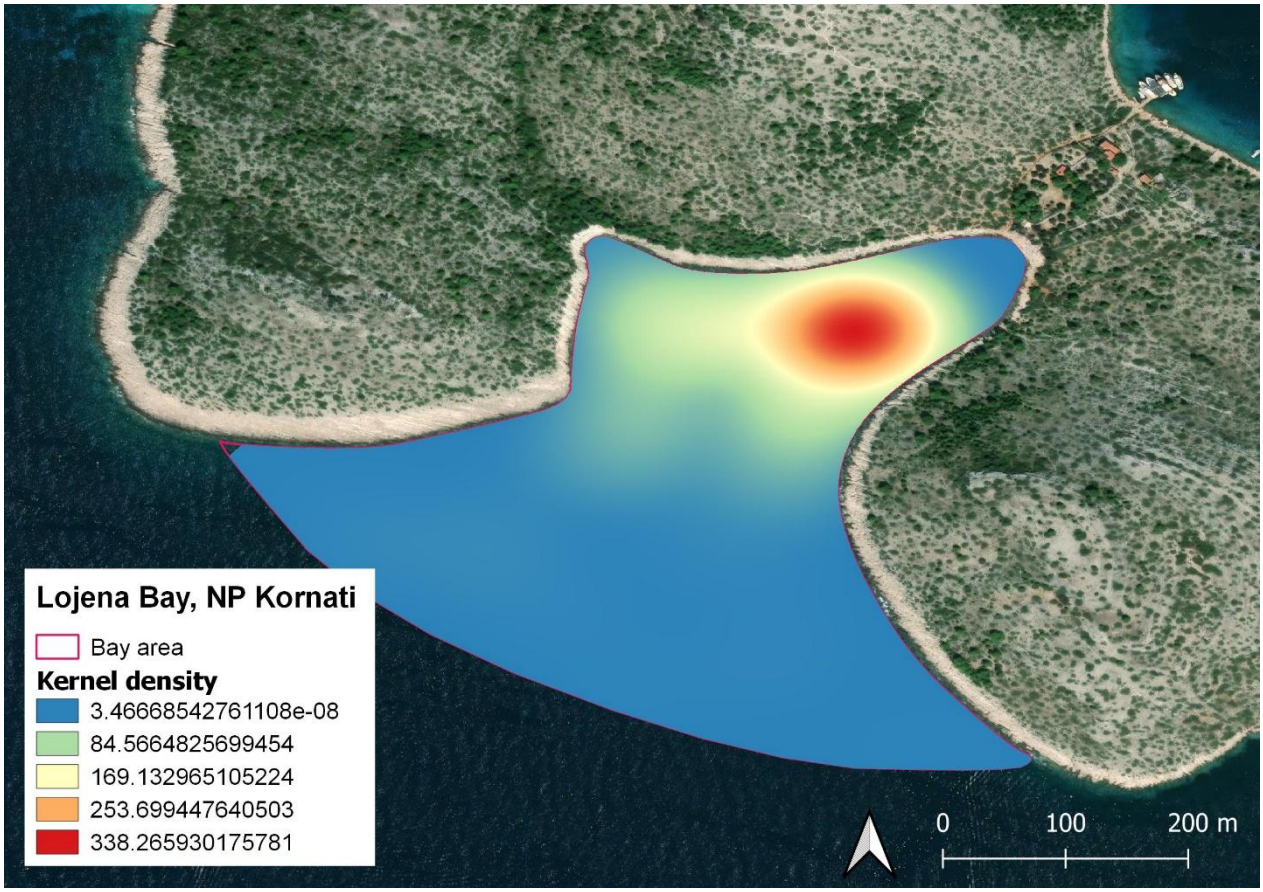


Figure 42 Kernel density estimation (KDE) of anchoring activity in Lojena Bay based on vessel locations recorded during the 2025 monitoring period. Eco-mooring locations installed in 2025 are shown for reference.

Comparison of the 2023 and 2025 hotspot analyses shows that the highest concentration of vessel activity remained located within the inner part of Lojena Bay. In both monitoring periods, the same general area was identified as the primary zone of vessel use, confirming its importance as the preferred anchoring location within the bay.

Despite an increase in the total number of vessels included in the analysis, from 461 in 2023 to 555 in 2025, the number of vessels recorded within *Posidonia oceanica* meadows decreased from 107 to 60. Consequently, the proportion of vessels located within sensitive seagrass habitats declined from 23.2% to 10.8%.

The results suggest that vessel activity became more concentrated within the designated anchoring and mooring area, while the spatial overlap between vessels and *Posidonia oceanica* meadows decreased. This pattern indicates a reduction in direct pressure on seagrass habitats and supports

the role of eco-mooring infrastructure as a management measure for reducing anchoring impacts within Lojena Bay.

Monitoring of nektonic fauna (active bioacoustics) at ecological moorings

The Kornati archipelago serves as an important study area for the BIOPRESSADRIA project, offering a unique gradient of ecological and management conditions. While Panzano Bay pilot site represents a mature and isolated system, the Kornati NP sites allowed for the investigation of mooring buoy effectiveness through two distinct experimental scenarios: a "physically limited" site (Kornati A) and a "Before-After" monitoring site (Kornati B). The primary objective was to evaluate the potential of these infrastructures to function as Fish Aggregating Devices (FADs) by assessing nekton biomass and spatial distribution in relation to the installation of new mooring systems.

Table 14 summarizes the main characteristics of the monitoring program together with the principal findings discussed in the following sections.

Table 14 Summary of the bioacoustic monitoring program and key findings.

Indicator	Value
Study site	Kornati Islands National Park (Levrnaka Island, Croatia)
Monitoring period	Late summer 2024; Late spring 2025; Late summer / Early fall 2025
Survey method	Active hydroacoustic monitoring
Survey design	Systematic parallel transects (Lojena Bay Site B); Fixed-point sampling (Anica Bay Site A)
Water depth	Variable (shallow inner bay for Site A; rapidly increasing depth for Site B)
Estimated fish biomass	1.0 – 249.0 kg ha^{-1} (site and period dependent)
Main ecological response	Significant FAD effect at Site B; Negligible aggregation at Site A
Management implication	Mooring buoys enhance nekton resource only if site selection accounts for abiotic constraints

Study area and monitoring approach

The Kornati A site ("Physically Limited") is situated within a small inner bay (Anica Bay) on Levrnaka Island, characterized by extremely shallow depths (500 m × 200 m) which represent a significant physical constraint for fish aggregation. The Kornati B site ("Before-After") is located in an outer bay

(Lojena Bay) on the same island, exposed to the open Adriatic Sea with a rapidly increasing depth profile suitable for supporting nektonic communities. Monitoring campaigns were conducted between 2024 and 2025 using active hydroacoustic techniques, employing systematic transects at site B and fixed-point sampling at site A, as the shallow depth at the latter precluded safe transect navigation (Figure 43).



Figure 43 Close-up of Levrnaka Island indicating the locations (Kornati A and Kornati B) of the monitoring stations.

Fish biomass and community response

Bioacoustic surveys revealed different responses between the two sites. At Kornati B, the installation of the buoy field generated a clear FAD effect: biomass increased significantly (rising from 151.5 kg ha^{-1} to 249.0 kg ha^{-1}) and nekton density increased more than six-fold (from 10,829 to 66,196 fish ha^{-1}) between the "Before" phase (summer 2024) and the "After" phase (fall 2025). Conversely, the Kornati A site consistently showed negligible biomass values (< 9 kg ha^{-1}), confirming that abiotic constraints, specifically extreme shallow depth, can nullify the aggregation potential of the buoys.

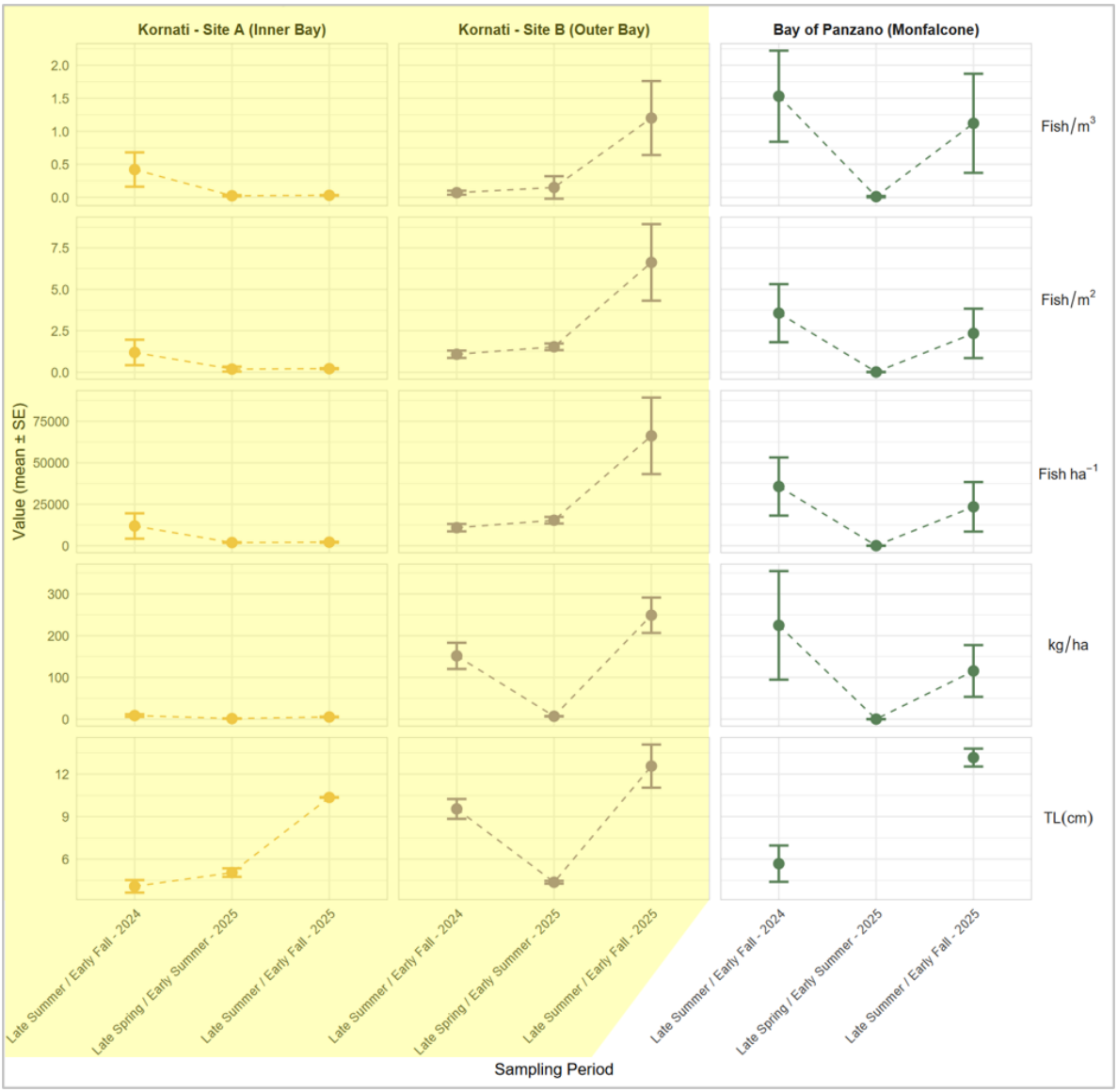


Figure 44 *Temporal trends from the three acoustic surveys conducted at the study sites (Kornati NP Site A and Site B are highlighted in yellow). Reported metrics include fish density, total length, and biomass per unit area.*

Ecological interpretation

It is clear that the ecological performance of these mooring systems is highly context dependent. The observed variability suggests that fish distribution in the Kornati sites is driven not only by the presence of structures, but also by seasonal patterns and human disturbance. The synchronized drop in nekton metrics across all sites during the spring 2025 survey likely points to the onset of the

recreational boating season; this suggests that noise and traffic may drive fish away, a hypothesis that highlights the need to pair biological data with real-world boating pressure indicators.

Management implications

The bioacoustic assessment demonstrates the value of non-invasive acoustic monitoring in evaluating the ecological performance of coastal management measures. For the Kornati archipelago, the data provide evidence that mooring fields can actively contribute to supporting nekton communities, provided that site selection is appropriate and accounts for physical limitations. Although available data do not allow for definitive conclusions regarding a universal aggregation effect, they highlight that managed areas can support relatively high fish biomass, underscoring the critical importance of integrating benthic habitat conservation, boating management, and continuous ecological monitoring into future integrated coastal management strategies.

3.2.5 Implications for Pilot Actions and future monitoring

In conclusion, the Kornati National Park Public Institution continues to develop a sustainable mooring system and plans to increase the number of ecological mooring buoys in order to reduce and eventually prevent free anchoring within the entire Park area. Together with continuous monitoring, responsible visitor management, and cooperation with local stakeholders and nautical users, these measures are essential for the long-term conservation of *Posidonia oceanica* meadows and the maintenance of their favourable conservation status

3.3. Pilot Site 3: Pakleni Islands (Croatia)

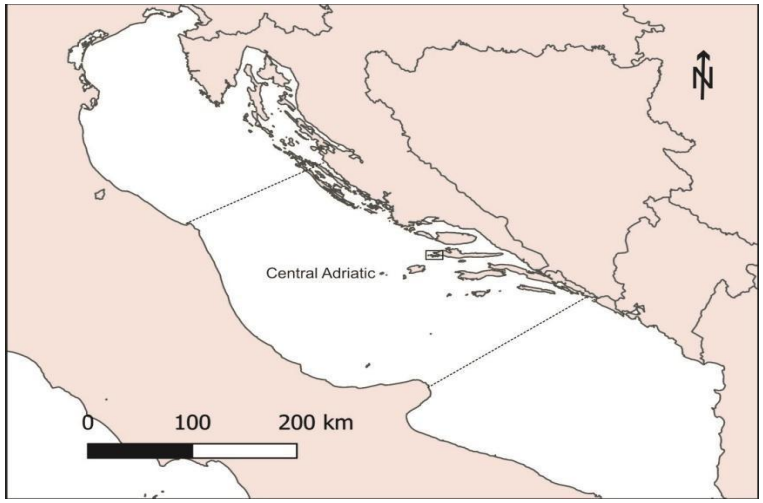
3.3.1 Geographical and morphological framework of the area of interest

The Pakleni islands are located in Croatia along the southern coast of the island of Hvar in the **Middle Adriatic**. Administratively, they belong to **Split-Dalmatia County** (regional self-government unit, https://www.dalmacija.hr/) and local self-government unit - **City of Hvar** (https://www.hvar.hr/portal/). The powers and duties of these two territorial units of different levels are defined by *the Law on Local and Regional Self-Government* (Official Gazette 33/01, 60/01, 129/05, 109/07, 125/08, 36/09, 36/09, 150/11, 144/12 , 19/13 , 137/15 , 123/17 , 98/19 , 144/20) and bylaws. Of the other public-legal bodies, the **Public Institution Sea and Karst** (https://moreikrs.hr/) has authority in its domain in terms of territorial management (https://moreikrs.hr/) based on *the Law on Nature Protection* (Official Gazette 80/13, 15/18, 14/19, 127 /19) and by-laws, and **Croatian Forests** (https://www.hrsume.hr/) based on *the Law on Forests* (Official Gazette 68/18, 115/18, 98/19, 32/20, 145/20) and by-laws acts.

The Pakleni Islands are a group of 16 smaller islands, islets and rocks: **Vodnjak Mali, Vodnjak Veli, Travna, Paržanj, Borovac, Sveti Klement, Dobri, Vlaka, Stambedar, Planikovac, Borovac - another island of the same name, Gojica, Marinkovac, Jerolim, Gališnik and Pokonji Dol**. The Pakleni Islands contribute significantly to the exceptional diversity of the western part of the island of Hvar. In addition, the Pakleni Islands are one of the main landscape features of both the entire island and the Town of Hvar. They have a characteristically indented coast, which gives the Hvar tourist area a special value and attractiveness. The Pakleni Islands are among the most beautiful and geomorphologically interesting on the Adriatic coast. **They were built from limestone**, which on the largest island, St. Klement, reached a height of 96 meters. There are interesting **areas of diluvial sands** in the bay of Palmižana and Port of Soline. The sandy and pebble beaches of Pakleni Islands represent a rare landscape value for the predominantly rocky coast of the Adriatic islands.
Due to the aforementioned characteristics, the Pakleni Islands land part **since 1968** enjoy the status of a **Significant Landscape** (except Gališnik and Pokonji Dol islets). With Croatia's entry into the EU **in 2013, the Pakleni Islands marine area** was declared an area of the **European ecological network Natura 2000** under the code HR3000095 to preserve the following habitat types: Posidonia beds (*Posidonion oceanicae*, code: 1120), sandbanks which are slightly covered by sea water all the time (code: 1110), mudflats and sandflats not covered by seawater at low tide (code: 1140), reefs (code: 1170) and submerged or partially submerged sea caves (code: 8330). The conservation area for Natura 2000 species and habitat types is 1996.60 ha, and the significant landscape is 712.88 ha.[7]
All measures to preserve the aforementioned habitat types of the marine ecological network Natura 2000, as well as measures to preserve the land part of Pakleni Islands protected in the category of significant landscape, are listed in the newly adopted **Management Plan for protected areas and sites of the ecological network (6105): Hvar**[8]. The measures further follow the specific activities and goals that the Public Institution Sea and Karst should implement and achieve in the period from 2023 to 2032. Most of them, however, refer to the entire island of Hvar, although some are specific to the Pakleni Islands. After two years of intensive work within the project "Integrated management of natural resources of small Mediterranean islands (SMILO-MED)", Pakleni Islands Committee was created on 20th November 2023., and at the beginning of October 2024. the committee adopted the **Pakleni Islands diagnosis and strategic plan (2024.-2029.)**. A SMILO label https://smilo-program.org/labelling-process/ on the sustainable island is expected soon. Also, the Public Institution Sea and Karst together with Association Sunce prepared a **Baseline Study** for the extension of the significant landscape over marine area and the designation of smaller marine

[7] Kurtović Mrčelić, J., Taraš, M., Petit, S., Ferretti, M. (2023): Pakleni Islands diagnosis and strategic plan. Split
[8] https://mzozt.gov.hr/UserDocsImages//UPRAVA%20ZA%20ZA%C5%A0TITU%20PRIRODE/NATURA%202000//PU%206105%20Hvar.pdf

reserve at the western part of the archipelago[9]. Interreg Biopressadria project is completely in line with all Pakleni Islands strategic documents moreover it will enable the realisation of many conservation activities.



b.



Figure 45 Location of Pakleni Islands in relation to the Adriatic Sea (black square) and the mainland (a) and the landscape of the archipelago (b) Source: Public institution for the management of protected parts of nature in the Split-Dalmatia County SEA AND KARST, author: Branimir Jukić

[9] Miletić Miloš A., Kurtović Mrčelić J., Špika M., Zrnčić V., Jakl Z., Dokoza F., Vladović D., Tudor T., Visković E. (2025): Stručna studija za potrebu izrade Stručne podloge za promjenu granica značajnog krajobraza Pakleni otoci s proširenjem zaštite na more i zaštitu zapadnog morskog dijela arhipelaga u kategoriji posebnog rezervata. Udruga za prirodu, okoliš i održivi razvoj Sunce, za naručitelja JU More i krš.

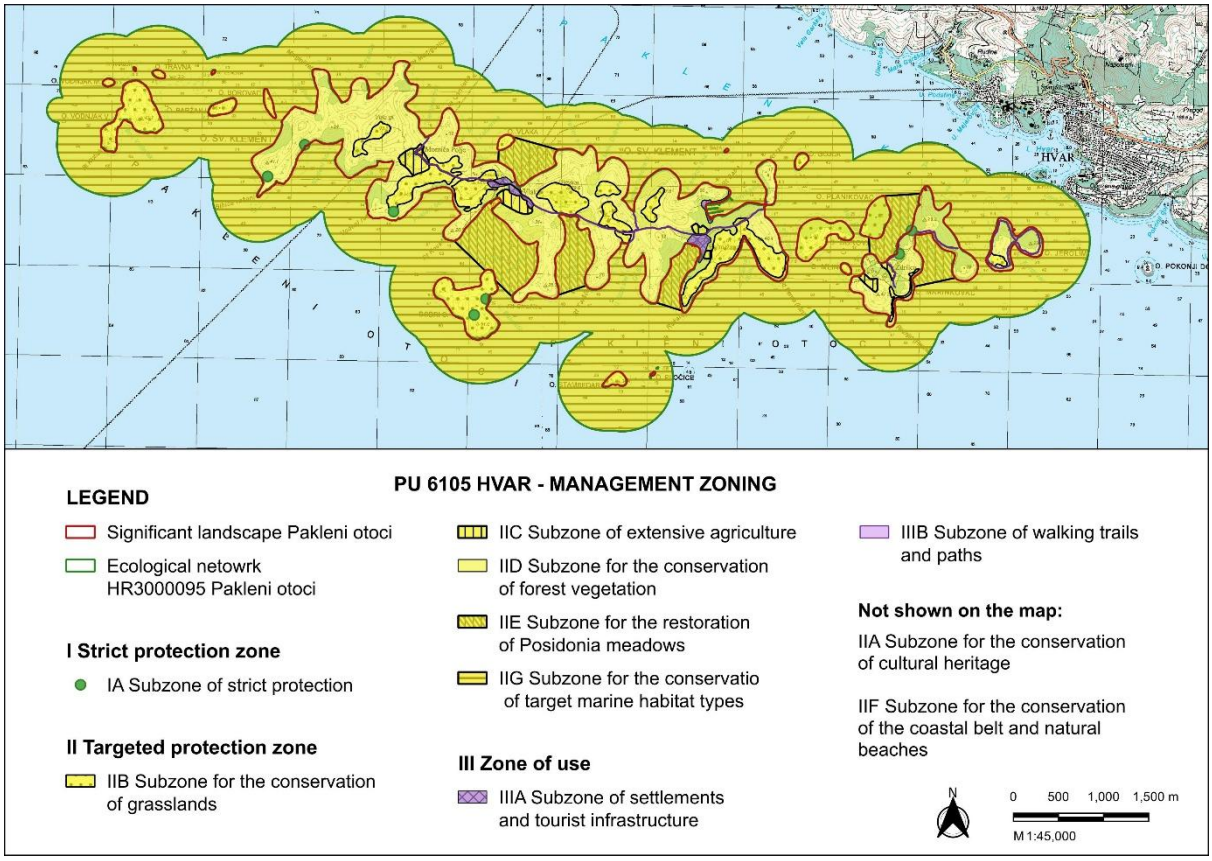


Figure 46 Significant landscape Pakleni Islands and area of ecological network HR3000095 Pakleni Islands, management zonation. In green strict protection zones. In yellow conservation zones. In purple usage zones. Source: Management Plan Hvar

3.3.2 Main users of the area

According to the population census from 2021, the settlement of Hvar, which also includes the Pakleni Islands, has 3,519 inhabitants. Pakleni Islands have **18 inhabitants**. During the season, the number of inhabitants increases. Some caterers accommodate workers on Pakleni Islands. It is estimated that there are at least **300 of them**. Most of them still travel back to Hvar. In terms of **tourists,** during the year 2022, **428** arrivals, i.e. a total of **3,423** overnight stays through **31** accommodation units, as part of the households or form of hotel business in Pakleni Islands. The number of overnight stays on the mainland of Pakleni is not a relevant indicator of the number of tourists. The largest number of visitors are **daily visitors** transported by local boats called *barkarioli*, who mostly spend the night in the town of Hvar, and taxi boats that bring visitors mainly from Central Dalmatia where they spend the night. A total of 3,634 one-day excursionists are estimated per day in the heart of the season (July and August), and **up to 333,569 one-day excursionists annually**. In addition to daily visitors coming by barkarioli and taxi boats, a significant part of tourists is represented by **leisure boats users** being **charter or private** vessels (sailboats and yachts). In 2022, a total of 15,162 vessels stayed per day in ACI marina Palmižana situated on Pakleni Islands. If an average of 5 people stay per vessel, the total number of visitors was approximately **75,808.** Estimating the annual number of vessels anchoring/mooring outside the ACI marina amounts to more than 30,534 vessels. If an average of 5 people stay per vessel, the total number of visitors is **152,671** per year. Based on the above estimates, we arrive at a figure of **565,471 visitors a year for Pakleni Islands.** In the aquatorium of Pakleni Islands in the passage between the islets of Marinkovac and Jerolim **mini cruisers with a length of over 24 m (mainly from the home port Krilo Jesenice, near town of Split),** waiting for berthing in the port of Hvar are anchoring. Their guests visit Pakleni Islands via taxi boats. It is estimated that about 15 of them anchor per day in the heart of the season[10].

Thorough **analyses of ecosystem services** carried out within the IMPRECO project showcase that the most important ecosystem service of the marine ecosystem of Pakleni Islands is related to tourism, i.e. *Characteristics of living systems that that enable activities promoting health, recuperation or enjoyment through active or immersive interactions*[11].

The Pakleni Islands have a rich tourist offer. In terms of **Hospitality services,** there are at least 17 establishments on Pakleni, maybe more because 25 of them pay utility bills: Colnago Winery, Konoba Dionis, The Fishermans House, Carpe diem, Restaurant Bacchus, Toto's restaurant, Zori Timeless restaurant & hotel, Lounge bar Laganini, Palmižana Meneghello, Meneghello Botanical Garden and Gallery, ACI Marina Palmižana, Patak Restaurant, Mamato Restaurant, Tri Grede Restaurant, Tartaja Mlini, Festina Lente Restaurant, Paradiso Tavern. **SCUBA diving** is organized in the marine area of

[10] J. Kurtović Mrčelić, Taraš M., Petit S., Ferretti M. (2024.): Analizastanja i strateški plan Paklenih otoka 2024.-2029., Javna ustanova More i krš, Split

[11] DOI: 10.13140/RG.2.2.26018.20160

Pakleni Islands by 2 facilities in Hvar: Aqualis and Viking diving centers. **Sea kayaking** is carried out by 2 facilities in Hvar with an offer on Pakleni: AndAdventure Croatia sea kayaking, Devotion jdoo Kayak & SUP Hvar. Many **tourist agencies** (18 facilities in Hvar, some with an offer on Pakleni) organize mainly transfers on Pakleni Islands: Šegorent - speed boat, TAXI DEL MAR, Pakleniotoci, Hvar Adventure, Hvaradise, Sailing Bare, SUN CITY rent, Alavia Hvar, Intours DMC Croatia, HVAR POINT, UKA RENT, Atlas Hvar, Pelegrini Tours Hvar, Navigare, Hvar Tours, Fontana Tours, Secret Hvar, Amazing Hvar[12]. More than 60 charter agencies have been identified however data on their offer in respect to Pakleni Islands is not available.
In addition to the tourist offer, fishing and agriculture are also present. For **agriculture,** information is available on 7 agriculture farms that deal with agriculture and 4 family farms that deal with animal husbandry. In terms of **fishing,** the stakeholders estimate that there are about 20 active fishermen (commercial fishing) in the area of the town of Hvar who use the Pakleni Islands as a fishing area. There is sport and recreational fishing[13].

[12] Kurtović Mrčelić, J., Taraš, M., Petit, S., Ferretti, M. (2023): Pakleni Islands diagnosis and strategic plan. Split

[13] Jakl Z., Miletić A., Špika M. (2023): A study on determining the type and extent of current fishing activities and proposals for recommendations for the preservation of the marine ecosystem of Pakleni Islands. Association for nature, environment and sustainable development Sun. Client PI SEA AND KARST



3.3.3 Existing pressures

The Pakleni islands are located in the heart of the navigation routes of the central Adriatic, which marked their history and shaped their current development. Exceptional gastronomic offer, the indented coastline with small pebble and sandy beaches, picturesque forests and the vicinity of the historical city of Hvar with important accommodation capacity, made Pakleni Islands a well-known nautical destination. However, because of a lack of proper management measures, the marine ecosystem of Pakleni Islands is under exceptional **pressure from nautical tourism**.

Hvar barcarioli with their small vessels (from 6 to 12 meters) are of special importance for the city of Hvar, considering the location of the city as well as the indentation of the coast, but also the attractiveness of the Pakleni Islands. Barcarioli are unique offer compared to others, so they are declared as special stakeholders of the nautical tourism of the Town of Hvar. There are about 30 barcarioli, i.e. owners of "barges"/boats (there is information that there were 35 of them in 2021), they seasonally perform almost all-day transportation on the route Luka Hvar – Pakleni Islands. They have their own association and guild. Passengers are disembarked at 4 locations on Pakleni Islands: Jerolim, Stipanska, Ždrilac and Palmižana. 15 barcarioli run to Jerolim and Stipanska, 6 barcarioli drive to Ždrilac. There are 9 barcarioli of 50 people driving to Palmižana. Most of the time barcarioli disembark guests at the docks, so we suppose that the anchoring pressure from this target group is low. But this is something that should be checked by remote sensing methods to completely exclude the anchoring impact from barcarioli. The main pressures from this target group relates to **marine litter, bilge water and fuel**. Another important group creates pressure not only in terms of marine litter and fuel but also **noise generation**. These are **taxi boats**. They often operate from the Port of Hvar towards Pakleni Islands, however, they also operate from other parts of Dalmatia, so their number can only be roughly estimated. Most often, they have direct arrangements with hospitality services in Vinogradišće, Ždrilca and Marinkovac. We suppose that they also use docs however this is something that should be checked by remote sensing methods to completely exclude the anchoring impact from taxi boats. In the aquatorium of Pakleni Islands in the passage between the islets of Marinkovac and Jerolim vessels **mini cruisers with a length of over 24 m, the co-called Kriljani** waiting for berthing in the port of Hvar are **anchoring**. Their big anchors represent a huge threat to Posidonia meadows. That is also the case with anchors of **sailboats and yachts** whether they are private or charter boats.

In addition to anchoring that poses a threat to habitats, the main pressures related to leisure boaters are **grey and black tanks, bilge water, as well as marine litter and noise production from yachts**. Depending on the origin, there are black waters that come from urinals and toilets, and grey waters that come from sinks, showers and kitchens. The impact on the marine environment of black waters is related to the intake of bacteria and viruses, while grey waters stimulate primary production due to the supply of nutrients. During the season, we estimate 400 vessels/day of different tank capacities depending on the size of the vessel (on average 3,000 L or 3 m). There is no pump for



emptying the vessel's tanks on Pakleni Islands, but also in the wider area, so it is obvious that the tanks are emptied into the sea, more or less close to the shore. In the conversation with the stakeholders, it was recorded that the tanks are often emptied at distances smaller than the prescribed 0.5 NM[14], and often inside the bay. **Monitoring of marine litter** has been carried out in the framework of ML-REPAIR project. The Pakleni Islands are mainly polluted by glass items, suggesting a local vessel-based source[15].

[14]Kurtović Mrčelić, J., Taraš, M., Petit, S., Ferretti, M. (2023): Pakleni Islands diagnosis and strategic plan. Split

[15] Stagličić N., Bojanić Varezić D., Kurtović Mrčelić J., Pavičić M., Tutman P. (2021): Marine litter on the shallow seafloor at Natura 2000 sites of the Central Eastern Adriatic Sea, Marine Pollution Bulletin, Volume 168, 2021, 112432, ISSN 0025-326X, Dostupno na: https://doi.org/10.1016/j.marpolbul.2021.112432 [26. travnja 2024.]



3.3.4 Target habitats and pressure impact evaluation

Habitats

Pakleni Islands marine area is part of the European ecological network Natura 2000 under the code HR3000095 to preserve the following habitat types: Posidonia beds (*Posidonion oceanicae*, code: 1120), sandbanks which are slightly covered by sea water all the time (code: 1110), mudflats and sandflats not covered by seawater at low tide (code: 1140), reefs (code: 1170) and submerged or partially submerged sea caves (code: 8330). The conservation area for Natura 2000 species and habitat types is 1996.60 ha[16], while the area covered by each habitat type is showcased in Table X.

*Table 15 Habitat types present on the site and assessment for them (**PF:** Value "1" indicates the priority form for habitat types that can have a non-priority as well as a priority form (6210, 7130, 9430); **NP:** Value "1" indicates a habitat type that no longer exists in the site; **Caves:** for habitat types 8310, 8330 (caves) the number of caves is entered if estimated surface is not available; **Data quality:** G = 'Good' (e.g. based on surveys); M = 'Moderate' (e.g. based on partial data with some extrapolation); P = 'Poor' (e.g. rough estimation); **Representativity** (Degree of representativity of the habitat type on the site): A= excellent, B=good, C=significant, D=non-significant; **Relative surface** (Area of the site covered by the natural habitat type in relation to the total area covered by that natural habitat type within the national territory): A = >15%, B = 2-15%, C = <2%; **Conservation** (Degree of conservation of the structure and functions of the natural habitat type): A = excellent conservation, B = good conservation, C = average or reduced conservation; **Global assessment** (Global assessment of the value of the site for conservation of the natural habitat concerned): A = excellent value, B = good value, C = significant value).*

ANNEX I HABITAT TYPES							SITE ASSESSMENT			
CODE	NAME	PF	NP	COVER (ha)	CAVES	DATA	A | B | C | D	A | B | C		
							Representativity	Relative surface	Conservation	Global
1110	Sandbanks which are slightly covered by sea water all the time	0	0	1.450		M	B	C	A	B
1120	Posidonia beds (*Posidonion oceanicae*)	1	0	330		G	A	C	B	A
1140	Mudflats and sandflats not covered by seawater at low tide	0	0	0,05	0	M	B	C	B	B
1170	Reefs	0	0	195		G	B	C	B	B
8330	Submerged or partially submerged sea caves	0	0		2	M	B	C	B	C

Recently a detailed habitat distribution map has been produced (Figure 47).

[16] https://interni.bioportal.hr/ekomreza/natura/report/site?site-code=HR3000095

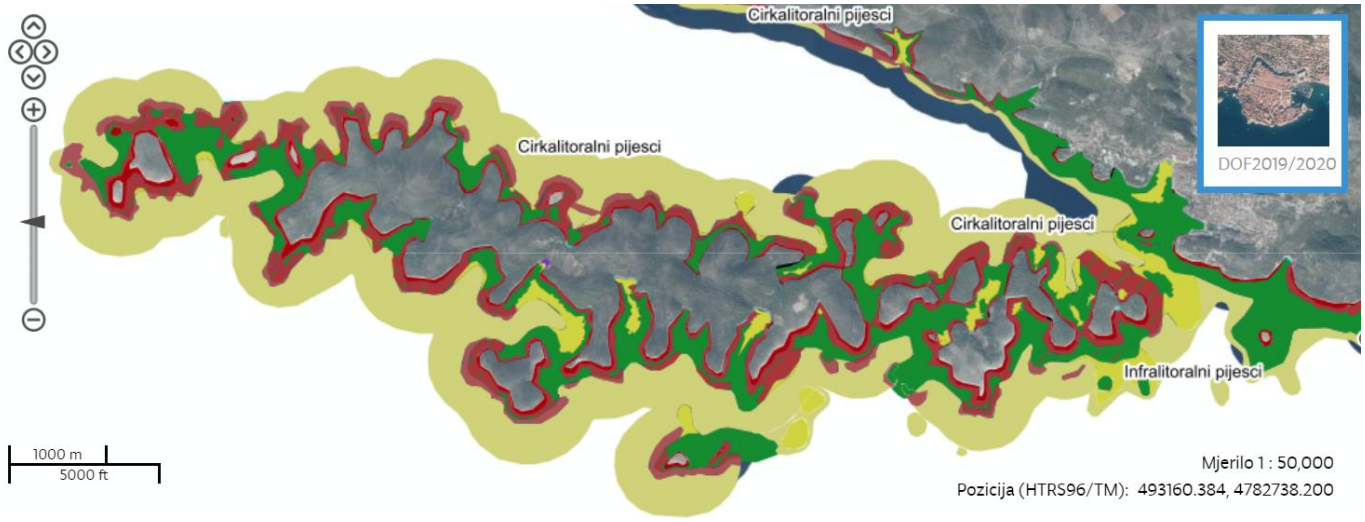


Figure 47 Marine habitats *map (in yellow: 1110 - Sandbanks which are slightly covered by sea water all the time, in red: 1170 - Reefs, in green: 1120 - Posidonia beds, note: 1140 - Mudflats and sandflats not covered by seawater at low tide and 8330 - Submerged or partially submerged sea caves are small surfaces not visible on this map), Source*: https://bioportal.hr/gis/

After the sandbanks which are slightly covered by sea water all the time, the most widespread habitat in the sea of Pakleni are **Posidonia beds (1120)** covering a surface of 330 ha (Table 1)**.** Posidonia beds characterize the infralittoral zone of the sea from a few tens of centimetres in the passages between the Pakleni Islands up to a maximum recorded depth of 35 meters. On hard or soft substrates, these settlements form the main climatogenic community. A related species and the basic constructor of the settlement is the flowering sea plant Posidonia (*Posidonia oceanica*), the most widespread and endemic seagrass of the Mediterranean, which produces significant amounts of oxygen, prevents the erosion of sand and gravel from the beaches, improves the transparency of the sea, and serves as a shelter and feeding ground for numerous marine species. Research throughout the Mediterranean has shown that about 400 species of plants and 1,000 species of animals depend on this habitat[17]. In short, the complete marine and coastal ecosystem relies on the preservation of Posidonia, therefore the conservation of this habitat type is extremely important. Due to the favourable ecological conditions, the leaves of this flowering plant around the island of Hvar reach their maximum length of over 1 meter. At certain locations, particularly in the channels between the islands, distinctive **"Posidonia atolls"** have developed, where the leaves of the seagrass extend almost to the sea surface. Over thousands of years, *Posidonia oceanica* has formed dense underwater terraces known as **mattes**, which serve as valuable natural archives of past environmental

[17] Boudouresque, Charles & G, BERNARD & Bonhomme, Patrick & Charbonnel, Eric & G, DIVIACCO & A, MEINESZ & Pergent, Gerard & Pergent-Martini, Christine & Ruitton, Sandrine & Tunesi, Leonardo. (2006). Préservation et Conservation des Herbiers à Posidonia oceanica.

conditions. Their great age is further confirmed by archaeological discoveries, including Late Antique pottery remains found on the seabed off the island of Marinkovac. The seabed surrounding the Pakleni Islands is characterised by an almost continuous belt of *Posidonia oceanica* meadows encircling the entire archipelago. This ecological connectivity facilitates the movement and genetic exchange of populations between different locations while providing essential nursery, spawning and shelter habitats for a wide range of marine organisms. *Posidonia* meadows support a highly diverse community of algae, molluscs, crustaceans, polychaete worms and echinoderms, as well as numerous fish species of both ecological and commercial importance. These include species from the families **Labridae** (wrasses) and **Sparidae** (seabreams), such as the gilthead seabream (*Sparus aurata*), common pandora (*Pagellus erythrinus*), dentex (*Dentex dentex*), black seabream (*Spondyliosoma cantharus*), two-banded seabream (*Diplodus vulgaris*), white seabream (*Diplodus sargus*), annular seabream (*Diplodus annularis*), bogue (*Boops boops*), salema (*Sarpa salpa*), saddled seabream (*Oblada melanura*), picarel (*Spicara smaris*), and many others.

Another less abundant seagrass, ***Cymodocea nodosa* covers shallow parts of Pakleni Islands marine area**. *Cymodocea nodosa* contributes to the diversity of habitats on the sandy substrate, by forming Association with the species *Cymodocea nodosa* (NKS[18] G.3.2.2.1.) present on the southeast side of the Ždrilca passage and in the interior of the Taršće cove in a mosaic with the Biocenosis of *Posidonia oceanica* species beds (NKS G.3.5.1.). The association with the species *Cymodocea nodosa* (NKS G.3.2.3.4.) is also widespread on the muddy sands of Luka Solina in the most sheltered part of the bay near Roman Villa[19].

[18] NKS – national clasification system according to Ordinance on habitat types list and habitat map (OJ 27/2021): https://narodne-novine.nn.hr/clanci/sluzbeni/2021_03_27_588.html

[19] Kurtović Mrčelić, J., 2017., „Studija zaštite podmorja ekološke mreže Natura 2000 na sidrištima Splitsko-dalmatinske županije“ Javna ustanova za upravljanje zaštićenim dijelo-vima prirode na području Splitsko-dalmatinske županije "More i krš", Split

Pressures

Threats, pressures, and activities with Impacts on the site[20] have been generally identified (Table 16).

Table 16 Threats, pressures and activities with Impacts on the site (Type: N = Negative, P = Positive

Rank: H = high, M = medium, L = low)

CODE	DESCRIPTION	TYPE	RANK	POLLUTION	OCCURENCE
D03.01.02	piers / tourist harbours or recreational piers	N	H		
E03.01	disposal of household / recreational facility waste	N	M		
E03.04	Other discharges	N	M		
F02	Fishing and harvesting aquatic ressources	N	M		
F05	Illegal taking/ removal of marine fauna	N	M		
G01.01	nautical sports	N	H		
G01.07	scubadiving, snorkelling	N	H		
H05.01	garbage and solid waste	N	H		
I01	invasive non-native species	N	M		

Public Institution Sea and Karst activities within Biopressadria project focus on Posidonia beds and anchoring which is currently the main threat to this priority habitat type.

Posidonia beds monitoring

Posidonia beds habitat type is present in most of the bays also attractive for nautical tourists and therefore under anchoring pressure. Systematic monitoring of the impacts of anchoring on *Posidonia oceanica* meadows was established in **2019** within the framework of the **ADRION IMPRECO Project**, in collaboration with **Dr Ante Žuljević** from the Institute of Oceanography and Fisheries. The monitoring programme was established at six sites. Four sites (Soline, Vinogradišće, Prevojice and Taršće) represent existing or planned nautical mooring areas, i.e. areas designated for the commercial use of the maritime domain. At the Soline and Vinogradišće sites, vessels are secured to fixed mooring blocks, whereas free anchoring takes place at the Prevojice and Taršće sites. Two additional sites, Okorija and Pakleni Bok, were selected as reference sites due to the absence of

[20] https://interni.bioportal.hr/ekomreza/natura/report/site?site-code=HR3000095

significant anchoring pressure. The monitoring programme was repeated in **2020** and **2021** to identify trends in the condition of *Posidonia oceanica* meadows and to evaluate the effects of different anchoring regimes on their conservation status[21].

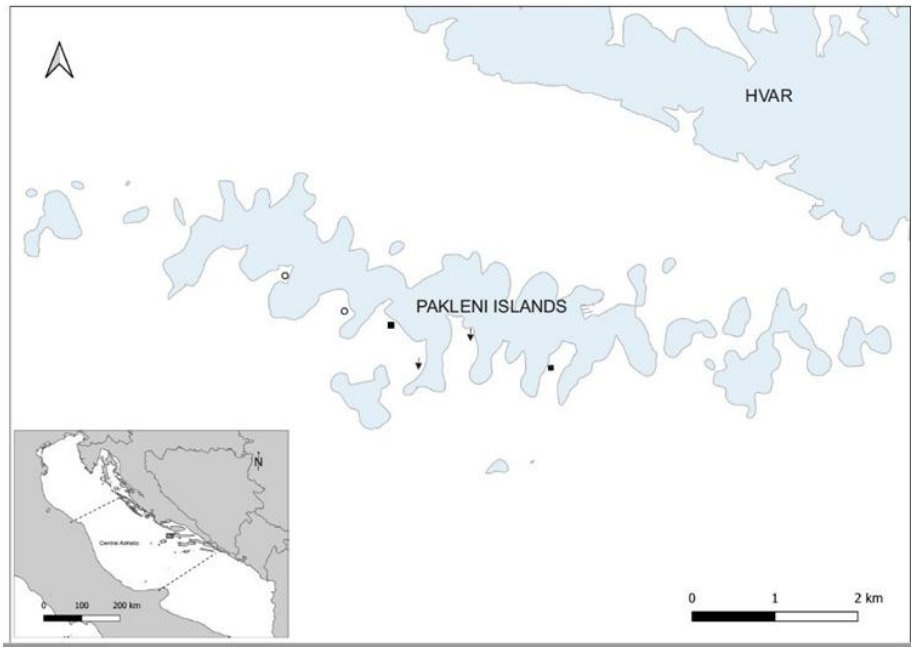


Figure 48 Sampling stations for monitoring of the impact of anchoring on the Posidonia beds (↓ free anchoring locations - Prevojice, Taršće; ■ locations with a mooring system - Vinogradišće, Soline; ○ reference locations - Pakleni bok, Okorija)

Monitoring of the condition of *Posidonia oceanica* meadows is carried out by a team of two to three scientific divers supported by a survey vessel. The monitoring methodology is based on the **POMI protocol**, with meadow cover assessed exclusively using the **Line Intercept Transect (LIT)** method. The main transect is deployed at a depth of **10 m**. At distances of **0, 25 and 50 m** along the main transect, a minimum of three **10-m LIT transects** are surveyed using a star-shaped sampling design (Figure 49)[22].

[21] Kurtović Mrčelić, J., Žuljević, A., Boban, J., 2021. Preliminarni rezultati praćenja utjecaja sidrenja na naselja posidonije unutar Natura 2000 područja Pakleni otoci, Hrvatska – ECOMAP kongres, URL: https://www.bib.irb.hr/1151179/download/1151179.Book_of_abstract.pdf

[22] RAC/SPA - UNEP/MAP, 2014. Monitoring protocol for Posidonia oceanica beds. By Guala I, Nikolic V, Ivesa L, Di Carlo G, Rajkovic Z, Rodic P, Jelic K. Ed. RAC/SPA - MedMPAnet Project, Tunis. 37 pages + annexes.

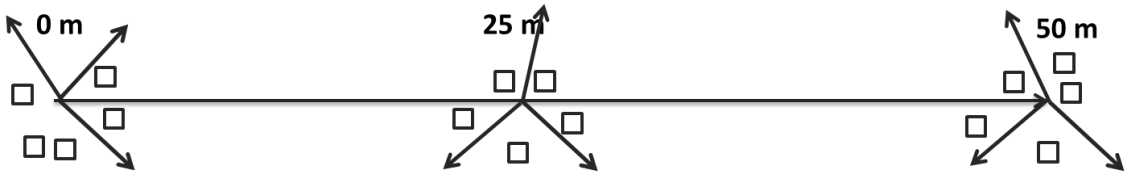


*Figure 49 Schematic representation of the monitoring methodology used to assess the impacts of anchoring on **Posidonia oceanica** meadows in the Pakleni Islands. Monitoring is conducted along a **50-m main transect** deployed at a depth of **10 m**. At distances of **0, 25 and 50 m** along the main transect, a minimum of **three 10-m Line Intercept Transects (LITs)** are surveyed.*

The conservation status results depend on the exact micro-location of the transect within the bay; therefore, monitoring must be conducted along a fixed transect position to ensure the comparability of results over time. Since **2020**, permanent stone markers fitted with surface marker buoys have been installed at the beginning and end of each transect (0 and 50 m). These markers ensure that the transect can be relocated accurately during subsequent monitoring surveys, providing a more precise and reliable reference than GPS positioning alone (Figure 50).



Figure 50 Permanent stone markers fitted with surface marker buoys are used to facilitate the accurate and consistent positioning of the beginning and end of the transect (0 and 50 m).

The Conservation Index (CI) of each site is calculated from the LIT data using the percentage cover of living *Posidonia oceanica* meadow and areas occupied by dead rhizomes, according to the following equation:

$$CI = P/(P + DM)$$

where *P* represents the percentage cover of living *Posidonia oceanica* meadow, and *DM* represents the percentage cover of dead rhizome areas recorded along the surveyed LIT transect. Based on the value of the Conservation Index (CI), *Posidonia oceanica* meadows are classified into five conservation status categories:

CI < 0.30 – Bad conservation status
0.30 ≤ CI < 0.50 – Poor conservation status
0.50 ≤ CI < 0.70 – Good conservation status
0.70 ≤ CI < 0.90 – Very good conservation status
CI ≥ 0.90 – Excellent conservation status

The similarity among monitoring sites, based on Conservation Index (CI) values, was statistically evaluated using analysis of variance (ANOVA).

Field surveys were carried out on two occasions, on 27 May and 22 July 2025, at six monitoring sites (Figure 48, Table 17) located in bays along the southern coast of the Pakleni Islands. In previous years, monitoring was conducted in autumn; however, in 2025 the surveys were undertaken in spring, prior to the nautical tourism season. This timing was selected because the longer daylight hours facilitate field operations, allowing the survey team to collect all required data during two-day trips from Split without the need to remain on site. The fieldwork was carried out by a team of two to three scientific divers, supported by one person responsible for locating and positioning the beginning and end points of each transect (Table 17). In 2025, most of the permanent transects were successfully relocated, although not all were immediately visible. Where permanent markers were found, the ropes and surface marker buoys had to be cleaned of biofouling before the surveys could be conducted.

Table 17 Selected monitoring sites used to assess the impacts of anchoring on the conservation status of Posidonia oceanica meadows within the Pakleni Islands anchoring areas:

Date	Location	Status	Beginning	End
22.07.2025.	Prevojice (=L. Soline istok)	anchoring	E00489322 N04779717	E00489321 N04779768
22.07.2025.	U. Taršće	anchoring	E00489915 N04780023	E00489877 N04780005
22.07.2025.	Vinogradišće	mooring - blocs	E00490874 N04779593	E00490905 N04779635
27.05.2025.	Soline	mooring - blocs	E00488943 N04780144	E00488982 N04780115
27.05.2025.	Pakleni bok	referent	E00488417 N04780382	E00488410 N04780438
27.05.2025.	U. Okorija	referent	E00487703 N04780719	E00487689 N04780665

Analysis of the data using the Line Intercept Transect (LIT) methodology revealed statistically significant differences among the monitoring sites (ANOVA, $F = 28.98541 > F_{crit} = 2.408514$). Based on the Conservation Index (CI), the sites were classified into three conservation status categories: poor (Prevojice), good (Taršće), and very good (Vinogradišće, Soline, Pakleni Bok and Okorija) (Figure 51).

In 2025, all monitoring sites, with the exception of Soline, exhibited a decline in their mean Conservation Index (CI) compared with the 2021 survey (Figure 51 and 52). As observed in 2021, the greatest variability in LIT values occurred at sites exposed to free anchoring. The most pronounced impact was recorded at **Prevojice**, where intensive free anchoring on a gently sloping seabed resulted in the Conservation Index declining **from poor to bad conservation status** (Figure 53). In contrast, at Vinogradišće, where vessels are secured to fixed mooring blocks, recent anchoring impacts were considerably less evident (Figure 54). Signs of anchoring-related degradation were also detected at the **reference sites Pakleni Bok and Okorija**, both of which, for the first time, were classified as having a **very good rather than an excellent conservation status** (Figure 55).

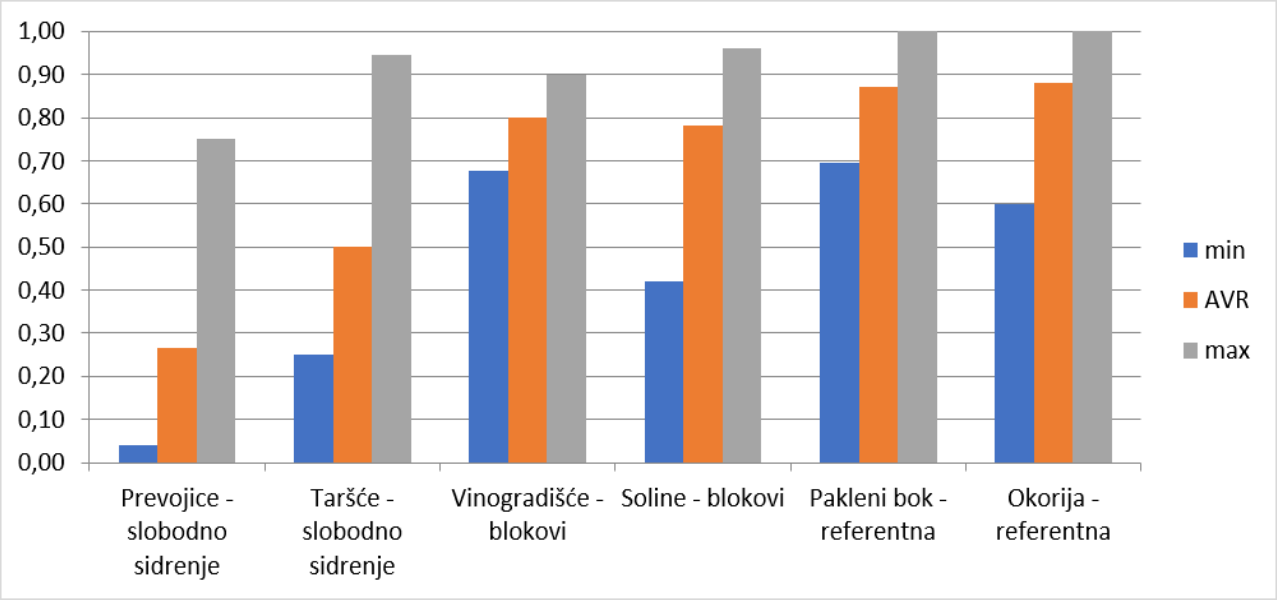


Figure 51 Conservation Index (CI) values for Posidonia oceanica meadows at the monitored sites based on the Line Intercept Transect (LIT) methodology (2025).

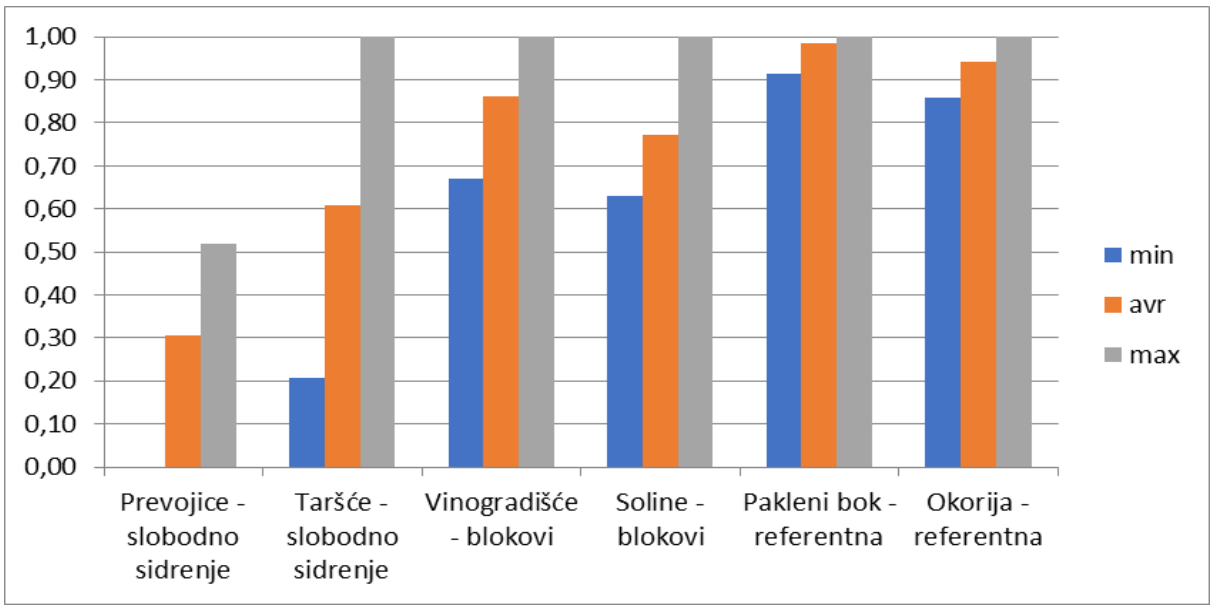


Figure 52 Conservation Index (CI) values for Posidonia oceanica meadows at the monitored sites based on the Line Intercept Transect (LIT) methodology (2021).

The overall mean Conservation Index (CI) across all monitoring sites decreased **from 0.75 (very good conservation status) in 2021 to 0.68 (good conservation status) in 2025**, indicating an overall decline in the ecological condition of the *Posidonia oceanica* meadows[23].

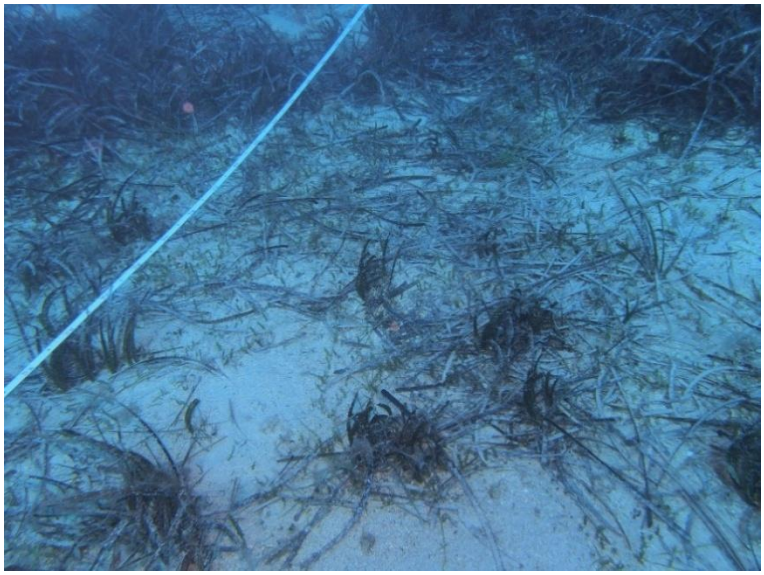


Figure 53 Prevojice Bay. LIT measurements and visual inspection revealed that the site is subject to intensive anchoring pressure, as evidenced by numerous gaps within the Posidonia oceanica meadow and recently uprooted seagrass shoots caused by anchor deployment. Exposed rhizomes are extensively overgrown by the invasive alga Caulerpa cylindracea

[23] Kurtović Mrčelić, J. J. Boban (2025): Četvrto razdoblje praćenja utjecaja sidrenja na području Paklenih otoka. Javna ustanova More i krš kroz Interreg projekt Biopressadria



Figure 54 Establishment of the monitoring transect in Vinogradišće Bay. The site exhibits extensive historical degradation of the Posidonia oceanica meadow caused by free anchoring before the installation of fixed mooring blocks.



Figure 55 Referent location Okorija

Pressures on Posidonia meadows

There are several pressures on Posidonia beds present on Pakleni Islands. In the past shore seine nets were present in the archipelago creating an important impact on this habitat type. This fishing tool has been forbidden in Croatia since 2021. based on Council Regulation (EC) No. 1967/2006. Today, the main pressures originate from tourism-related activities. These include seasonal pollution caused by inadequately treated wastewater from land-based systems (restaurants), as well as the illegal discharge of wastewater from boat holding tanks into shallow coastal waters. Also, climate change and invasive species such as *Caulerpa cylindracea* are a constant threat. However, the most significant identified pressure is mechanical damage by anchoring.

In 2022, a total of 15,162 vessels stayed per day in ACI marina Palmižana situated on Pakleni Islands. Estimating the annual number of vessels anchoring/mooring outside the ACI marina amounts to more than 30,534 vessels[24]. During the monitoring carried out in 2016 it was recorded that in the heart of the season at the beginning of August, during stable weather conditions, the total daily number of vessels within 11 bays was 265, respectively[25].

Although previous surveys provided an approximate estimate of the number of vessels present in the Pakleni Islands, their accuracy was limited. Through the Interreg BIOPRESSADRIA project, the Public Institution Sea and Karst commissioned SeaCras Ltd. to carry out a **comprehensive analysis of nautical tourism pressures using remote sensing techniques**. The detailed methodology and results are presented in two technical reports prepared by SeaCras Ltd[26]. The following section summarizes the main findings and conclusions of these analyses.

The **total cumulative number of detected vessels** during the 2025. monitoring period amounted to **15,009**. Analysis of the seasonal dynamics revealed a clear concentration of vessel traffic during the peak tourist season, namely in **July and August**, whereas considerably lower activity was recorded at the beginning and end of the season. The highest number of vessels was recorded on 11 August 2025, when a total of **460 vessels** were detected. During the peak season, between 10:40 a.m. and 11:45 a.m., the number of vessels frequently ranged from 300 to more than 400, while the average daily number of vessels in July and August was **approximately 300**.

With regard to space use, almost **half of all vessels** (49.3%, or approximately 58% when the ACI Marina Palmižana is excluded) **were anchored**, confirming the considerable pressure exerted on the seabed. The fleet was dominated by **vessels 10–16 m in length (42.8%)**, followed by vessels less than 10 m long (37.2%), while large vessels (≥24 m) accounted for the smallest proportion (7.2%).

[24] J. Kurtović Mrčelić, Taraš M., Petit S., Ferretti M. (2024.): Analiza stanja i strateški plan Paklenih otoka 2024.-2029., Javna ustanova More i krš, Split

[25] Javna ustanova More i krš (2016): Monitoring plovila na sidrištima Splitsko-dalmatinske županija, Split

[26] Karadža J., Šulc R., Kurtović Mrčelić J., Špadina M. (2025): Analiza pritiska nautičkog turizma 2025. godine i usporedba s 2023. godinom za pilot područje ekološke mreže Natura 2000, HR3000095 Pakleni otoci. SeaCras za naručitelja Javna ustanova More i krš, Interreg projekt BIOPRESSADRIA

Nevertheless, these largest vessels were the ones most frequently using free anchoring, indicating a lack of adequate mooring infrastructure capable of accommodating them. In contrast, smaller vessels more commonly berthed alongside quays, whereas medium-sized vessels predominantly used mooring buoys.

The spatial distribution of vessels was highly uneven. The **eastern part of the archipelago**, particularly the area extending eastwards from Vlaka, represented the principal hotspot of nautical tourism, while the western part was subjected to considerably lower pressure (Figure 56). Nevertheless, vessels were recorded throughout almost the entire archipelago, including nearly all bays and shallow-water areas, highlighting the widespread attractiveness of the area for recreational boating. The highest concentrations of vessels were recorded in **Palmižana, Vinogradišće and Ždrilca** (Figure 57). Maximum daily vessel numbers reached 87 in Palmižana, 72 in Ždrilca, 56 in Vinogradišće and 51 in Taršće. At locations such as Vinogradišće and Ždrilca, these peak values indicate that vessel density is approaching the spatial carrying capacity, with boats occupying the available space at very short distances from one another and in an irregular distribution.

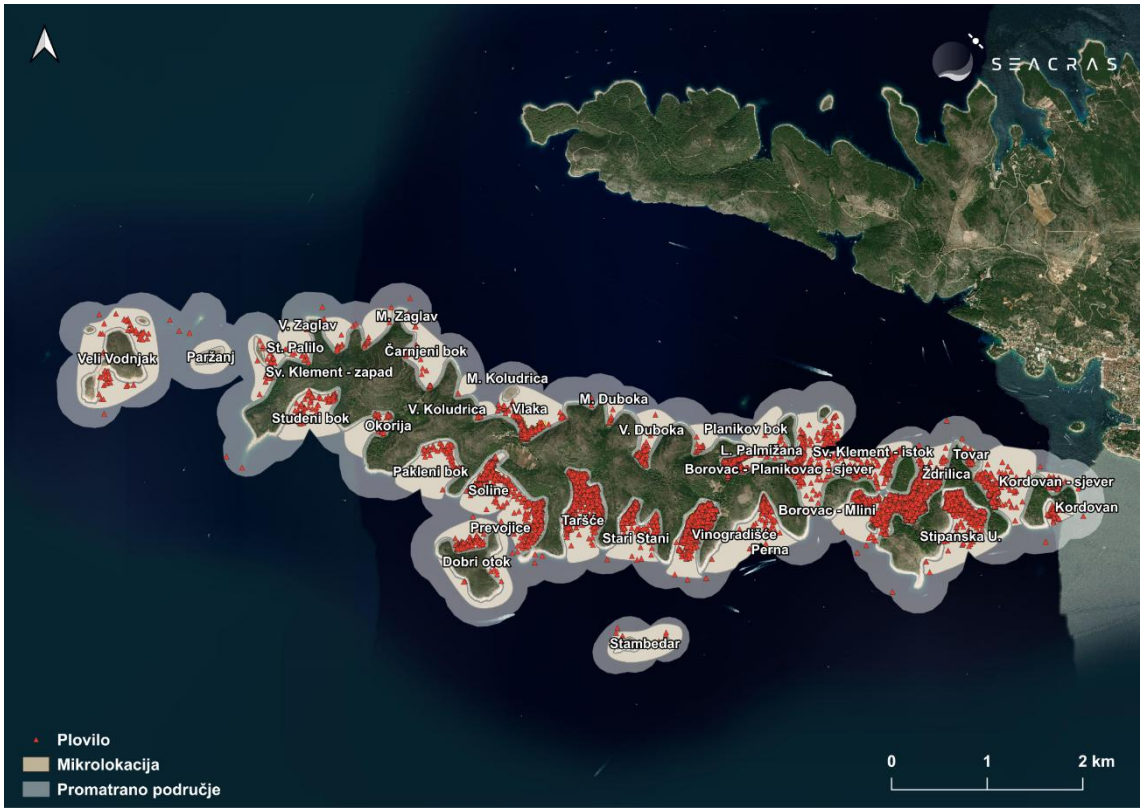


Figure 56 All detected vessels within the surveyed micro-locations (red spots)



Figure 57 Generalized spatial distribution of detected vessels by location (1 April–31 October 2025). Number of detected vessels in numbers and represented by red cyrcle.

Anchoring pressure on ***Posidonia oceanica*** meadows was particularly significant. The highest absolute number of vessels anchored directly above *Posidonia* meadows was recorded in the **Ždrilca** area (Figure 58), while the highest relative proportion was observed in the **Soline–Prevojice** area, where **84.81% of anchored vessels were located above *Posidonia* habitat**. In contrast, locations such as **Vinogradišće, Vlaka, Soline-West**, and the waters surrounding **Palmižana** exhibited substantially lower proportions of anchoring above *Posidonia* meadows, clearly demonstrating the positive effect of buoy mooring systems in reducing pressure on sensitive benthic habitats.

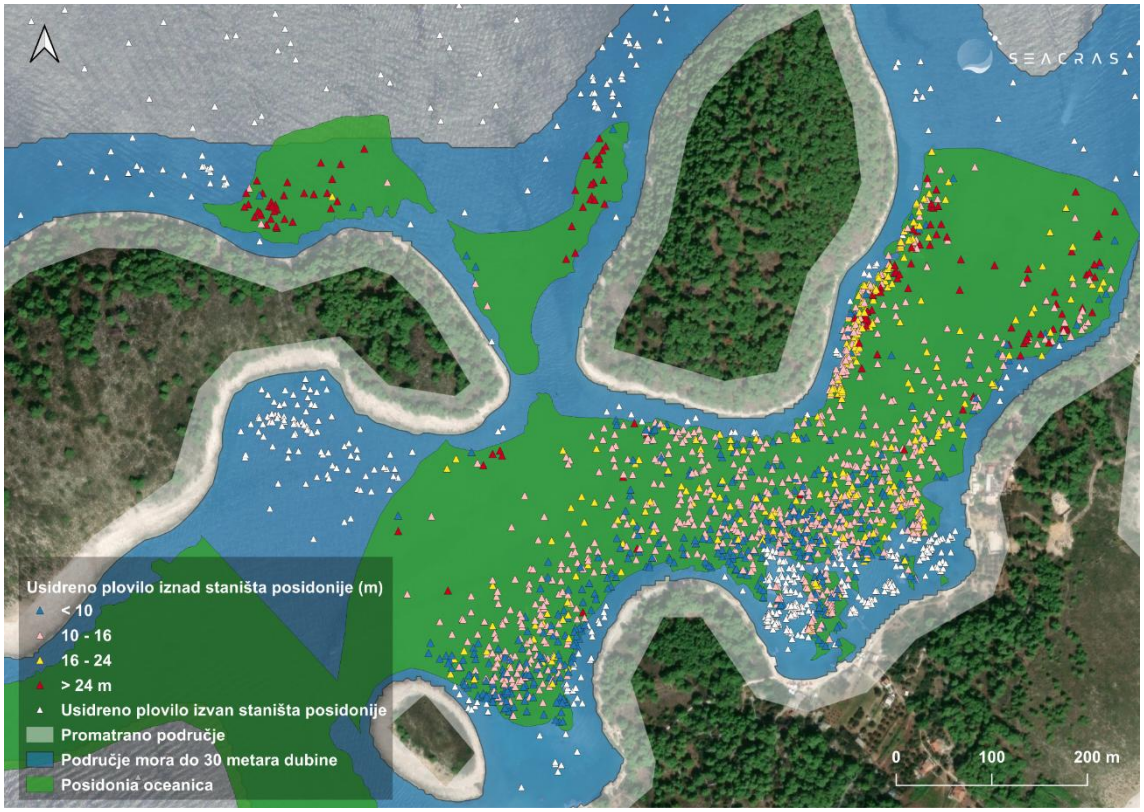


Figure 58 Distribution of all detected anchored vessels and vessels anchored above Posidonia oceanica meadows, by vessel length category, within part of the study area (1 April–30 October 2025).

Spatial analyses further identified several highly vulnerable zones, with **Ždrilca** and **Mlini** emerging as the principal hotspots of nautical tourism. Their attractiveness is enhanced by shallow-water conditions, resulting in vessels anchoring across almost the entire extent of these areas. Additional zones of elevated risk include the **eastern coast of Sveti Klement Island, the northern coast of Borovac, and the western coast of Planikovac, where the frequent anchoring of large vessels** (> 24m) represents a particular concern (Figure 59).

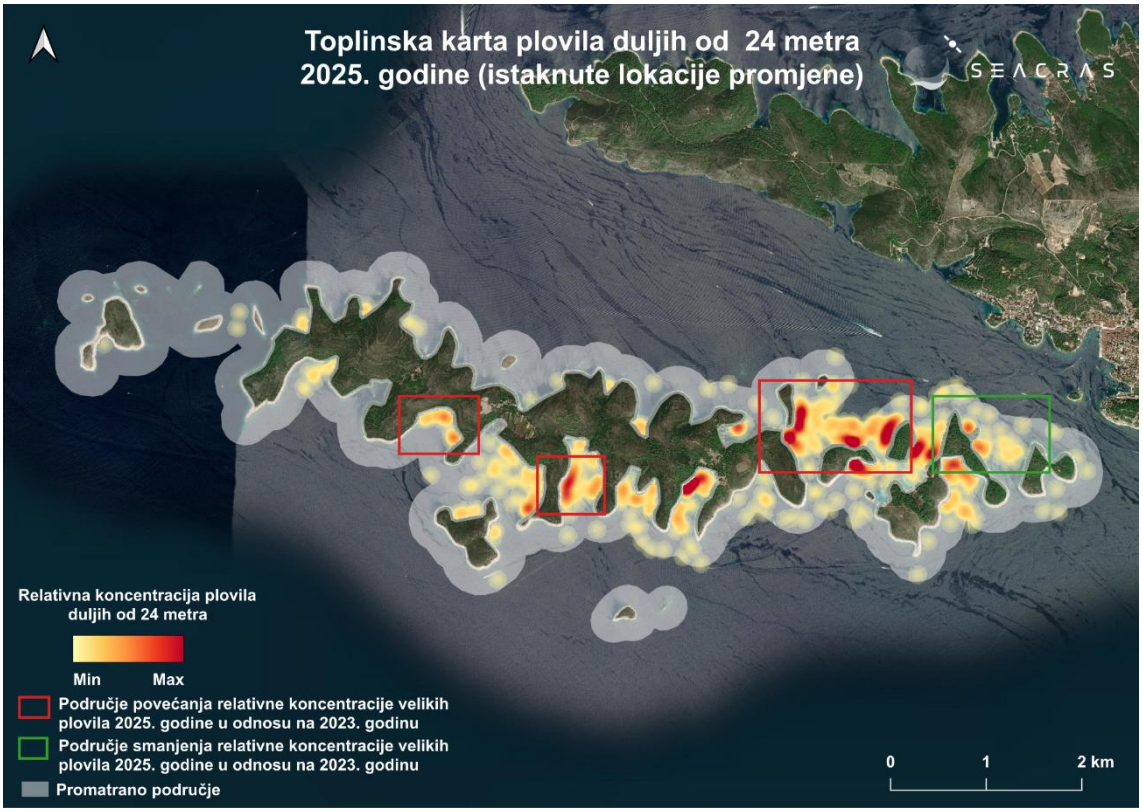


Figure 59 Heat map of detected vessels longer than 24 m in 2025. In red highlighting areas of increase compared with 2023. In green highlighting areas of decrease compared with 2023.

Comparison of the 2023 and 2025 results indicates that the overall spatial patterns of nautical activity remained largely unchanged, while the intensity of use increased considerably. The total number of detected vessels **increased by 9%,** accompanied by an increase in both the maximum number of vessels recorded on a single day and the number of days with more than 300 detected vessels. The largest **increase in vessel numbers** was observed during the **pre-season and post-season**, highlighting the growing importance of nautical tourism within the overall tourism sector of the destination.

The principal hotspots of nautical activity remained unchanged between 2023 and 2025, although minor shifts were observed in the distribution of large vessels (>24 m). In 2025, these vessels were detected across a considerably wider area of the Pakleni Islands, including almost all bays. Increased concentrations were also observed along the western shore of Taršće Bay, the waters off the eastern coast of Sveti Klement Island, the northern coast of Borovac, and the western coast of Planikovac, whereas the hotspot previously identified in the Jerolim–Marinkovac Channel became less

pronounced.

The proportion of **anchored vessels located above *Posidonia oceanica*** meadows increased by **3.5 percentage** points between 2023 and 2025, rising from 27.5% to **31.0% across the study area**. The most vulnerable *Posidonia* meadows were identified in the **Ždrilca** area and along the eastern coast of **Sveti Klement Island**.

3.3.5. Implications for Pilot Actions and future monitoring

In conclusion, the results of both the underwater monitoring programme and the remote sensing analyses are consistent and mutually reinforcing. Together, they clearly demonstrate the urgent need to implement environmentally friendly ecological mooring systems throughout the Pakleni Islands archipelago, strengthen the management of nautical tourism, and prohibit anchoring by vessels longer than 24 m above Posidonia oceanica meadows. These measures are essential to halt the ongoing degradation of this priority habitat and to preserve the ecosystem services it provides.

3.4 Pilot Site 4: Dubrovnik Neretva County, Badija and other Natura 2000 sites with target habitat 1120 Posidonia beds (Croatia)

3.4.1 Geographical and morphological framework of the area of interest

The maritime area of Dubrovnik Neretva County (DNC) covers 7,489.88 km², which accounts for 81% of the county's total surface area and 2% of Croatia's territorial waters. The coastline is highly indented, ranging from sheltered bays with sandy beaches to steep cliffs exposed to the open sea, and includes the Pelješac Peninsula and 223 islands, islets, and reefs. The unique ecological conditions of this region are influenced by the deep southern Adriatic, the waters of the eastern Mediterranean, and the Neretva River with its numerous freshwater sources. Marine protection is of strategic importance for the county's economic development, as it preserves the ecological balance essential for maintaining a high quality of life.

The coastal area and islands of DNC feature a diverse geology, ranging from sheltered bays with sandy beaches to steep cliffs exposed to the open sea. The geological formation includes karstic limestone, which is typical of the Adriatic coast. The maritime climate of Dubrovnik-Neretva County is characterized by mild, wet winters and hot, dry summers. The prevailing winds include the bora (northeasterly) and the sirocco (southeasterly). These winds significantly influence the wave and current patterns in the region, affecting both maritime traffic and coastal erosion.

Most coastal and marine habitats in DNC are under significant pressure, leading to a reduction in their size. The main sources of pressure on the marine environment are maritime traffic, fishing and mariculture, tourism, and the introduction of pollutants from land-based activities. The increasing intensity of maritime traffic during the tourist season also elevates the risk of pollution from oil derivatives, as well as levels of underwater noise and light pollution. Rapid urbanisation along the coast, inadequate waste management infrastructure, and the development of tourism and transport corridors have all contributed to negative impacts on the marine environment. The introduction of non-native species into the Adriatic has further affected the region's biodiversity.

Posidonia oceanica meadows have been identified as EU priority one of the most endangered marine habitats, one of the main pressures in anchoring.

The touristic offer of Dubrovnik-Neretva County is primarily focused on the coast, with sun and sea as the main attractions. Nautical tourism represents a significant potential within this offering. According to the Croatian Bureau of Statistics, in 2020 the county had a total of 1,173 berths across 14 nautical tourism ports; by 2022 the number of ports had increased to 15. Although DNC leads among Croatian counties in cruise ship visits, it ranks behind other coastal counties in terms of the number of nautical tourism ports, berths, and revenue. DNC is home to 74 local ports, seven county-level ports, and two ports of significant international economic importance (Gruž and Ploče). The annual passenger traffic at Dubrovnik's port exceeds 1 million, and during the peak season cruise ships can reach up to 73 vessels, with further growth expected.

The diversity of the waters and the intricate coastline make the islands a favourable destination for nautical tourism. There are three marinas on the islands (Korčula, Lumbarda, and Vela Luka) with a total capacity of 406 berths. The reported revenue generated by nautical tourism ports in the county is relatively low - 6.3 million euros in 2021, compared to 16 million euros in Istria County and 33.2 million euros in Šibenik-Knin County. One of the major challenges is the significant lack of berths relative to demand, which drives uncontrolled free anchoring in ecologically sensitive areas.



Figure 60 Special-purpose ports of Dubrovnik-Neretva County (Blue dot - Nautical tourism and sports port, Purple dot - Other ports- fishery, shipyard, police).

The Spatial Plan of Dubrovnik-Neretva County anticipates a limited number of nautical tourism anchorages (sidrišta). It stipulates a maximum capacity of 60 buoys outside urban areas, with concrete block or helical screw anchoring systems. The minimum distance between buoys is 30 m, and the area per one buoy is 900 m². In smaller bays, anchoring on two buoys is allowed to accommodate a larger number of vessels. Despite these provisions, only one formally designated nautical anchorage exists in the county, at Uvala Slano, beside those managed by the Lastovo Islands Nature Park public institution. Several locations operate informal buoy mooring systems without formal concession, and direct mooring to shoreline rocks and coastal vegetation has been documented at multiple uninhabited islands.

The pilot area in Dubrovnik-Neretva County comprises 12 selected Natura 2000 ecological network sites where habitat type 1120 Posidonia beds is present (Table 18), either as a target habitat or due

to its broader ecological relevance. The pilot action monitors boat activities, anchoring patterns, and environmental conditions across these Natura 2000 sites county-wide, with a particularly focused assessment in the eastern part of Korčula Island (Badija area), where intensive nautical tourism pressure, prior field research, and the availability of a comparable baseline from 2020 allow for a robust initial-to-final survey comparison. The data collected across the county will serve as the evidence base for developing a nautical study and integrating sustainable boating regulations into county-level spatial planning documents, following the best-practice model of project partner PP8 Sea and Karst.



Figure 61 National marine habitats map 2023 – 1120 Posidonia meadows (Croatian national habitats classification NKS G.3.5.1. Biocenosis Posidonia oceanica).

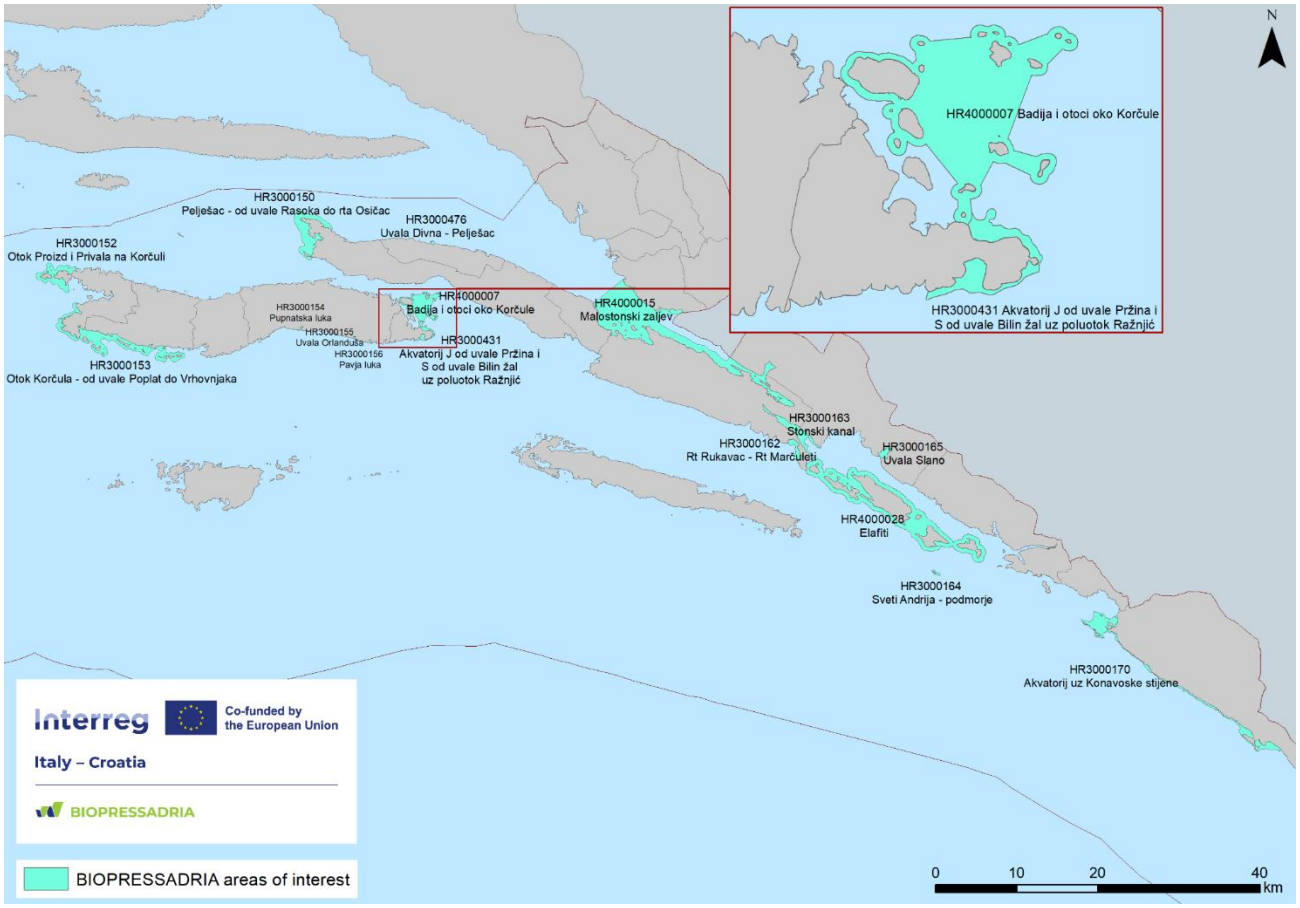


Figure 62 Dubrovnik Neretva County pilot areas (Natura 2000 sites with present Posidonia oceanica meadows.

Table 18 Selected Natura 2000 sites with habitat type 1120 Posidonia beds in Dubrovnik-Neretva County

Site code	Natura 2000 site name	Marine surface	1120 Posidonia beds habitat type surface (ha) according to SDF *habitat present but not listed as target habitat for the site	1120 Posidonia beds habitat type surface (ha) according to 2023 National marine habitats map
HR3000431	Akvatorij J od uvale Pržina i S od uvale Bilin žal uz poluotok Ražnjić	120.8	50	32.04
HR3000170	Akvatorij uz Konavoske stijene	1370.58	445	421.93
HR4000007	Badija i otoci oko Korčule	894.2	520	358.56
HR4000028	Elafiti	4030.28	600	719.75
HR4000015	Malostonski zaljev	5717.24	-*	147.52
HR3000153	Otok Korčula - od uvale Poplat do Vrhovnjaka	1903.2	1300	564.45
HR3000152	Otok Proizd i Privala na Korčuli	639.03	500	237.89
HR3000150	Pelješac - od uvale Rasoka do rta Osičac	1022.95	910	332.14
HR3000162	Rt Rukavac - Rt Marčuleti	175.48	50	46.73
HR3000163	Stonski kanal	569.18	340	105.39
HR3000476	Uvala Divna - Pelješac	20.09	12	13.05
HR3000165	Uvala Slano	133.41	6.5	6.22
	TOTAL	**16596,44**	**4733.5**	**2985.67**

HR3000170 Akvatorij uz Konavoske stijene

This site covers 1,370.6 ha of marine area along the south-eastern tip of Croatia, extending from Cavtat to Molunat, and including islands. The coastline is predominantly rocky, with vertical limestone cliffs, semi-submerged caves, and fully submerged marine caves. The seabed is composed of rocky substrates, detrital bottoms, and sandy patches, supporting diverse benthic communities. The main habitat types include *Posidonia oceanica* meadows, large shallow inlets and bays, reefs, and submerged sea caves. The SDF lists 445 ha of Posidonia beds, with the conservation status assessed as good; 2023 mapping confirmed 421.93 ha, showing stable meadow coverage. Field surveys in 2016-2017 recorded *Posidonia oceanica* on 80% of transects and *Caulerpa cylindracea* on over 80% of transects, indicating significant invasive colonisation. Intensive nautical anchoring occurs at Cavtat

(Tiha Cove is frequently used as a free anchorage for mega-yachts) and Molunat, and wastewater inputs from households and tourist facilities represent additional pressures.



Figure 63 HR3000170 Akvatorij uz Konavoske stijene

HR4000028 Elafiti

The Elafiti site encompasses a group of islands (Olipa, Tajan, Jakljan, Crkvina, Mišnjak, Kosmeč, Šipan, Lopud, Koločep) in the South Adriatic. The sea is characterized by rocky habitats, richness of marine caves and diversity of benthic organisms. South sides of the Islands usually goes steep into the sea until they reach sandflats and mudflats plate. The area is subject to multiple pressures due to its proximity to Dubrovnik and its popularity as a nautical tourism destination. Intensive seasonal anchoring occurs in several bays, directly affecting the upper limits of *Posidonia meadows*. According to the SDF, Posidonia beds cover 600 ha of the 4,030 ha marine area, with conservation status rated as good. Most recent mapping (2023) estimated the Posidonia area at 719.75 ha, with meadows present practically along the entire coastline except sea-facing exposures.



Figure 64 HR4000028 Elafiti

HR3000165 Uvala Slano

Slano Bay (approximately 2.5 km long, oriented southeast-northwest) historically supported a well-developed *Posidonia oceanica* meadow. The most recent monitoring conducted by the Sunce Association assessed the meadows as heavily degraded, with approximately half of the original meadow area dead, extensive dead matte, and coverage significantly below expected values. The northern shore of the bay is mostly urbanised, with the settlement of Slano and its small harbour. ACI Marina Slano (193 sea berths, open year-round) is located within the bay; smaller yachts also anchor in the sheltered Banja cove, while larger vessels may anchor outside the bay entrance, southwest of Cape Gornji. According to the SDF, Posidonia covers 6.50 ha of the 133.41 ha site, with conservation status assessed as reduced. The 2023 mapping confirmed 6.22 ha, showing that the area has not significantly changed but quality continues to decline due to anchoring, nautical traffic, coastal development, and wastewater inputs.

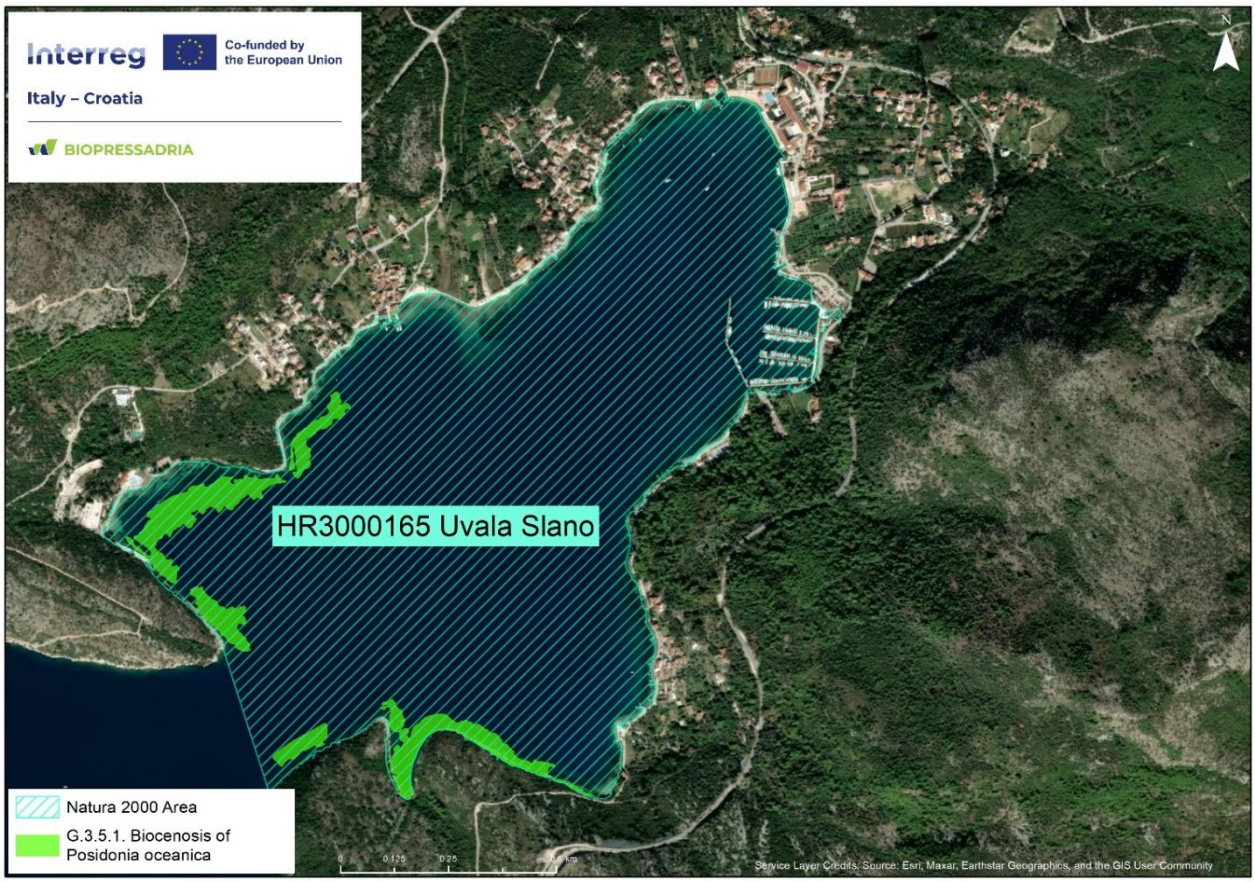


Figure 65 HR3000165 Uvala Slano

HR3000162 Rt Rukavac - Rt Marčuleti

This site covers the marine area from Cape Rukavac to Cape Marčuleti, including four bays: Smokvina, Prijezba, Marčuleti, and Pržina. Coast is mostly rocky except for Pržina bay which has sand beach. Research by the Sunce Association in 2019 documented significant mechanical damage to Posidonia meadow habitat in Marčuleti and Pržina coves, in the form of large trenches and uprooted Posidonia rhizomes and roots caused by anchoring. *Caulerpa cylindracea* was observed on 78% of surveyed transects, across all habitats. Additionally, a significant amount of large debris was recorded in Smokvina Cove, consisting mostly of glass and plastic bottles and other plastic items.

According to the SDF, Posidonia beds cover 50 ha, with conservation status assessed as good. The 2023 mapping estimated the surface at 46.73 ha.

HR3000163 Stonski kanal

This long, narrow bay penetrates deeply into the landmass at the beginning of the Pelješac Peninsula. The channel entrance is 800-1,500 m wide and 20-53 m deep, narrowing abruptly to about 150 m and 2-5 m depth beyond Broce, then continuing as a narrow waterway up to 50 m wide from Broce to Ston. *Posidonia oceanica* meadow quality and extent decrease progressively from the channel entrance towards the inner part, whether due to natural sedimentation or wastewater inflow from the Ston area. *Caulerpa cylindracea* is present throughout the entire channel. The SDF lists 340 ha of Posidonia beds within the 569.19 ha site, with conservation status assessed as good. However, the 2023 mapping estimated only 105.39 ha, suggesting significant regression. Monitoring data from 2019 show lower shoot densities compared to reference sites.

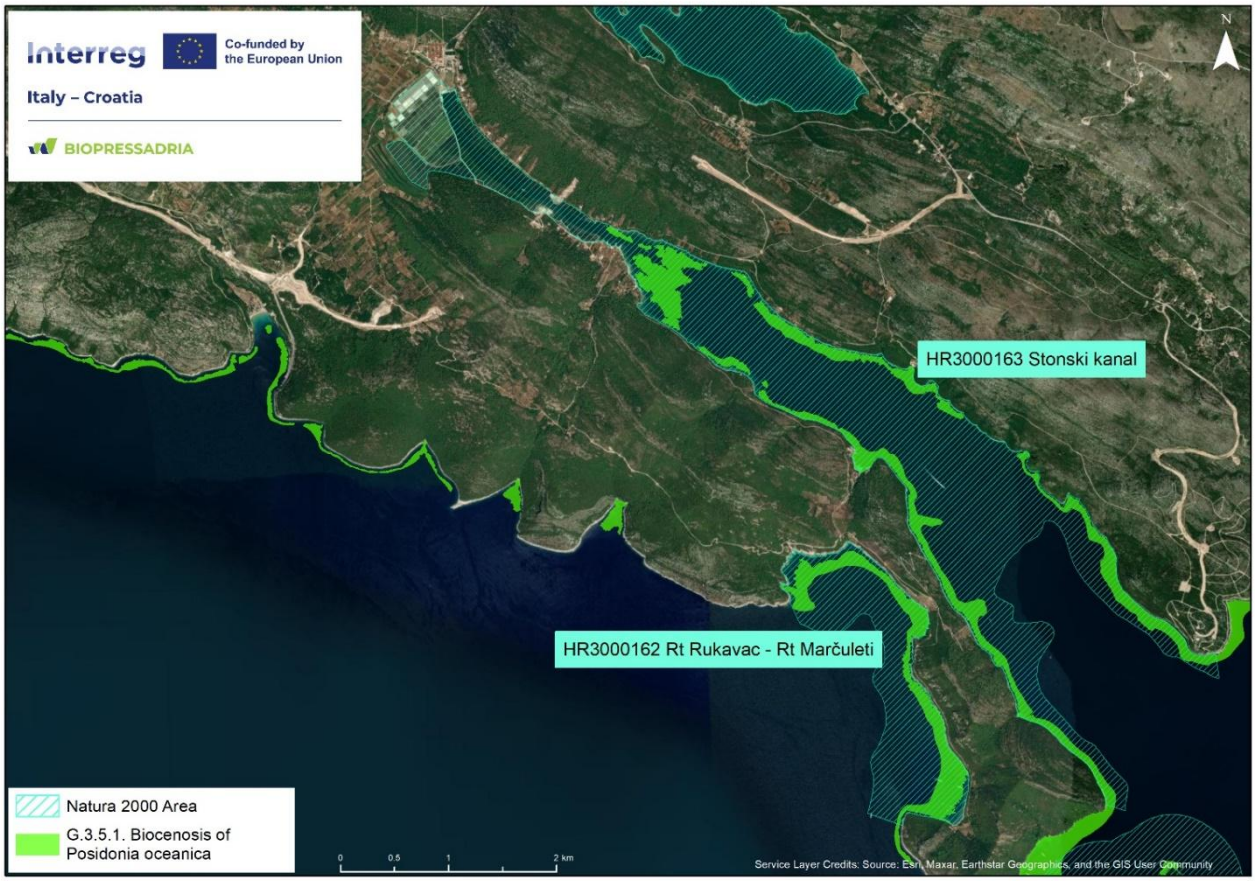


Figure 66 HR3000162 Rt Rukavac - Rt Marčuleti, HR3000163 Stonski kanal

HR4000015 Malostonski zaljev

Malostonski Bay is a semi-enclosed marine area located at the entrance to the Neretva Channel, between the Pelješac Peninsula and the mainland. It is characterised by a narrow entrance, limited water exchange, and predominantly muddy seabed, internationally recognised for shellfish farming (*Ostrea edulis* and *Mytilus galloprovincialis*). *Posidonia oceanica* meadows are present mainly in the outer, more exposed parts near the bay entrance; the bay also supports *Cymodocea nodosa* meadows in the inner parts. Anchoring pressure is considered low, as most vessels are linked to farming operations and use fixed moorings. Maritime traffic primarily consists of vessels between 2.5 and 15 meters used for aquaculture work, with limited recreational or fishing use. Traffic mainly originates from municipal harbors with operational shores open to domestic traffic, including Mali Ston, Hodilje, Luka, Brijesta, Sutvid, Drače, Sreser, and routes leading toward them. However, navigation also occurs in more secluded parts of the bay, such as Bistrina Cove, which has a mooring area for a small number of vessels.

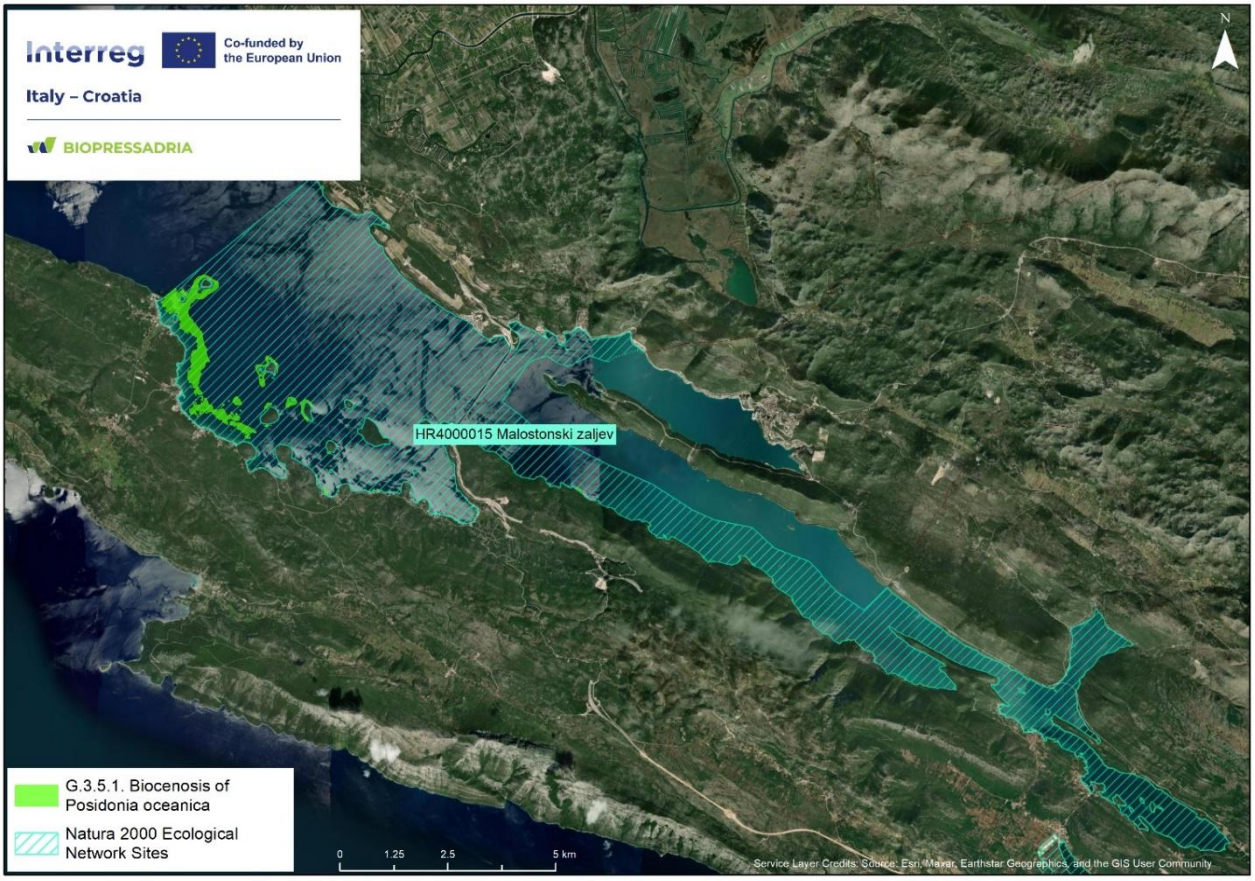


Figure 67 HR4000015 Malostonski zaljev

HR3000476 Uvala Divna - Pelješac

Divna Bay features a gravel beach approximately 250 m long adjacent to a camping facility. According to the Management Plan of the Public Institution, the bay is not considered attractive for anchoring, resulting in minimal direct pressures from nautical tourism on Posidonia beds. Based on the Standard Data Form (SDF), Posidonia meadows cover 12.00 ha of the site (total area 20.10 ha), with the conservation status assessed as good. The most recent mapping (2023) indicates a meadow area of 13.05 ha, which is slightly higher than the SDF figure, suggesting stable or potentially recovering habitat extent. Meadow continuity appears intact, with no significant fragmentation observed during recent surveys.



Figure 68 HR3000476 Uvala Divna – Pelješac

HR3000150 Pelješac - od uvale Rasoka do rta Osičac

This site includes three target habitat types: large shallow bays and coves, Posidonia beds, and sandy bottoms permanently covered by water. The area hosts the Lovište nautical tourism port with 80 berths. Its natural protection from winds makes it a popular summer destination for sailing boats and yachts, creating anchoring pressure on Posidonia beds located just outside the cove and to the north. According to the SDF, Posidonia beds cover 910 ha of the 1,022.95 ha site, with conservation status rated as average. The most recent mapping (2023) shows a Posidonia extent of 332.14 ha, found throughout the coastal part of the network.

The site experiences limited coastal development, with small settlements and occasional recreational use. Nautical traffic is moderate, and anchoring mainly occurs in more sheltered coves, potentially affecting the upper meadow limits in those areas. Other pressures include fishing activities and potential nutrient inputs from nearby land-based sources.

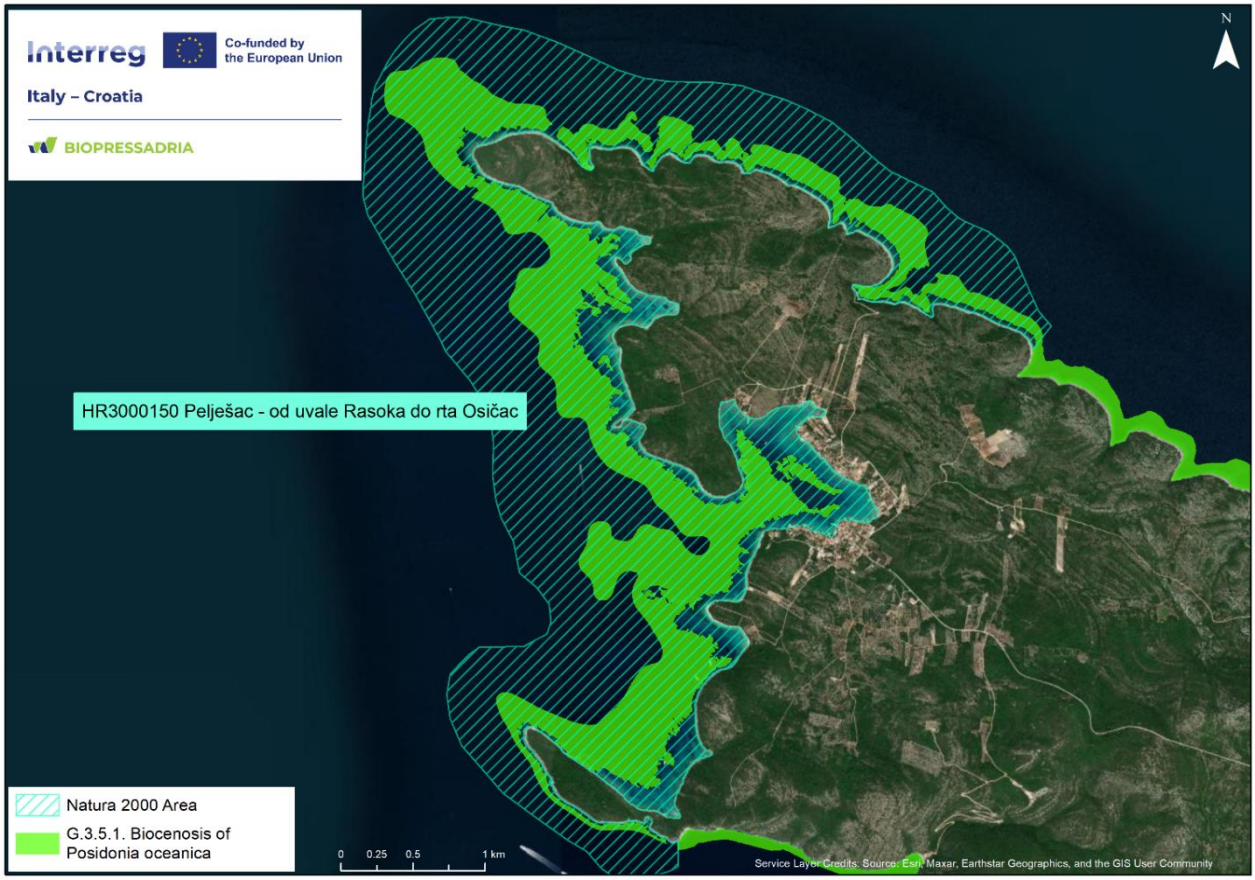


Figure 69 HR3000150 Pelješac - od uvale Rasoka do rta Osičac

HR4000007 Badija i otoci oko Korčule and HR3000431 Akvatorij J od uvale Pržina i S od uvale Bilin žal uz poluotok Ražnjić

HR4000007 Badija i otoci oko Korčule does not cover Badija alone but a cluster of islands and islets in the eastern Pelješac Channel, including Badija itself, Vrnik, Sutvara, Planjak, Majsan, Bufalo, and the twin islets of Stupa (Vela and Mala), separated from Korčula by the Ježevica Channel and served by regular water taxi connections. Badija, the largest island in the group at 0.79 km², is home to a Franciscan monastery and a seasonal restaurant and is largely covered with macchia and pine forest; its coastline is rocky except for the developed southern part, where the majority of anchoring on the island is concentrated, although vessels anchor freely around Badija and the surrounding islets alike. HR3000431 Akvatorij J od uvale Pržina i S od uvale Bilin žal uz poluotok Ražnjić adjoins this island group and covers the marine area along the Ražnjić peninsula on the Korčula mainland coast, between the coves of Pržina to the south and Bilin žal to the north - both popular anchoring and swimming destinations.
According to the SDF for HR4000007, Posidonia beds cover 520 ha of the 894.20 ha area; conservation status is assessed as reduced. The most recent mapping confirmed a reduced habitat size of approximately 358.56 ha (2023 national mapping). For HR3000431, Posidonia beds cover 50 ha according to the SDF, but updated mapping shows only 32.04 ha, indicating significant regression.

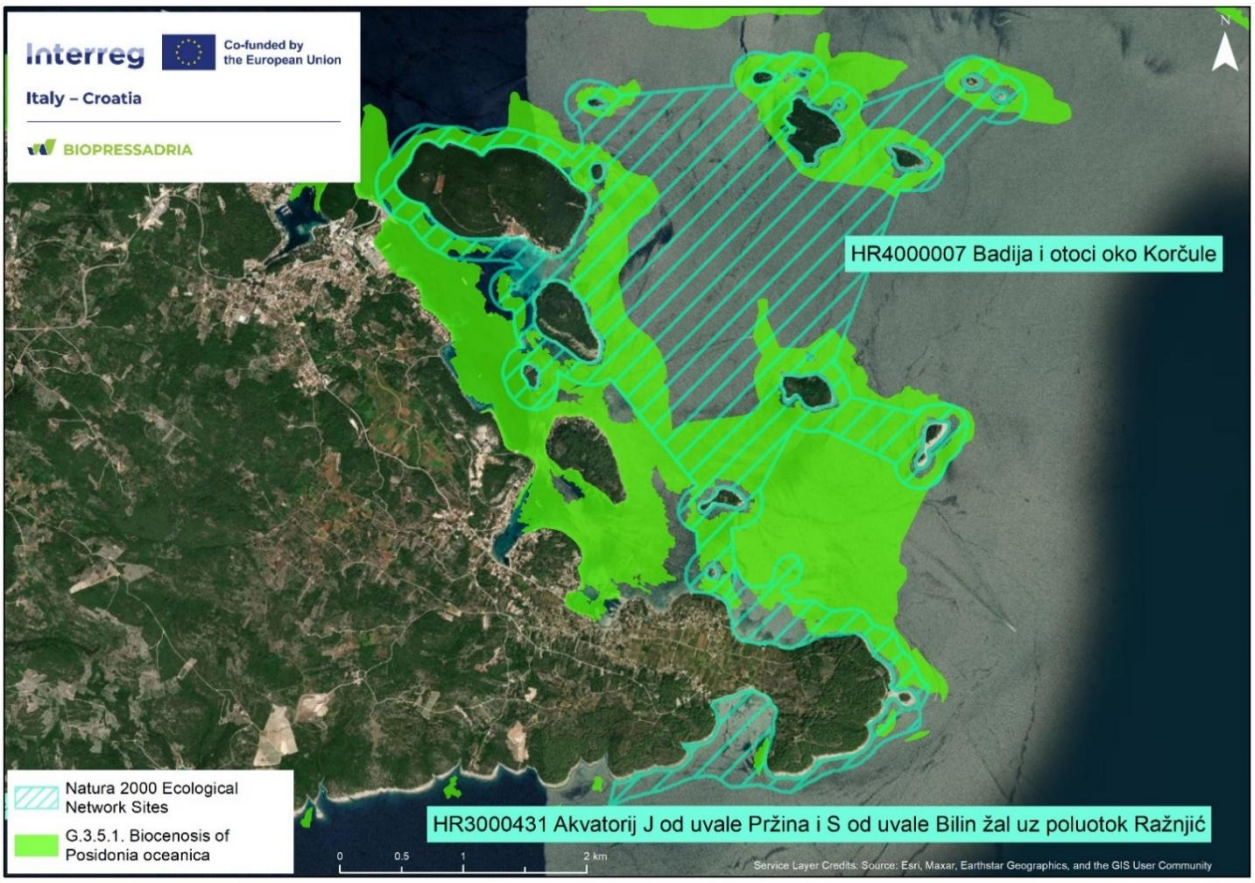


Figure 70 HR3000431 Akvatorij J od uvale Pržina i S od uvale Bilin žal uz poluotok Ražnjić and HR4000007 Badija i otoci oko Korčule

HR3000152 Otok Proizd i Privala na Korčuli

The site encompasses the islet of Proizd and the adjacent Privala coast on Korčula, both popular destinations for day-trip and anchoring tourism due to their beaches and clear water. *Posidonia oceanica* meadows develop along the sheltered coves of Proizd and the Privala shoreline, including the well-known anchorages of Veli Bili Bok, Tarita, and Meja. According to the SDF, Posidonia beds cover 500 ha of the 639.03 ha site, with conservation status assessed as good. The 2023 mapping estimated the surface at only 237.89 ha, less than half of the SDF baseline, suggesting marked regression of the meadow.

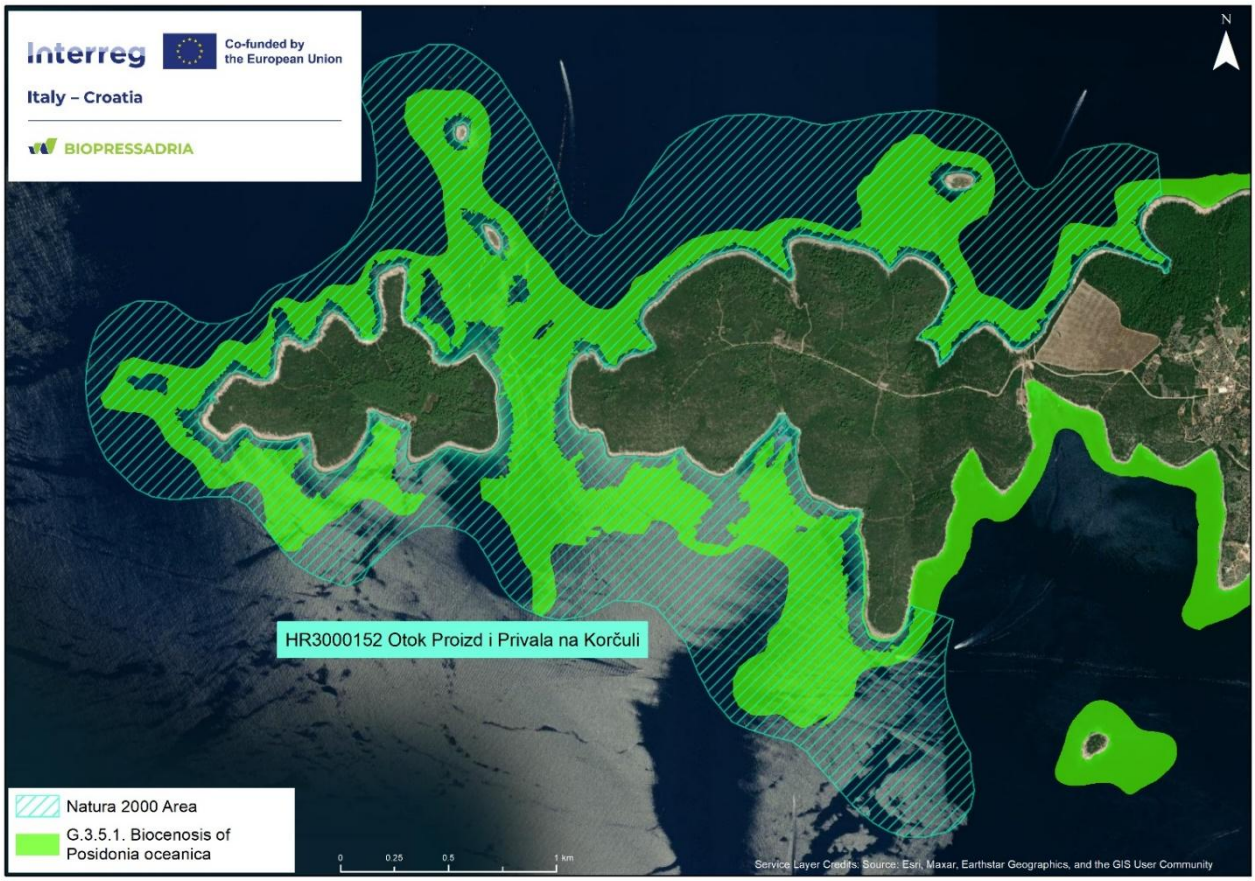


Figure 71 HR3000152 Otok Proizd i Privala na Korčuli

HR3000153 Otok Korčula - od uvale Poplat do Vrhovnjaka

The site covers the western coastal waters of the island of Korčula, extending from Uvala Poplat to the headland of Vrhovnjak, and includes Uvala Triporte and the waters around the islet of Veli Pržnjak. *Posidonia oceanica* meadows develop along the shallow coastal shelf of this stretch, particularly within Uvala Triporte, which offers good natural shelter and is popular for both day-trip and overnight anchoring. According to the SDF, Posidonia beds cover 1,300 ha of the 1,903.2 ha site, with conservation status assessed as good. However, the 2023 mapping recorded a substantially reduced extent of only 564.45 ha, indicating marked regression relative to the SDF baseline.



Figure 72 HR3000153 Otok Korčula - od uvale Poplat do Vrhovnjaka

In 2023, PIDNC, in coordination with the Sunce Association, finalised and adopted management plans for majority of Dubrovnik-Neretva County Natura 2000 sites, assessing habitat condition and identifying pressures. Common pressures across sites included illegal waste disposal, unlawful construction, shoreline and beach infilling, unauthorized structures, wastewater discharge, marine

litter, invasive species, inadequate infrastructure, and anchoring. As data were generally insufficient for quantifying these pressures, BIOPRESSADRIA focused specifically on maritime traffic and anchoring as key pressures on *Posidonia oceanica* meadows.
Beyond anchoring and unmanaged maritime traffic, these sites face a range of additional, cumulative pressures. Coastal urbanisation and inadequate wastewater treatment infrastructure remain persistent issues, with untreated or partially treated discharges from settlements such as Korčula Town, Lumbarda, and Ston contributing to localised eutrophication, particularly in semi-enclosed bays with limited water exchange. Illegal waste disposal and unauthorized construction continue to degrade shoreline habitats, while unlicensed concrete structures and coastal infilling reduce the natural extent of sensitive zones. Marine litter, including debris transported by currents, accumulates in coves and along the seabed, affecting both Posidonia oceanica meadows and associated fauna. The spread of invasive species - notably *Caulerpa cylindracea*, and more recently the first record of *Halophila stipulacea* at Badija - represents a growing threat, as these species colonise areas already weakened by mechanical damage or reduced water quality. These pressures interact cumulatively: physical damage from anchoring creates openings for invasive colonisation, while nutrient loading from wastewater amplifies the stress already imposed by intensive nautical tourism, making a multi-pressure management approach essential.

3.4.2 Main users of the area

Here, we will focus on eastern part of Korčula Island as focused assessment priority area. This pilot area in the eastern part of Korčula Island comprises ecological networks HR3000431 Akvatorij J od uvale Pržina i S od uvale Bilin žal uz poluotok Ražnjić and HR4000007 Badija i otoci oko Korčule, as well as the connecting area including the Ježevica channel. This area has been designated as the primary focus of the BIOPRESSADRIA monitoring effort due to the concentration of nautical tourism pressure, the presence of high-quality *Posidonia oceanica* habitat, and the existence of prior baseline field research (2020) that enables a robust comparison with the 2025 final survey.
Maritime traffic in the Korčula island area primarily consists of recreational and fishing boats (2.5-15 m), with seasonal passenger boats. Key nautical infrastructure includes ACI Marina Korčula (159 berths, year-round) and Marina Lučica Lumbarda (115 berths, year-round). Despite this infrastructure, unmanaged anchoring outside marinas remains the key pressure on sensitive habitats. Several discharge pipes from Korčula Town and Lumbarda release untreated or insufficiently treated wastewater into the sea, representing an additional pressure on seagrass through eutrophication.
In this area the main users are split between those seeking leisure activities (swimming, hiking) and boaters using the island's coves for anchorage. During peak season the island and its surrounding waters can become very busy.

Demographics and tourism scale:

- The Town of Korčula has approximately 5,500 permanent residents, while Lumbarda has around 1,200 residents.
- Tourism is the dominant economic activity. In 2023, Korčula recorded over 180,000 tourist arrivals and more than 800,000 overnight stays; Lumbarda received about 50,000 tourist arrivals and 250,000 overnight stays.
- Peak visitation occurs in July and August, when the local population can increase four- to six-fold.

Marine and tourism infrastructure:

- Diving centres: At least four registered diving centres operate in Korčula and Lumbarda, offering excursions to reefs, wrecks, and *Posidonia oceanica* meadows.
- Tour operators: More than 15 local agencies run boat excursions, kayaking tours, and island-hopping packages.
- Boat taxi services: Several operators provide regular transfers between Korčula, Lumbarda, and Badija, with departures every 30-60 minutes during high season.

Main user groups and activities

- **Tourists:**
  - Day-trippers from Korčula visit Badija for sightseeing, swimming, sunbathing, and cultural tourism (Franciscan Monastery).
  - Water sports such as snorkelling, paddleboarding, and kayaking are popular around the island.
- **Boaters and Yachtsmen:**
  - Badija's western cove is a known anchorage for small to mid-sized boats and yachts.
  - Peak season sees dozens of yachts per day anchoring for short visits.
- **Tour Operators:**
  - Include Badija in multi-island tours with nearby islets such as Vrnik and Stupe.
  - Offer guided snorkelling trips with marine ecology interpretation.

3.4.3 Existing pressures

Nautical tourism – DNC level

As part of the BIOPRESSADRIA project, PIDNC commissioned a county-wide satellite monitoring of nautical tourism pressure in DNC across 17 distinct sites of interest, in 12 Natura 2000 ecological network sites, covering approximately 117 km² of sea surface. Monitoring was performed using AI-powered vessel detection applied to very high spatial resolution (VHSR) satellite imagery, covering two peak seasons: June-September 2023 (initial survey) and June-September 2025 (final survey). Each detected vessel was classified by type of maritime operation and by length category, enabling differentiated analysis by vessel type. Georeferenced vessel positions were overlaid in GIS with *Posidonia oceanica* habitat distribution data and maritime infrastructure inventories to produce location-based pressure indicators. A complementary water quality monitoring component - covering chlorophyll-a (MSFD Descriptor D5) and total suspended matter (MSFD Descriptor D7) - was conducted for the Badija/Korčula sub-area (HR4000007 + HR3000431), with 48 satellite images used in 2023 and 52 in 2025. The 2025 campaign also extended the analysis to produce integrated risk maps for greenhouse gas emissions, underwater noise (MSFD Descriptor 11), and cumulative ecological pressure in this sub-area.
Across the two monitoring seasons, approximately 220,000 vessel detections were recorded, making this the most spatially detailed evidence base on nautical tourism pressure ever assembled for this county. County-wide, approximately 25% of all anchored vessels were detected anchoring directly above *Posidonia oceanica* meadows, rising to 88-90% at the most critically affected locations. Between 2023 and 2025, overall vessel detections increased by 4.5% across the county, with anchored vessels growing by 9.3%. The spatial and seasonal distribution of maritime activity remained almost identical between the two years, confirming that anchoring hotspots reflect well-established seasonal patterns rather than incidental fluctuations - a finding that directly supports the case for targeted spatial zoning measures.

3.4.4 Target habitats and pressure impact evaluation

Nautical pressure monitoring - satellite analysis – easter part of Korčula island

The Badija/Korčula area (HR4000007 + HR3000431) is the highest-traffic anchoring location across the entire county-wide monitoring network. In 2023, over 21,600 vessel detections were recorded in this area alone, with an average of approximately 80 vessels anchoring daily during peak season and a single-day maximum of 106 anchored vessels (10 July 2023). By 2025, the peak had risen to 123 simultaneously anchored vessels (5 August 2025). Approximately 33% of anchored vessels in 2023 were found anchoring directly on *Posidonia oceanica* habitat; by 2025 this proportion had increased

to 46.5% - a rise of nearly 13 percentage points. The primary anchoring hotspots are located south and east of Badija island, around the Ježevica channel, near the islets Bufalo, Majsan, and Račište, and along the passage west of Planjak. Vessels larger than 24 m anchor systematically within the seagrass zone, generating the greatest mechanical impact per event. Water quality monitoring showed spatial and seasonal patterns consistent with eutrophication pressure, partly attributed to wastewater inputs from Korčula town.

Posidonia oceanica field monitoring – easter part of Korčula island

Two rounds of field monitoring of Posidonia oceanica meadows were conducted in the HR4000007 area using the standardised MedPAN South protocol, enabling direct comparison between the 2020 initial survey (Badija and Majsan) and the 2025 final survey, which added a third location, Mala Stupa, selected on the basis of the BIOPRESSADRIA satellite pressure analysis. All measurements were taken at approximately 15 m depth, the zone of highest anchoring concentration.
At Badija, average shoot density declined to 90 shoots/m² by 2025 (abnormally low; worst category), with dead matte covering roughly 60% of the seabed and the Conservation Index (CI) falling to 0.23, confirming serious, ongoing degradation driven by long-term anchoring. Mala Stupa, monitored for the first time in 2025, showed 236 shoots/m² (low density; CI = 0.84), reflecting moderate degradation linked to growing anchoring pressure since a nearby restaurant opened; this location represents an important transitional zone where intervention could still prevent further decline. Majsan, the reference site with no anchoring, remained stable at 312 shoots/m² (normal; CI = 0.93). The strong contrast with Badija, only around 2 km away, confirms that anchoring, not broader environmental change, is driving the decline. Even so, a 48 m sailing vessel was found anchored directly in the Majsan meadow during the 2025 survey, underscoring the need for protection even at this reference site.
The 2025 monitoring also recorded the first documented occurrence of the invasive tropical seagrass *Halophila stipulacea*, found at Badija. This species has shown strongly invasive behaviour in the eastern Mediterranean and Caribbean, displacing native seagrass over large areas, and its appearance here represents a new ecological threat requiring systematic monitoring. *Caulerpa cylindracea*, already noted in 2020, was also confirmed at Badija, further inhibiting recovery.
The 2020 survey found HR3000431 in excellent condition, with minimal anchoring traces. No repeat field survey was carried out there under BIOPRESSADRIA, but satellite data suggest anchoring pressure has remained lower than at Badija throughout both seasons.

Underwater Monitoring of Anchoring Damage (SCARS Protocol)

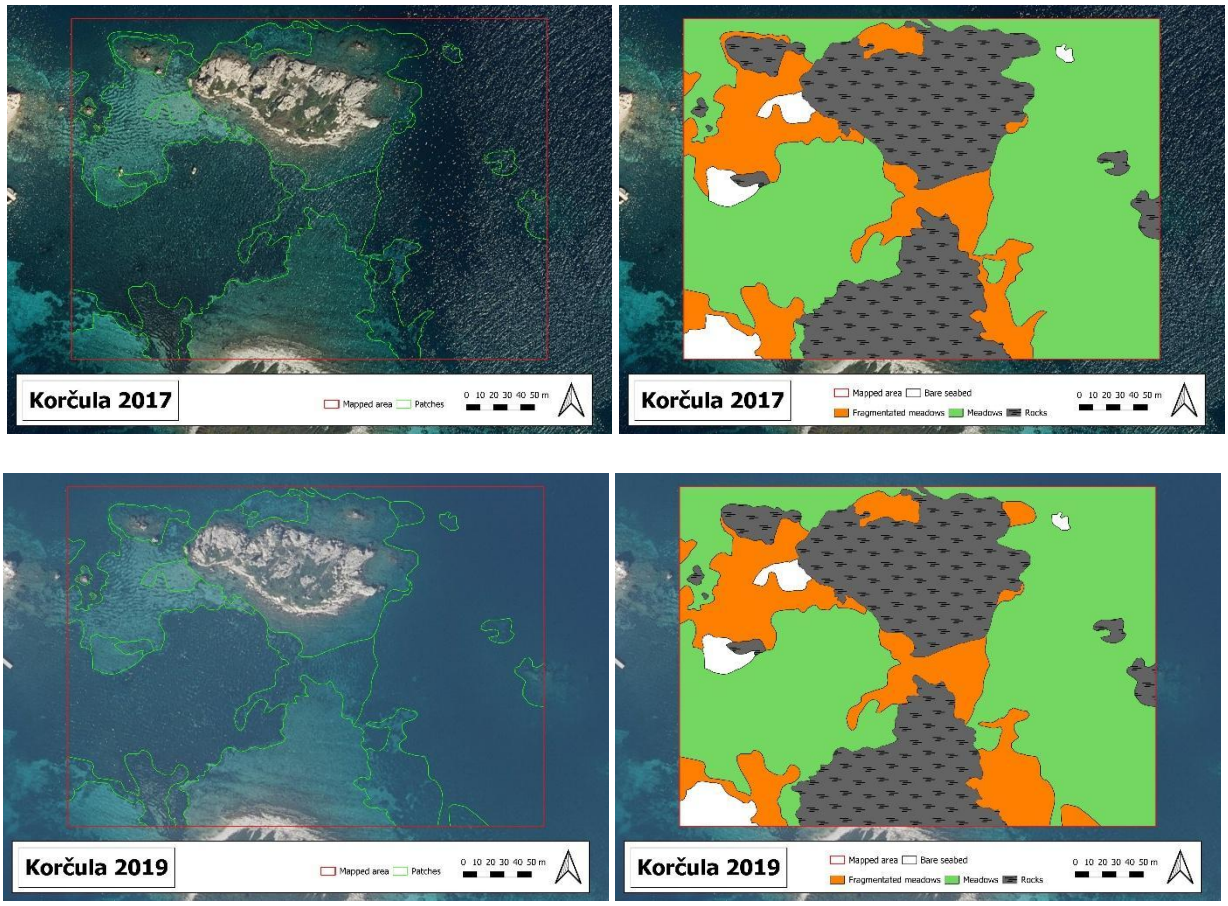
Within the study area (Badija and the islands around Korčula), the SCARS protocol was utilized to assess how recreational anchoring affects *Posidonia oceanica* meadows. The study combined a desk-based examination of aerial photographs (aimed at locating potential scars) with field-based

underwater surveys, which were necessary to identify whether the damage was due to human impact or natural erosion.

Temporal Dynamics of Seagrass Meadows (2017–2023)

The long-term assessment of seabed coverage within the study area (Badija and the islands around Korčula) reveals a resilient ecosystem, demonstrating overall stability between 2017 and 2023. Analysis of the mapped area, consistently measured at approximately 87,510 m^2, highlights that dense seagrass meadows remain the dominant feature, with coverage levels fluctuating slightly from 52% in 2017 to 54% in 2023 (Figure 73).

While the "fragmented meadows" category experienced minor variations, peaking at 18% in 2021 before returning to 15% in 2023, this does not indicate a sustained trend of habitat degradation. Furthermore, the proportion of rocky substrates and bare seabed remained remarkably stable throughout the observation period, accounting for 28% and 3% of the total area, respectively. These trends suggest that the local habitat has maintained a high degree of ecological integrity, despite the ongoing anthropogenic pressures typical of the Adriatic coastal zone.



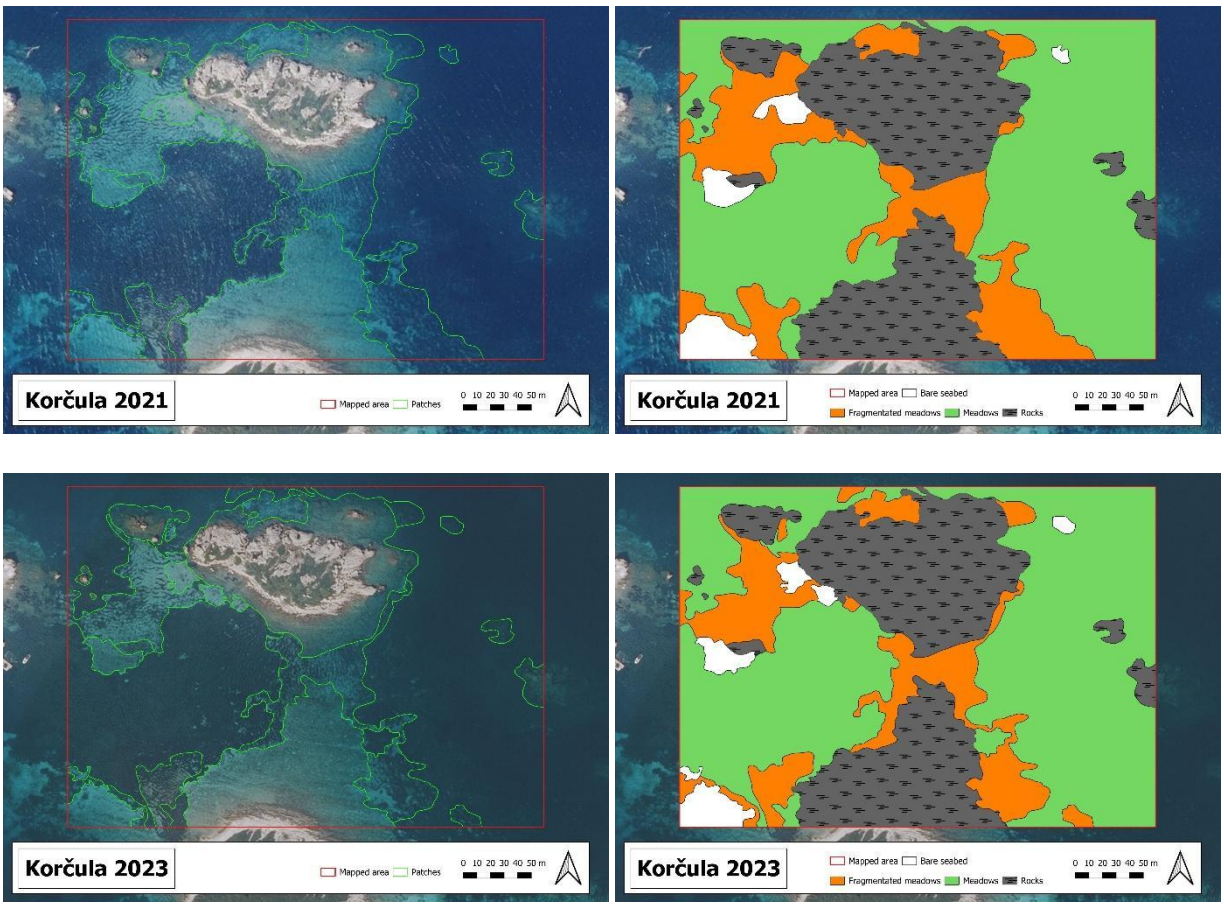
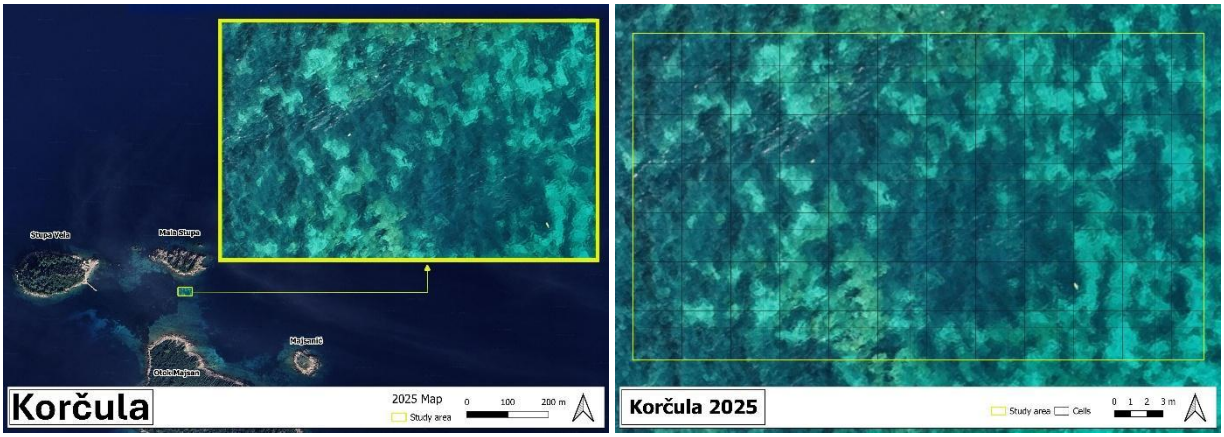


Figure 73 Monitoring of anchoring damage in the study area: temporal assessment of Posidonia oceanica coverage (2017–2023). The maps illustrate the progressive spatial evolution of the habitat, highlighting the shift from continuous meadows to fragmented areas due to anthropogenic pressure.



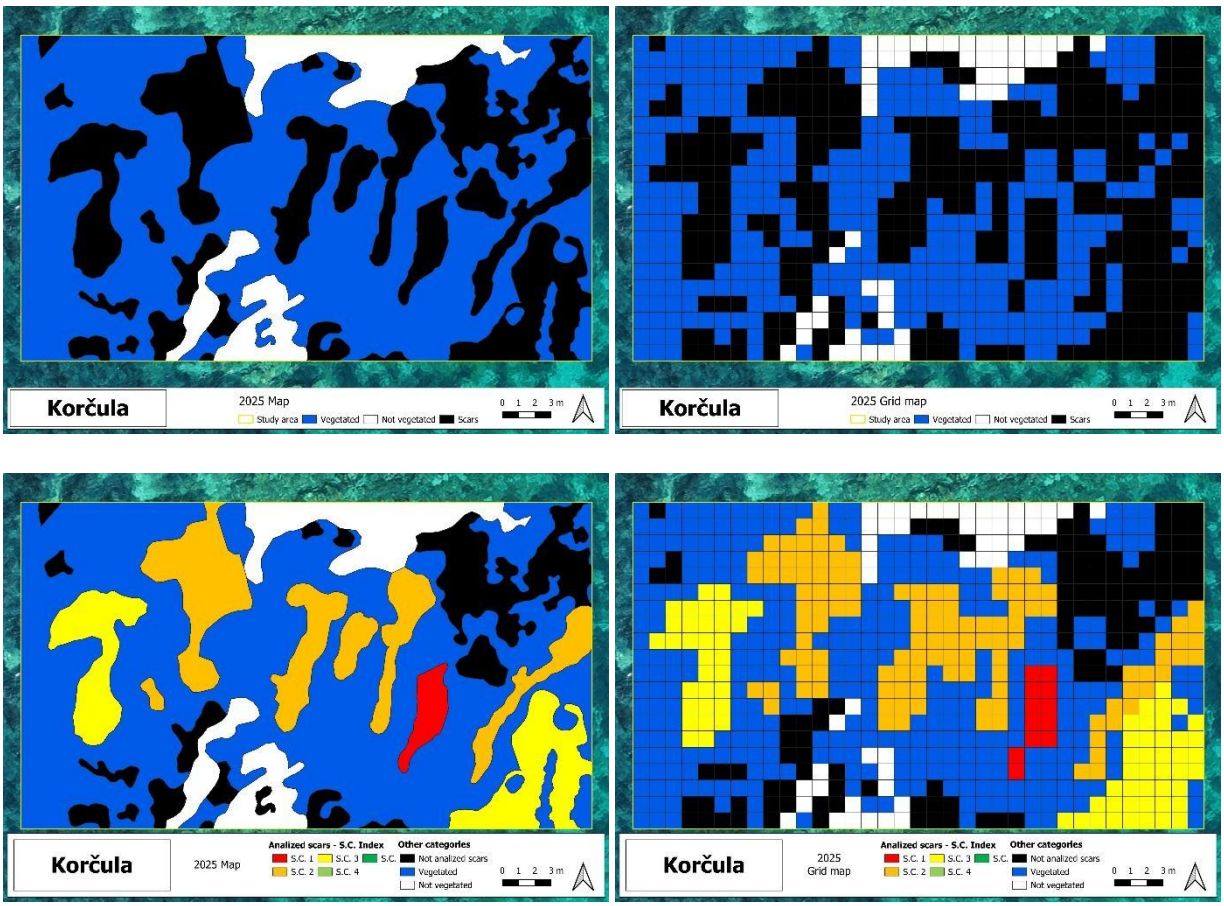


Figure 74 Monitoring of anchoring damage in the monitored area. The maps illustrate the spatial distribution of anchoring scars, classified by the Scar Damage Class (S.C.) index. The mechanical damage is visualized through a color-coded gradient: red represents S.C. 1 (very high impact), orange represents S.C. 2 (high impact), and yellow represents S.C. 3 (moderate impact).

Application of the SCARS Assessment Protocol

A fine-scale monitoring campaign was conducted in 2025 to quantify direct physical impacts on the seabed, specifically focusing on anchoring scars. The monitored sector covered approximately **700.7 m²**, consisting of **402.6 m²** of *Posidonia* meadow, **66.3 m²** of naturally unvegetated seabed, and **231.8 m²** identified as potential anchoring scars through preliminary GIS analysis. Overall, 33% of the surveyed area exhibited clear evidence of physical disturbance from anchoring, while 57% remained characterized by healthy meadow coverage, with the remaining 9% consisting of non-vegetated

seabed. To assess degradation severity, 9 scars were verified underwater, representing **67%** of the total mapped scar surface (155 m²)[27] (Figure 74).

The assessment confirmed that all monitored scars fall into:

Scar Damage Class 2 (S.C. 2), characterized by exposed or damaged rhizomes, is the most prevalent, accounting for 56% of the analyzed impacted surface.

Scar Damage Class 3 (S.C. 3), representing moderate impact with damaged leaves but intact rhizomes, accounts for 38% of the scars.

Scar Damage Class 1 (S.C. 1), indicating the most severe impact with dead or missing rhizomes, constitutes 6% of the assessed area.

Notably, no impacts corresponding to S.C. 4 or 5 were detected, indicating that the current disturbance is concentrated in categories of moderate-to-high structural damage.

The monitoring results for the pilot site present a critical picture: while the overall habitat shows resilience, the 33% footprint of anchoring scars serves as a clear warning. The dominance of S.C. 2 and S.C. 3 highlights that traditional anchoring is actively eroding the continuity and health of the seagrass meadows.

Consistent with the methodology applied at other pilot sites, the pilot area was evaluated using a standardized multi-indicator framework. This approach quantified anthropogenic pressure levels by focusing on three key drivers of habitat disturbance, each scored on a scale from 1 (lowest) to 5 (highest): Degradation Risk (DR), Recovery Potential (RP), and Anchoring Pressure (AP).

The results of this analysis for the pilot site are summarized in Table 19.

The total score of 13 assigned to the pilot site indicates a significant level of cumulative pressure, signaling that the environment is currently under critical stress. The analysis reveals a consistent and high contribution from all three identified human drivers (DR: 4; RP: 5; AP: 4), confirming that the site is facing multi-faceted anthropogenic impacts. Among these, the “Recovery Potential” (RP) component, with a score of 5, emerges as the most critical factor, reflecting a severely compromised capacity for natural regeneration that significantly heightens the site's fragility. The overall “High impact” classification indicates that the habitat is currently operating under significant stress, underscoring the need for timely management actions. By implementing targeted interventions, it is possible to alleviate existing pressures and facilitate a shift toward more stable conditions, thereby ensuring the long-term health and resilience of the site.

[27] As it was not always possible to clearly distinguish, throughout the monitored area, whether bare seabed patches corresponded to natural sandy gaps, dead matte, or the direct result of seagrass removal caused by anchoring, the Conservation Index (C.I.) could not be calculated.



Table 19 Integrated Scoring Matrix

	DR	RP	AP	Total	Interpretation
Pilot site (analyzed area)	4	5	4	13	High impact; management actions are necessary to prevent further degradation and to foster recovery or protection. (**Biopressadria pilot action 1: Integrate monitoring data into regional spatial planning to establish regulated anchoring zones**)

The assessment highlights that current usage levels are incompatible with long-term habitat conservation at the pilot site. Consequently, management actions are not only recommended but necessary to mitigate these pressures. Priority should be given to strategies aimed at fostering habitat recovery and ensuring robust protection, such as the implementation of spatial zoning or the introduction of regulated access points, to alleviate the cumulative pressure identified by this monitoring framework.

3.4.5 Implications for Pilot Actions and future monitoring

The monitoring carried out within the BIOPRESSADRIA project provides, for the first time, a comprehensive, quantitative, and county-wide evidence base on the distribution and intensity of nautical tourism pressure on *Posidonia oceanica* meadows in Dubrovnik-Neretva County. Across all pilot Natura 2000 sites, anchoring and unmanaged nautical traffic have been identified as the primary anthropogenic pressures on seagrass habitats, compounded by a structural infrastructure deficit (only one formal nautical anchorage for the entire county) and growing seasonal demand.

The eastern Korčula area (HR4000007 Badija i otoci oko Korčule and HR3000431 Akvatorij J od uvale Pržina i S od uvale Bilin žal uz poluotok Ražnjić) emerges as the most critically pressured location across the county network. The satellite monitoring recorded the highest anchoring intensity in the county, with significant and growing overlap between anchored vessels and *Posidonia oceanica* habitat (33.3% in 2023, rising to 46.5% in 2025). The Posidonia field monitoring (2020 vs. 2025) confirms that this pressure is causing measurable, continuing habitat degradation at Badija, while the nearby reference site Majsan - free from anchoring, has maintained excellent meadow condition over the same period. This comparison constitutes clear evidence that anchoring, not broader environmental factors, is the primary driver of seagrass decline in this area.

At county level, although the overall extent of Posidonia meadows remains significant, habitat quality in the most frequently used zones is visibly declining at several sites (particularly Uvala Slano, Stonski kanal, Rt Rukavac/Marčuleti, and Badija). Invasive species - primarily *Caulerpa cylindracea*, now also joined by the first Croatian record of *Halophila stipulacea* at Badija - represent a compounding threat that accelerates habitat loss once anchoring damage creates degraded areas for colonisation.

The data and analysis produced through this pilot action - the satellite-derived pressure maps, vessel detection results, water quality indicators, and field monitoring comparisons - provide the evidence base required to develop a nautical study for Dubrovnik-Neretva County and to integrate sustainable boating regulations into county-level spatial planning documents. Key areas identified as priorities for future regulation and management include the Badija/Ježevica area, the Elafiti islands (particularly Jakljan, Olipa, and Lopud), Lovište (Pelješac) and the Konavoske stijene/Cavtat area.

3.5 Pilot Site 5: Porto Cesareo (Italy)

3.5.1 Geographical and morphological framework of the area of interest

The Porto Cesareo Marine protected Area (PC-MPA), is established by the Environment Ministry in 1997 by a Ministerial Decree dated 12/12/97., thus, this is a National Marine Reserve. Porto Cesareo MPA is entrusted to a Management Public Body, formed by the Porto Cesareo and Nardò Municipalities, (in which territory the Reserve is) and the Province of Lecce. The PC-MPA covers an area of 16,654 hectares and 32 km of coastline, encompassing the shores of Porto Cesareo and Nardò, and lies in the eastern part of the Gulf of Taranto (Ionian Sea).It is one of the biggest MPAs in Italy and the biggest in the Apulia Region. of Puglia and the third for its size among those instituted recently in Italy. The purposes of the MPA are the protection of the sea environment, the promotion of social-economic eco-compatible development, the realization of environment educational projects for interested people without age limit as well as promotions and realizations of projects of scientific research.

Table 20 The MPA is structured into 2 A Zones, 2 B Zones, and 1 C Zone:

		MAIN PROVISIONS	
CODE	**AREA DESIGNATION**	**PROHIBITED**	**ALLOWED under Regulation and Authorized by Management Body**
A	Area Restricted to Use (No Take Zone)	Swimming, underwater activities, navigation, anchoring, fisheries	Scientific research and guided tours only if allowed by the Managing Authority
B	Regulated Uses	Recreational fisheries	Navigation, Professional artisanal fisheries, Swimming, snorkelling, diving, navigation
C	General Uses	Anchoring	Anchoring, mooring, Recreational fisheries

The limits of the MPA consists of the Punta Prosciutto (to the north) and Inserraglio Tower (to the south).

The southern coast is rocky partially low and partially with high cliffs. The northern coast is sandy, with dune systems.
Two large bordered marine areas are in the MPA: the firstone, about 1km long and about 500 metres large, is partly closed by the "Isola Grande" in the South-west, and by a series of other little islands and little rocks; the secondone bordered area, 2500 m long and 1000 m large, is closed in the South-west by the "La Strea" peninsula, 1500 m long and bordered in the South by two little creeks localized at Tower Squillace sides.
Next to the creek, in the South of Tower Squillace, there is about 1 km of coast nearly rectilinear, in NW-SE direction, and a series of little creeks until Tower S. Isidoro Bay, 500m long, opened in the NW and partly closed in the West by a little island of about 200m long. A series of little creeks and promontories with rocks at short distance from the cost is the characteristic of the South coast until Inserraglio Tower. Backdunal basins handmade made give mild waters through a series of superficial and underground channels. The characteristic of the landscape is the presence of seven towers built in order to defend from Turkish invasions.

In the MPA fall back three SACs (Special Areas of Conservattion), established according to Habitat Directive (92/43/EC), and one SPA (Special Protection Area) established according to Bird Directive (2009/147/EC).
The Natura 2000 network is, therefore, represented by:
- ***Porto Cesareo***" SAC (IT9150028 Code), falling in the C Zone of the MPA, with a surface of 21,8 ha;
- "***Palude del Capitano***" SAC (IT9150013 Code), falling in the C and B Zones, with a surface of 1.676 ha. - "***Palude del Conte and Dunes of Punta Prosciutto***" SAC (IT9150027 Code), falling partially in the C Zone, with a surface of 3659,5 ha, and partially in A Zone with a surface of 1047,6 ha.
- **"Porto Cesareo"** SPA (IT9150042 Code), covering completely the MPA, with a total surface of 16780,66 ha.
The coastal landscape is also carcterized by the presence of two Regional Protected Areas:
- the Regional Directed Preserve "***Palude del Conte and coastal Dune- Porto Cesareo***", given to the Town of Porto Cesareo;
- the Regional Natural Park "***Portoselvaggio-Palude del Capitano***" given to the Town of Nardò, into the which there are 5 SIC earth's sites, three of them include the already said marine parts.



Figure 75 Map of Pilot Area



Figure 76 Porto Cesareo MPA Zoning

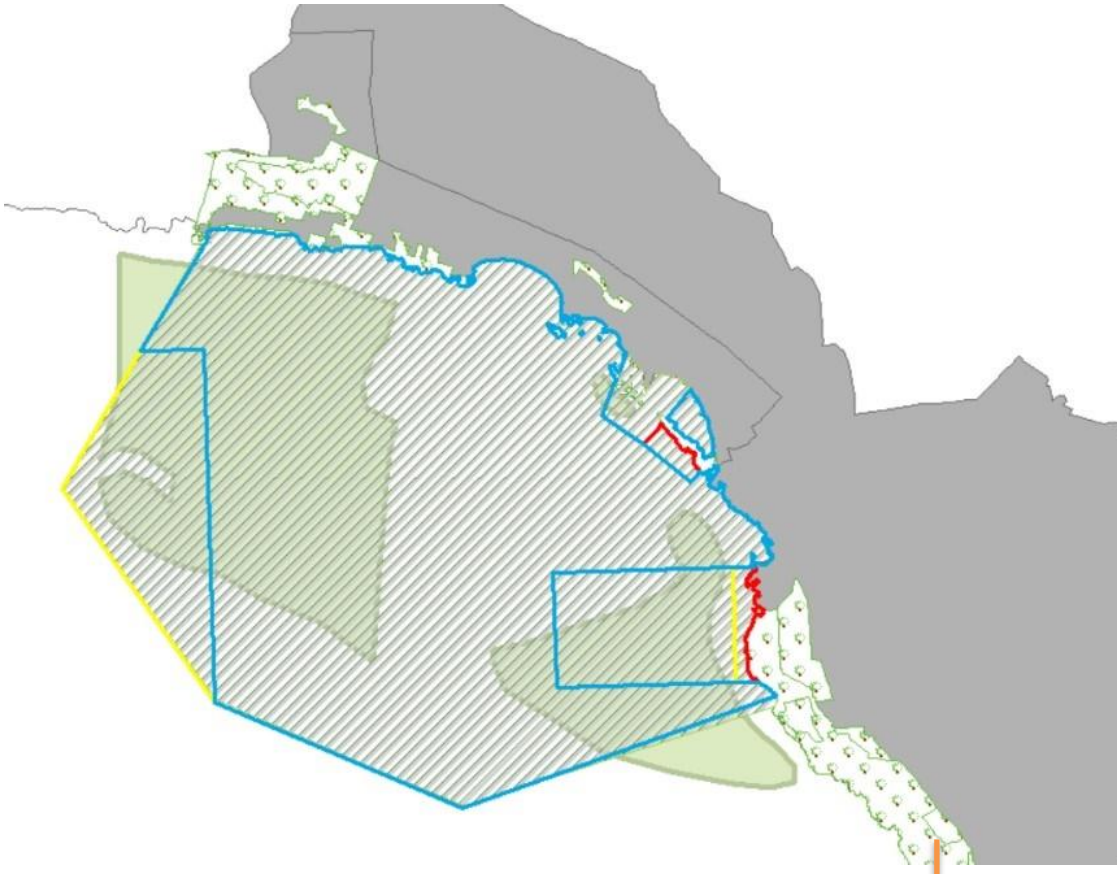


Figure 77 Natura 2000 Network falling on the Porto Cesareo MPA

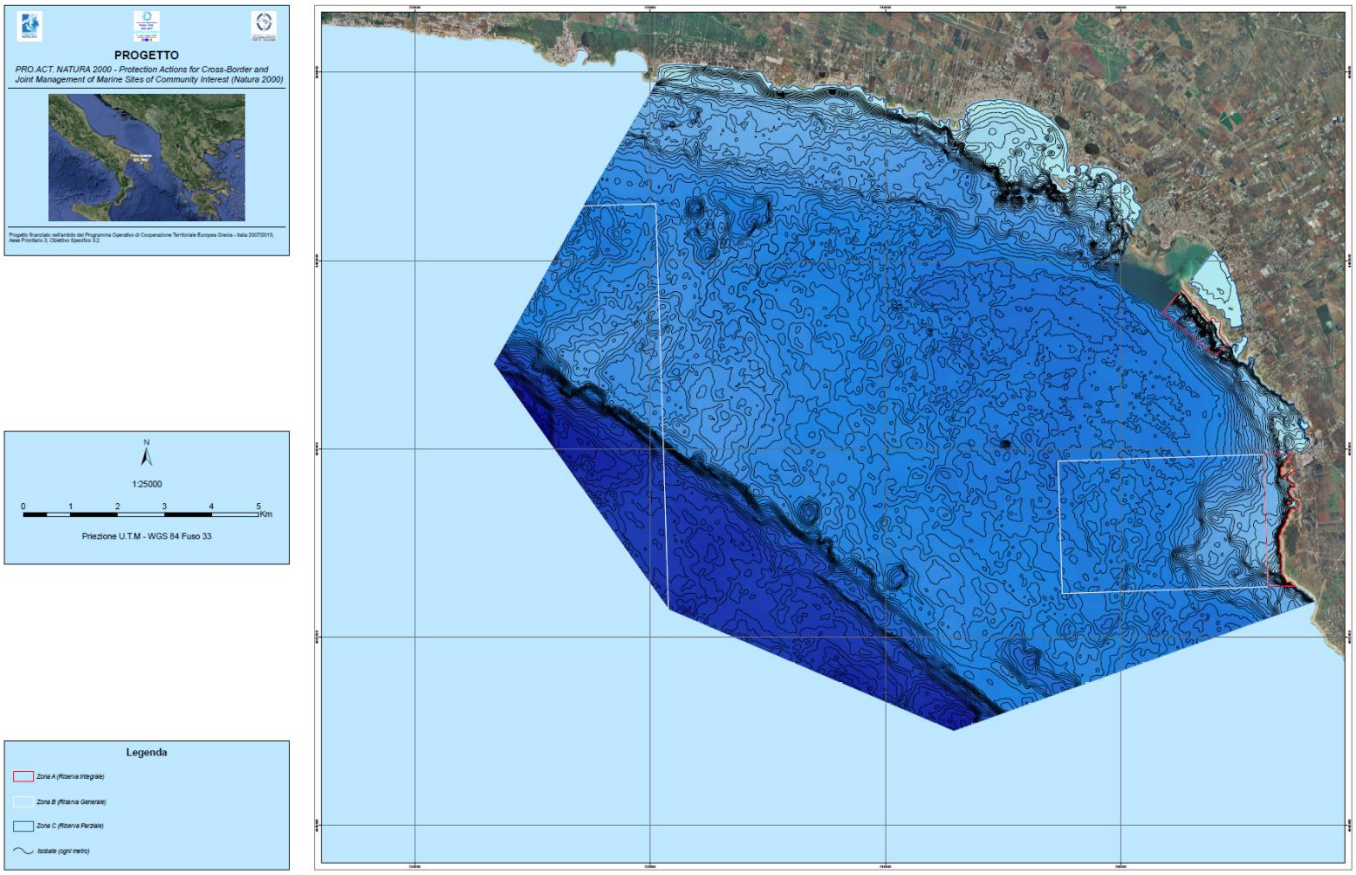


Figure 78 Bathymetric Map of Porto Cesareo MPA

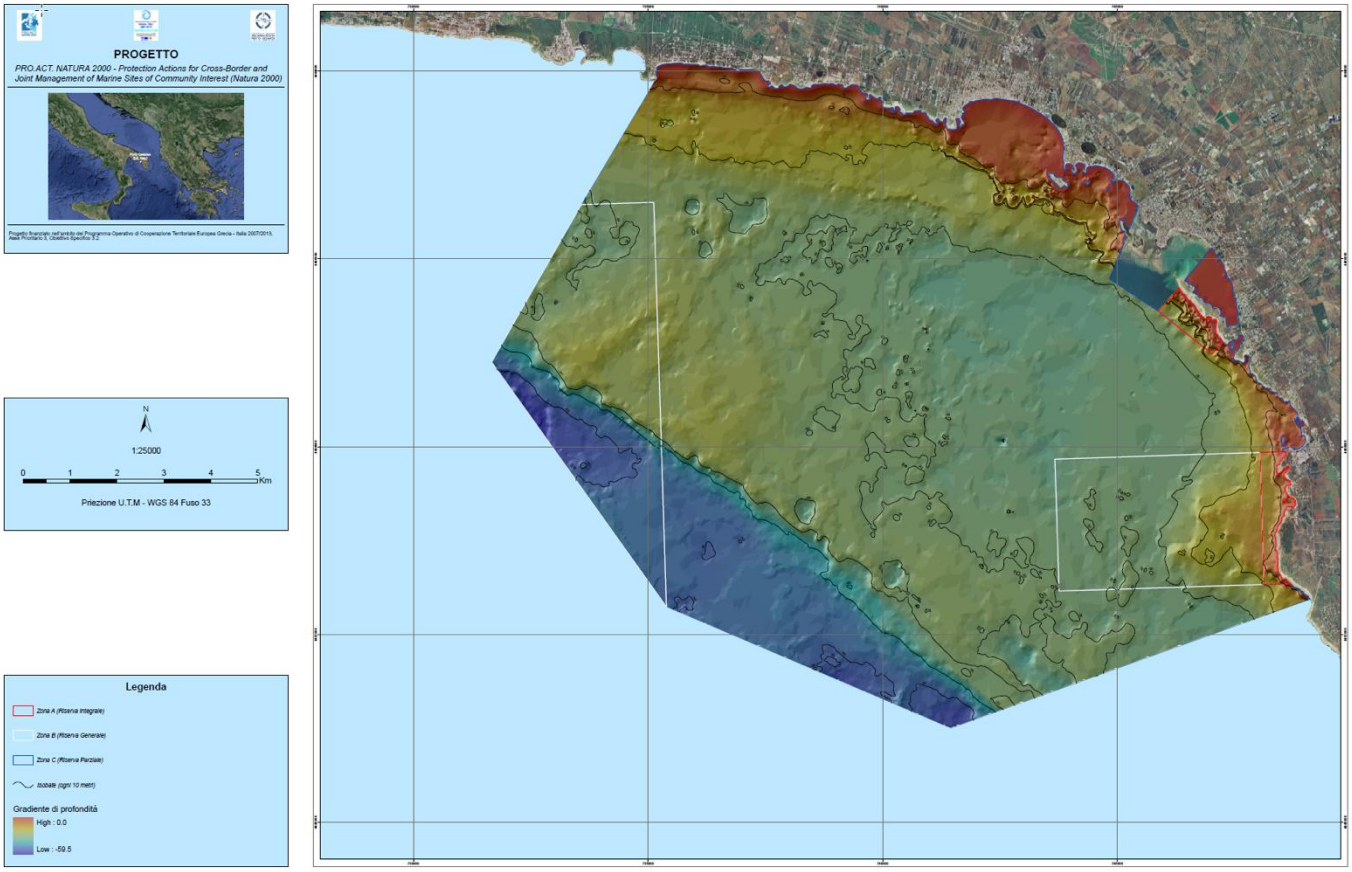


Figure 79 Digital elkevation model (DEM) of Porto CesareoMPA

Biodiversity target

The emerged, submerged and intertidal habitats summed to 16.654,10 ha. For preventing erosion rate, marine habitats seagrass meadows such as *P. ocenica* and *Cymodocea nodosa*, as well as coralligenous bioconstructions, play a major role. The attenuation effect of *P. oceanica* on the hydrodynamics is related to the wave height attenuation, wave energy decay and reduction of the

sediment transport in wave-current[28][29][30].
Within the MPA, *Posidonia oceanica* meadows mainly colonize the substrates of the 3 SACs and form coastal habitats such as banquettes. In the winter and autumn periods, banquettes are widely distributed along the coast, creating deposits up to several meters high[31], which play a very important ecological role in containing erosive phenomena in the coast.

Table 21 Bentic habitat with SPA-RAC code

SPA-RAC CODE	Habitat	Area (ha)
III. 2. 3. 4.	Association with *Cymodocea nodosa* on superficial muddy sands in sheltered waters	18,60
IV. 3. 1.	Coralligenous biocenosis	389,60
III. 6. 1.	Biocenosis of infralittoral algae	423,90
III. 2. 3.	Biocenosis of superficial muddy sands in sheltered waters	55,40
III. 2. 3.	Biocenosis of coarse sands and fine gravels mixed by the waves	138,10
III. 3. 2.	Biocenosis of coarse sands and fine gravels under the influence of bottom currents	7.988,50
III. 5. 1. 3	Facies of dead "mattes" of *Posidonia oceanica* without much epiflora	132,80
III. 6. 1. 1.	Overgrazed facies with encrusting algae and sea urchins	714,10
IV. 3. 2.	Semi-dark caves	10,60
IV. 3. 1/III.3. 2.	Mosaic of coralligenous biocoenosis and biocenosis of coarse sands and fine gravels under the influence of bottom currents	1.566,70
IV. 3. 1./ III. 5. 1	Mosaic of Coralligenous and *Posidonia* meadows	1.852,40
III. 5. 1.	Posidonia beds (Posidonion oceanicae)	3.363,40
		16.654,10

[28] GACIA E., DUARTE M. (2001), Sediment Retention by a Mediterranean Posidonia oceanica Meadow: The Balance between Deposition and Resuspension. Estuarine, Coastal and Shelf Science 52: 505–514.
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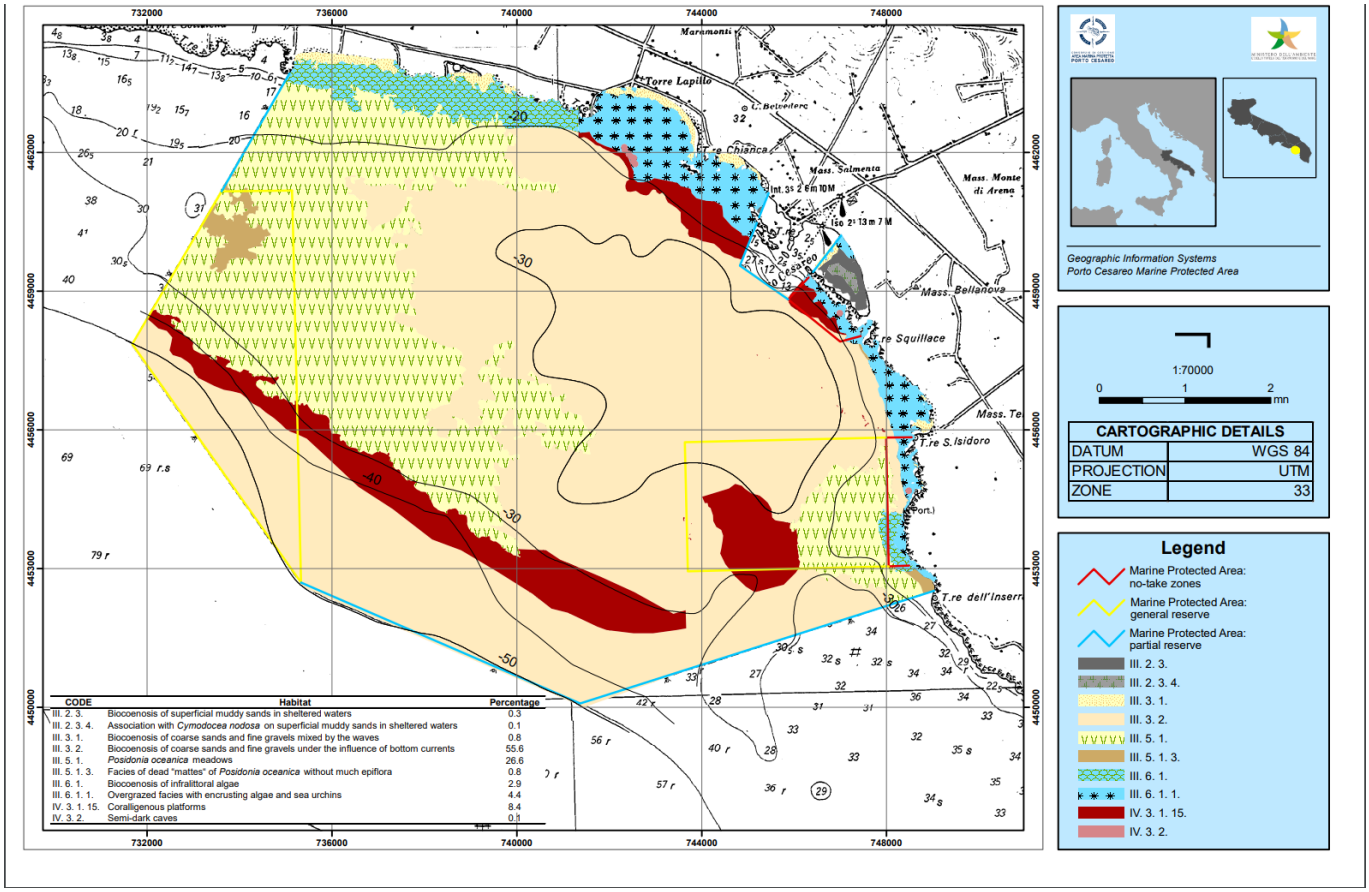


Figure 80 Habitat Map of Porto Cesareo MPA

Fish abundance within the MPA was surveyed based on catches made within the SAMPEI project[32]. The taxa surveyed are reported in **Error! Reference source not found.**.

Table 22 List of taxa in the MPA Porto Cesareo

Fish		**Molluscs**
Apogon imberbis	*Raja brachyura*	*Astrea rugosa*
Blennius ocellaris	*Sarda sarda*	*Bolinus brandaris*
Boops boops	*Sardinella aurita*	*Callista chione*
Bothus podas	*Sarpa salpa*	*Callistoctopus macropus*
Centrolophus niger	*Sciaena umbra*	*Cardium* sp.
Chelidonichtys lucerna	*Scomber japonicus*	*Eledone cirrhosa*
Chromis chromis	*Scomber scombrus*	*Eledone moschata*
Conger conger	*Scorpaena maderensis*	*Galeodea echinophora*
Coris julis	*Scorpaena notata*	*Glycimeris glycimeris*
Coryphaena hippurus	*Scorpaena porcus*	*Hexaplex trunculus*
Dactylopterus volitans	*Scorpaena scrofa*	*Loligo vulgaris*
Dasyatis pastinaca	*Seriola dumerilii*	*Natica stercusmuscarum*
Dentex dentex	*Serranus cabrilla*	*Octopus vulgaris*
Diplodus annularis	*Serranus hepatus*	*Pinna nobilis*
Diplodus puntazzo	*Serranus scriba*	*Sepia officinalis*
Diplodus sargus	*Solea solea*	*Spondylus gaederopus*
Diplodus vulgaris	*Sparisoma cretense*	*Tonna galea*
Engraulis encrasicolus	*Sphyraena sphyraena*	*Venus verrucosa*
Epinephelus costae	*Sphyraena viridensis*	
Gobius sp.	*Spicara maena*	
Labrus merula	*Spicara smaris*	**Crustaceans**
Lepidorhombus whiffiagonis	*Spondyliosoma cantharus*	*Carcinus aestuarii*
Lithognathus mormyrus	*Symphodus mediterraneus*	*Galathea strigosa*
Liza aurata	*Symphodus ocellatus*	*Liocarcinus corrugatus*
Merluccius merluccius	*Symphodus roissali*	*Melicertus kerathurus*
Microchirus ocellatus	*Symphodus tinca*	*Palinurus elephas*
Monochirus hispidus	*Synapturychthys kleinii*	*Scyllarides latus*
Mullus barbatus	*Synodus saurus*	*Scyllarus arctus*
Mullus surmuletus	*Torpedo marmorata*	
Muraena helena	*Trachinus araneus*	

[32] TERLIZZI A., TEDESCO P., MANGIA D., IZZI C. (2015), Progetto S.A.M.P.E.I. – Progetto pilota per il miglioramento della selettività degli attrezzi da posta all'interno dell'Area Marina Protetta di Porto Cesareo, per la riduzione delle catture accessorie e dei rigetti in mare, Relazione Finale, febbraio 2015

Oblada melanura	*Trachinus draco*	**Echinoderms**
Ophidion barbatum	*Trachurus mediterraneus*	*Paracentrotus lividus*
Ophisurus serpens	*Trachurus trachurus*	*Sphaerechinus granularis*
Pagellus acarne	*Trigloporus lastoviza*	
Pagellus erythrinus	*Trisopterus minutus*	
Pagrus pagrus	*Uranoscopus scaber*	
Phycis phycis	*Xyrichtys novacula*	
Pomatomus saltatrix	*Zeus faber*	

3.5.2 Main users of the area

The Porto Cesareo MPA represents a well-regulated ecological and economic system where different user groups interact with its resources. These groups, which include professional fishermen, recreational users, scientific researchers, and economic operators, utilize the area under strict governance to ensure the sustainable use of its ecosystem services.
Porto Cesareo, in particular, is a small town with 6.380 inhabitants in December 2023(Source: *https://www.comune.portocesareo.le.it/sezione-informazioni/utilita/dati-istat*), working both in tourism and fishing. In Nardò, in 2023, there were 30788 inhabitants (https://www.tuttitalia.it/puglia/59-nardo/statistiche/popolazione-eta-sesso-stato-civile-2023/).
Below are listed official data about use of the MPA, collected from the MPA in the year 2023:
- 76 vessels licensed for professional fishing
- 78262 permits (permit days) for recreational fishing, issued from MPA;
- 3903 permits (permit days) for underwater activities;
- 660 mooring buoys and 20609 permit days for mooring;

Professional fishing is allowed only in the B and C zones, and only for resident fishermen using selective artisanal gears. Fishing has a long and consolidated tradition in the area. In fact, there is a large small-scale coastal fishing fleet, consisting of about 200 fishermen. Commercial fishing plays a fundamental role in the local economy. In addition to being a source of employment and food supply, it is also crucial for the social and cultural role it plays in relation to the many activities that animate the coast. Most small-scale fishers work on their own, outside organised structures.
The MPA imposes stringent regulations to balance resource use with conservation. Only fishers with legal or operational bases in the municipalities of Porto Cesareo or Nardò are permitted to operate, and only within B and C zones, excluding the "La Strea" inlet.
Recreational activities represents a significant component of MPA usage. Bathing, snorkeling, and diving are the most popular activities, with bathing allowed freely in B and C zones and diving regulated through a permitting system. In recent surveys, over 10,000 individuals participated in guided diving activities annually, contributing to local economic dynamics.
The MPA is also a focal point for scientific research and education. Research initiatives have cataloged 103 species of fish, molluscs, crustaceans, and echinoderms through projects like SAMPEI.
Visual census studies conducted within the MPA have demonstrated higher biodiversity and biomass compared to non-protected areas. Educational programs regularly engage schools and universities, fostering awareness and promoting the importance of marine conservation among younger generations.

Economic stakeholders such as diving centers, tour operators, and boat rental services are integral to the MPA's operations. These businesses generate employment and revenue while adhering to

conservation guidelines. The presence of these stakeholders underscores the economic importance of the MPA, where sustainable tourism is a key component. Surveys indicate that the majority of tourists express a willingness to pay for access to the protected area, demonstrating the perceived value of its ecological services.

Every year the MPA presents to the Italian Ministry an ISEA scheme (Standardized interventions for the effective management of marine protected areas) that resumes the Governace of the MPA (target of biodiversity, direct and indirect treats and strategies).

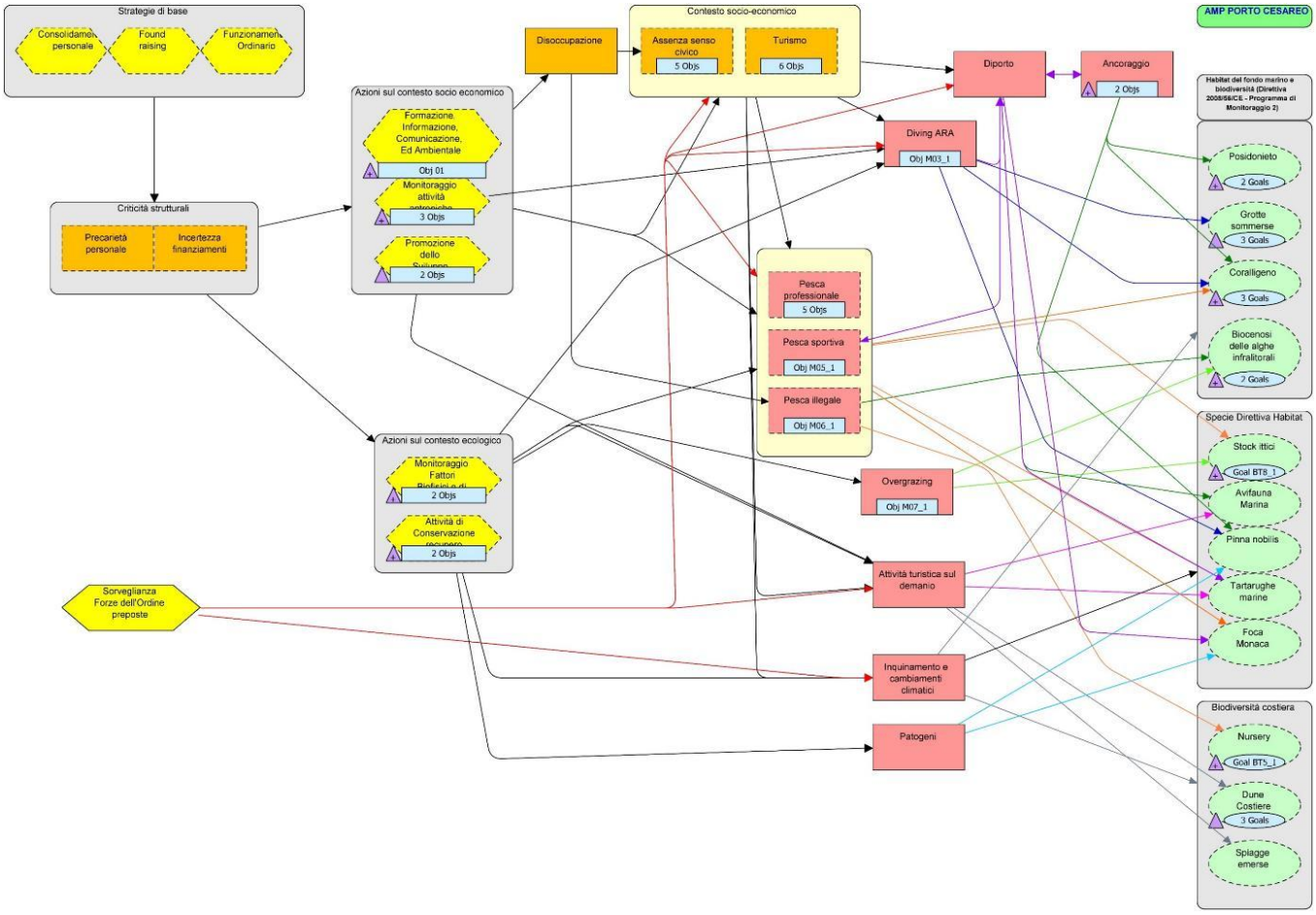


Figure 81 ISEA scheme of Porto Cesareo MPA

Porto Cesareo MPA is SPAMI (Special Protected Area of Mediterranean Importance) since 2011. The AREA is also in the ECST list (European card for Sustainable Tourism) since 2018 and it is EMAS certified (Eco-Management and Audit Scheme) since 2022.
The governance of the MPA is carried out by a management consortium that enforces regulations, oversees the zoning system, and that collaborates with stakeholders to promote sustainable practices. The consortium has also implemented strategic erosion control measures, including dune restoration and the construction of eco-barriers for fish restocking, funded through European and national programs. The environmental accounting model demonstrated the sustainability of the investment: for one euro of public funding, the wealth produced by the Porto Cesareo MPA is 3.7 euro.
In conclusion, the MPA of Porto Cesareo exemplifies an integrated management approach where ecological conservation and socio-economic activities are balanced. The diverse user groups, supported by scientific research and strict governance, contribute to the sustainability of the area. The data-driven regulation ensures that the ecological integrity of the MPA is preserved while allowing for economic and cultural benefits to the local communities. This model serves as a benchmark for balancing human activity with marine conservation.

3.5.3 Existing pressures

The MPA Regulations include mandatory larger net mesh sizes—20 mm between October and January and 24 mm for the rest of the year—to protect juvenile fish and support natural stock replenishment.
Despite this, in a recent project, funded with FEAMP funding (Fondo Europeo per gli Affari Marittimi e la Pesca), Managers of the MPA and fishermen, together, decided to increase the net mesh sizes from 24 to 33 mm.
The fishing effort was mapped in SAMPEI Project and it was putted in relationship with benthic habitat, to evaluate the fishing pressure on the habitats

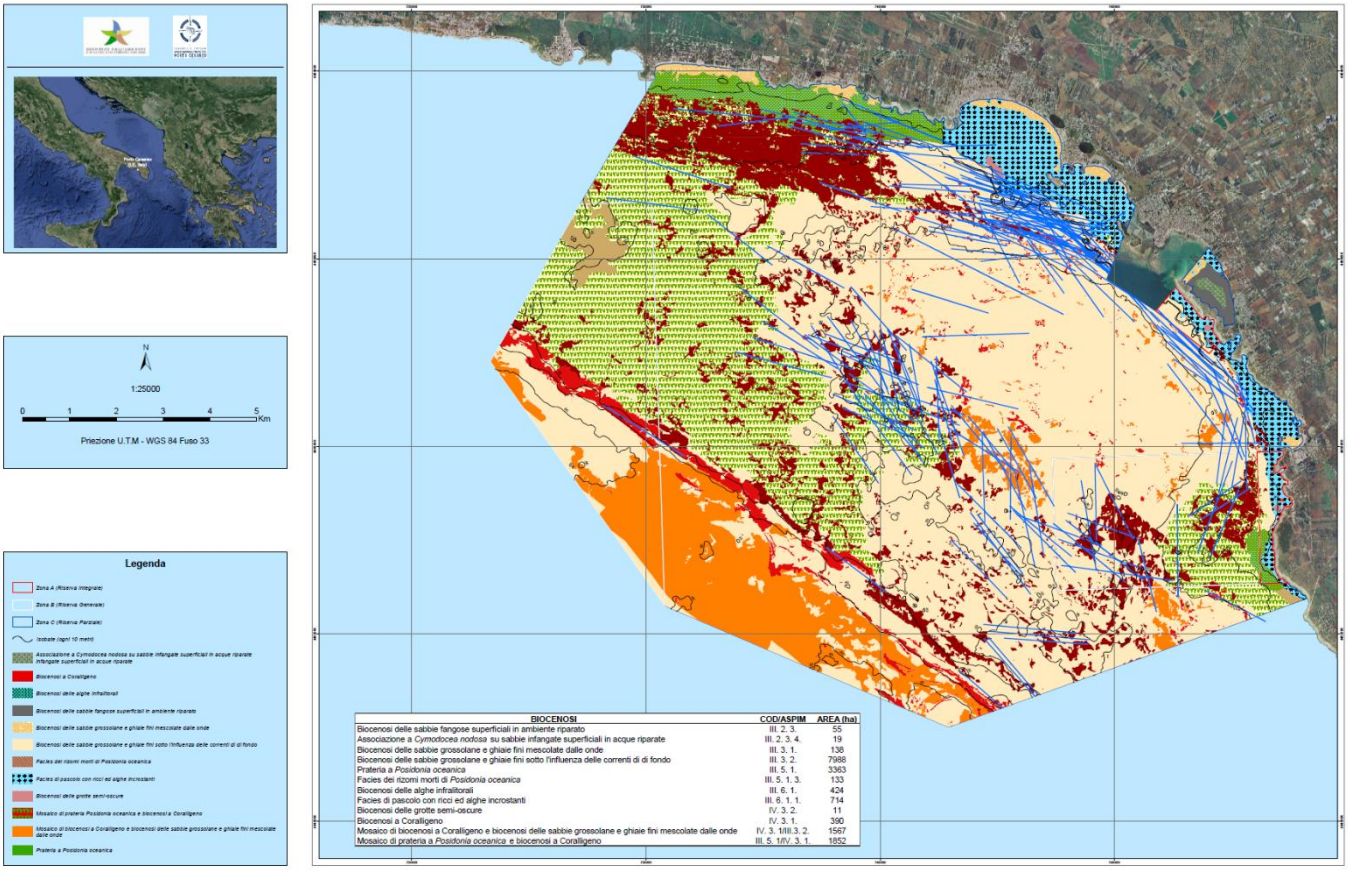


Figure 82 Overlay of Fishing effort and benthic habitat

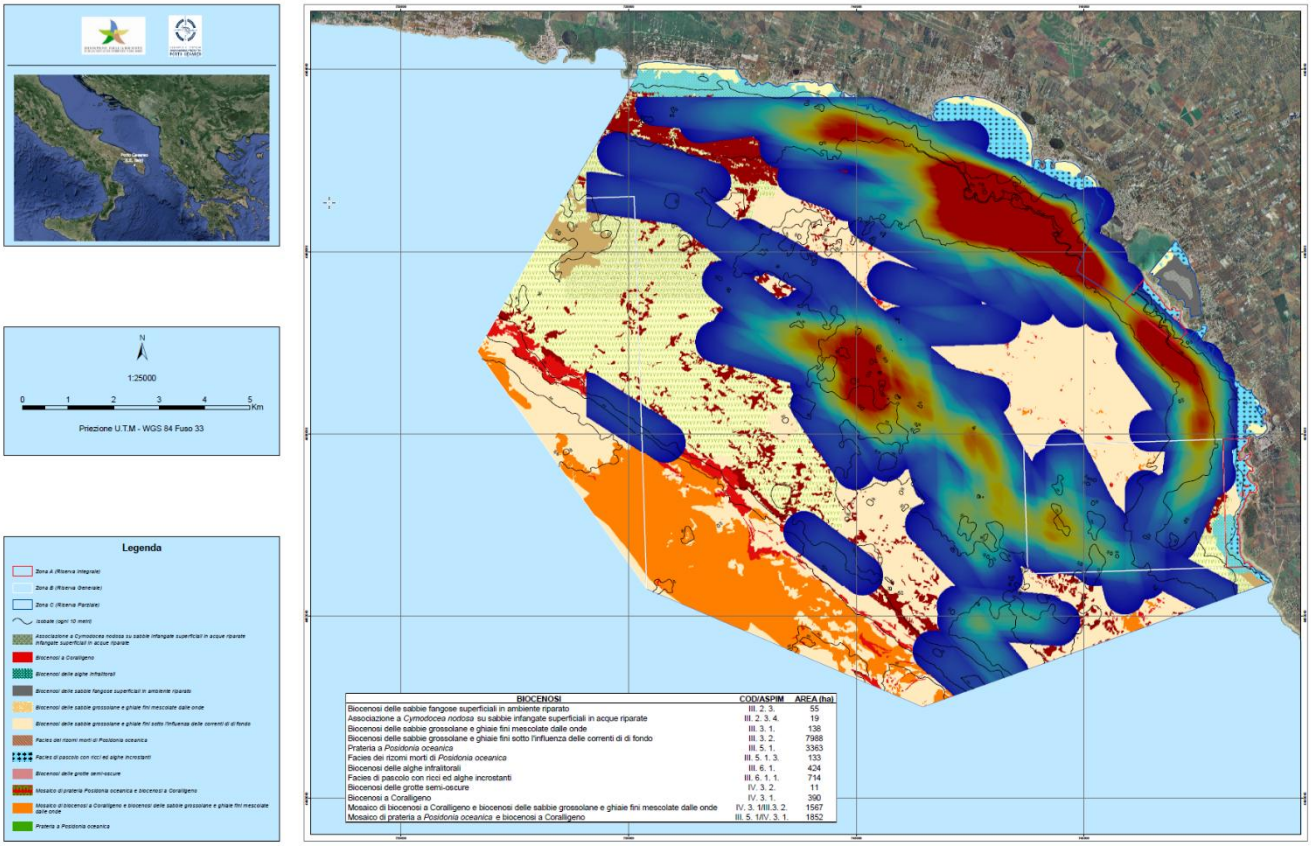


Figure 83 Distribution of fishing pressure on benthic habitat

In 2014, 104 authorized fishing vessels conducted 14,150 fishing trips, yielding a total catch of approximately 93.5 tons from within the MPA, with an average catch per trip of 6.6 kg. The economic value of these catches was estimated at €1,013,771, reflecting the added market value provided by the "reserve effect," which increases fish size and fetches premium prices [33]

The coastline is about 32 km long. It is characterized by a jagged coastline in which white beaches alternate with low cliffs, dunes that can reach several meters in height forming a characteristic dune ecosystem. Coastal erosion in the MPA is a generalized and historicized phenomenon. The fight against erosive processes can be achieved on the one hand through mitigation and blocking of erosive agents, and on the other hand through conservation and reconstruction of the natural environments of the beach system. In order to act in this direction in 2016 and within the framework

[33] TERLIZZI A., TEDESCO P., MANGIA D., IZZI C. (2015), Progetto S.A.M.P.E.I. – Progetto pilota per il miglioramento della selettività degli attrezzi da posta all'interno dell'Area Marina Protetta di Porto Cesareo, per la riduzione delle catture accessorie e dei rigetti in mare, Relazione Finale, febbraio 2015

of the European Charter for Sustainable Tourism, a Planning Document was drafted that envisages: closure of intersections between urban roads and the emerged beach; rehabilitation of the dune system and closure of dune crossings through naturalistic engineering techniques; beach nourishment; temporary sea wave contrast interventions; communication and awareness raising.

These pressures collectively result in a decline in biodiversity, reduced effectiveness of ecosystem services, and heightened vulnerability of the MPA to external shocks. The MPA's management strategies, such as restrictions on fishing gear and educational campaigns, aim to mitigate these pressures, but the scale and complexity of the challenges necessitate continuous monitoring and adaptive governance. The integration of scientific research and stakeholder cooperation is critical to balancing human use with ecological preservation in the Porto Cesareo MPA.

3.5.4 Target habitats and pressure impact evaluation

Drone-based monitoring activities

In 2024, dedicated drone-based monitoring activities were carried out within the Porto Cesareo Marine Protected Area (MPA) in order to support the characterization of coastal and shallow-water habitats and to contribute to the assessment of pressures on Natura 2000 sites. These activities were developed within the framework of two experimental Bachelor's theses conducted at the University of Salento (Academic Year 2023/2024), namely:

- **Caragiuli, I. (2024)** – *Application of conservation measures in a Natura 2000 site: use of spatially explicit data for the definition of the dunal foot (habitat 2250*) in the Porto Cesareo Marine Protected Area*;
- **Leone, G. (2024)** – *Construction and analysis of photogrammetric models applied to the conservation of priority habitat of the Natura 2000 network in the Porto Cesareo Marine Protected Area*.

The drone surveys were designed as a complementary monitoring tool within WP1, providing high-resolution spatial data capable of supporting habitat mapping, pressure detection and management-oriented analyses. Unmanned Aerial Vehicles (UAVs) were employed to acquire very high spatial resolution imagery of selected coastal sectors, with particular focus on areas characterized by priority habitats of conservation interest, including coastal dune systems (habitat 2250*), beach–dune transition zones, shallow sandy bottoms and nearshore areas adjacent to *Posidonia oceanica* meadows.



Figure 84 Drone photogrammetry

Flight planning was conducted in accordance with good practice standards for environmental monitoring, taking into account meteorological conditions, sea state, solar angle and visibility, in order to ensure optimal data quality. UAV missions were carried out at low to medium flight altitudes, allowing the acquisition of detailed imagery suitable for photogrammetric processing and fine-scale spatial analyses.

The acquired datasets were processed using Structure-from-Motion (SfM) photogrammetric techniques, leading to the production of:

- high-resolution orthomosaics of coastal and nearshore environments;
- georeferenced digital surface models (DSMs) of emerged and semi-emerged areas;
- detailed spatial products supporting the identification and delineation of habitat boundaries and ecotones.

In particular, the drone-based approach proved highly effective in supporting the identification and spatial definition of the **dunal foot** within the coastal dune system, a key element for the correct interpretation and management of habitat 2250*. The integration of UAV-derived products with

existing cartographic data allowed for a more accurate and objective delineation of habitat extents, reducing uncertainties linked to traditional field-based surveys alone.

Moreover, drone imagery enabled the detection and qualitative assessment of several anthropogenic pressures affecting coastal and transitional habitats, including:

- trampling and mechanical disturbance related to recreational use;
- informal access paths and fragmentation of dune systems;
- localized erosion phenomena and sediment redistribution;
- signs of human pressure in shallow coastal waters, such as anchoring impacts and coastal infrastructure proximity.

From a WP1 perspective, these activities demonstrated the added value of UAV-based monitoring as a **non-invasive, repeatable and cost-effective tool** for enhancing habitat characterization and pressure assessment at local scale. The high spatial resolution of drone data allowed the detection of fine-scale spatial patterns that are often not captured by satellite imagery or standard marine surveys, particularly in highly dynamic coastal environments.

The results obtained within the two academic theses highlight the strong potential for replicability and upscaling of drone-based methodologies within the Interreg IPA ADRION framework. UAV monitoring can effectively support adaptive management strategies by providing updated spatial information, baseline data for temporal comparisons, and operational support for conservation measures within Marine Protected Areas and Natura 2000 sites.

Overall, the integration of drone-based monitoring within WP1 activities contributes to strengthening the evidence base for habitat pressure assessment and supports informed decision-making processes aimed at improving the conservation status of priority habitats in the Porto Cesareo MPA.

In line with Interreg's emphasis on harmonisation and replicability, the 2024 UAV activities can be framed as the first step toward a shared "light monitoring protocol" for high-resolution coastal mapping, to be integrated with in-water surveys and existing habitat monitoring programmes. This integration supports adaptive management by enabling faster detection of emerging issues and better targeting of field validation.



Integrated environmental accounting

Using all existing ecological and using data, an Integrated Environmental Accounting was computed for Porto Cesareo MPA[34]:

Human activities:

1. **Diving operations** typically use vessels consuming 9.5 liters of fuel per trip, and the annual carbon footprint of these activities has been calculated at 103,763 kg CO2 equivalent. Additionally, recreational fishing, both from shore and boats, is permitted under controlled conditions. In 2016, there were 897 authorized recreational fishers, with an estimated total of 82,866 fishing days, each contributing an average carbon footprint of 6.8 kg CO2 equivalent.
2. **Fishing Activities**:
    - **Artisanal Fishing**: Despite regulations, professional fishing within the MPA places stress on fish stocks, particularly when fishing methods are not fully aligned with sustainability measures. For instance, artisanal fishing accounts for substantial resource extraction, as evidenced by 93.5 tons of fish caught within the MPA in 2014, representing 85% of the total regional catch.
    - **Recreational Fishing**: With 897 authorized recreational fishers, the cumulative impact of 82.866 fishing days per year (averaging 6.8 kg CO2 emissions per fishing day) highlights the strain on marine resources and carbon footprint.
3. **Tourism and recreational use**:
    - **Bathing**: Beach activities generate significant environmental costs, with an estimated carbon footprint of 4.569.640 kg CO2 annually.
    - **Diving and Boating**: These activities lead to physical degradation of sensitive habitats such as seagrass meadows. Diving alone contributes to 103.763 kgCO2 annually, while boating's carbon footprint reaches 3.645.783 kgCO2.
4. **Marine Litter and pollution**:
    - Land-based runoff, including agricultural pesticides and urban waste, introduces pollutants that degrade water quality.
    - Littering from tourism and fishing activities exacerbates habitat contamination, harming marine life.
5. **Coastal erosion and urbanization**:
    - Unregulated coastal development disrupts dune systems and natural barriers, leading to increased erosion and habitat loss.

[34] Visintin, F.; Tomasinsig, E.; Spoto, M.; Marangon, F.; D'Ambrosio, P.; Muscogiuri, L.; Fai, S.; Troiano, S. Assessing the Benefit Produced by Marine Protected Areas: The Case of Porto Cesareo Marine Protected Area (Italy). Sustainability *2022,* 14*, 10698.*

- Infrastructure construction and urban encroachment diminish the MPA's natural resilience against environmental pressures.

Environmental and Climatic Factors

1. **Climate change**:
   - Rising sea temperatures and ocean acidification threaten the delicate balance of habitats such as *Posidonia oceanica* meadows, which play a crucial role in carbon sequestration and coastal stability.
   - Sea-level rise exacerbates the erosion of beaches and dunes, critical components of the MPA's coastal protection.
2. **Erosion and sedimentation**:
   - Natural processes, combined with human-induced changes, lead to sediment displacement, reducing the stability of the seabed and coastal zones.
3. **Invasive species**:
   - The introduction of non-native marine species through ballast water or other vectors disrupts local ecosystems, often outcompeting native species.
4. **Habitat fragmentation**:
   - Physical barriers and human activities fragment habitats, reducing biodiversity and limiting the natural migration of marine species.The Marine Protected Area of Porto Cesareo faces several significant pressures, primarily stemming from human activities, environmental factors, and climatic changes. Based on the report's findings, the key pressures are detailed below:

The seagrass meadows extension was used to assess the "Regulation of chemical composition of atmosphere and oceans" ES. The *Posidonia oceanica* meadows cover 3.363 hectares and play a vital role in sequestering carbon. The estimated annual carbon sequestration by these meadows is 3.044 tons, with an associated economic value of €412.436 based on the Social Cost of Carbon.

Table 23 Carbon fixation and annual benefit

Carbon fixation (tC/a)	Carbon sink (tC/a)	CO_2 (tCO_2/a)	Benefit – SCC (€/a)
8,740,471	3,044	11,171	412.436,70

The annual flow account is resumed in the following tables

Table 24 Porto Cesareo MPA annual flow account

Costs	(€)	Benefits	(€)
Expenditures	**580,652.44**	**Revenues**	**783,479.93**
Current expenditures	453,103.21	Current transfers	627,091.50
Capital expenditures	91,820.10	Non-tax revenue	43,982.75
Third Party expenditures	35,729.13	Capital transfers	57,966.97
		Third party revenue	54,438.70
Environmental costs	**370,600.38**	**Environmental benefits**	**2,476,725.98**
MPA institutional activity	1,041.14	Wild marine animals used for nutritional purposes	1,013,771.94
Professional fishing	37,878.04	Control of erosion rate and Mass flows	--
Bathing	168,711.11	Regulation of chemical composition	412,436.70
Diving	3,830.93	Ch. that enable active or immersive interactions	1,048,277.34
Boating	134,602.31	*Ch. that enable scientific investigation*	*372,161.35*
Recreational fishing	24,536.85	*Ch. that enable education and training (MPA)* Ch. that enable education and training (ec. operators)	*2,500.00* 2,240.00
Total costs	**951,252.82**	**Total benefits**	**3,260,205.91**
		Net benefit	**2,308,953.10**
		Tourism impact	**70,442,807.47**
		Total	**72,751,760.57**

Table 25 Porto Cesareo MPA annual flow account: economic indicators

Economic indicator	Unit of measurement	Value
Benefits / Costs	(n)	3.4
Net benefits / public funding	(n)	3.7
Self-financing	(€/a)	12,880.00
Self-financing / Total expenditures	(%)	2.2

Table 26 Porto Cesareo MPA annual flow account: social indicators

Social indicator	Unit of measurement	Human resources	Fte
Scientific and institutional activity	(n)	20	10.3
Economic operators	(n)	162	n.a.

Table 27 Porto Cesareo MPA annual flow account: environmental indicators

Environmental indicator	Unit of measurement	Value
CO_{2eq} emission (Carbon footprint)	(tCO_{2eq}/a)	10,037
of which bathing	*(tCO_{2eq}/a)*	*4,570*
of which boating	*(tCO_{2eq}/a)*	*3,646*
CO_{2eq} fixation	(tCO_2/a)	3,044
CO_{2eq} fixation / CO_{2eq} emission	(%)	30.3
Catches (professional fishing)	(kg/a)	93,500
Catches (recreational fishing)	(kg/a)	107,726

In terms of communication, the eValue integrated environmental accounting model has shown that the Porto Cesareo MPA is not a limiting factor in terms of local economic development. In fact, the environmental benefit produced within the MPA amounted to approximately 2.5 million euro, most of which were economic activities related to professional fishing and tourism activities, plus a further 70 million euro of local economic impact strictly dependent on economic activities that enhanced ESs. In terms of environmental policy, management required public funding in terms of current and capital transfers to support nature conservation.

Beach Carrying Capacity Analysis

The carrying capacity analysis followed an integrated approach combining environmental, social and management criteria. The assessment included:

- analysis of beach morphology and available recreational surface;
- estimation of tourist attendance through field surveys and visual census;
- analysis of aerial imagery to estimate occupied and available beach surface;
- visitor questionnaires to determine average permanence time and perception of crowding;
- assessment of environmental and management constraints affecting beach use;

- calculation of Physical Carrying Capacity (PCC), Real Carrying Capacity (RCC) and Effective Tourist Carrying Capacity (TCC) according to internationally recognised methodologies.

The analysis highlighted that tourism pressure within the Porto Cesareo pilot area is strongly seasonal and spatially heterogeneous. Significant differences were observed among beaches due to variations in available surface, accessibility, concession areas, presence of sensitive habitats and visitor distribution patterns.

The assessment demonstrated that tourist carrying capacity cannot be considered a fixed value but depends on multiple environmental and management factors, including meteorological conditions, habitat conservation requirements and site-specific management measures. In particular, the presence of Natura 2000 habitats and protected species requires the adoption of precautionary approaches capable of reconciling public enjoyment with biodiversity conservation.

The study also confirmed that recreational use of beaches represents one of the principal anthropogenic pressures affecting the coastal system and should therefore be continuously considered within management and planning activities.

3.5.5 Implications for Pilot Actions and future monitoring

The carrying capacity analysis provides a practical decision-support tool for the adaptive management of the Porto Cesareo Marine Protected Area.

The results may support:

- sustainable regulation of visitor flows;
- planning of beach access and recreational use;
- identification of areas requiring particular conservation attention;
- reduction of anthropogenic pressures on coastal habitats;
- future monitoring of tourism dynamics;
- integration of conservation objectives with sustainable tourism management.

The methodology developed within BIOPRESSADRIA is also potentially transferable to other Adriatic protected coastal areas experiencing similar seasonal tourism pressures.

The BIOPRESSADRIA pilot action significantly improved the knowledge of tourism dynamics affecting the Porto Cesareo Marine Protected Area by providing a quantitative assessment of beach carrying capacity and of the main factors influencing sustainable recreational use.

The study confirms that effective conservation of coastal biodiversity cannot rely exclusively on regulatory measures but requires evidence-based management supported by objective environmental and socio-economic information. Carrying capacity assessment therefore represents



an important management tool for balancing ecosystem conservation, visitor experience and sustainable local development.
The results produced within BIOPRESSADRIA constitute a useful scientific basis for future planning and adaptive management of the pilot area, contributing to the long-term conservation of coastal habitats while supporting sustainable tourism policies within the Marine Protected Area.

4. Annex I - Advanced 3D technology supporting the monitoring of *Posidonia oceanica* meadows

The activities carried out within BIOPRESSADRIA provided the scientific framework for exploring innovative approaches aimed at improving the assessment of anchoring impacts on *Posidonia oceanica* meadows. Building on experience gained from implementing the SCARS protocol, a collaborative study by one of the BIOPRESSADRIA partners investigated the potential of advanced three-dimensional reconstruction techniques as complementary tools for seagrass monitoring. Although developed as an exploratory research activity, the study demonstrates how Digital Twin approaches can enhance the documentation, visualization, and quantitative assessment of seagrass habitats affected by anchoring[35].

4.1 Development of an integrated 3D monitoring approach

The proposed methodology combined underwater ecological surveys[36] with Structure-from-Motion (SfM) photogrammetry to generate detailed three-dimensional reconstructions of *Posidonia oceanica* meadows.

Field activities began with scientific dive surveys conducted in accordance with the SCARS protocol[37]. Divers documented the meadow's ecological condition, verified the presence of anchoring scars, and

[35] Part of these results and methodologies were derived from data collected within the framework of the BIOPRESSADRIA project, specifically from field data gathered at the **Dubrovnik-Neretva County pilot site (Badija–Korčula)**, and have been further developed and presented at the 9th European Conference on Scientific Diving (Ponta Delgada, Azores, June 15–19, 2026), in the study titled "*Quantifying anchoring damage in* Posidonia oceanica *meadows using diver surveys and 3D photogrammetry*" by Simone Modugno and Giuseppe Castaldelli (University of Ferrara), Rachele Castro (University of Catania) and Andrea Rismondo (**SELC Soc. Coop. project manager – BIOPRESSADRIA partner**).
[36] BIOPRESSADRIA Activity 1.1 - Pilot areas characterization and pressures monitoring development.
[37] BIOPRESSADRIA Deliverable D.1.1.1 - Protocol definition for monitoring beach and leisure boating tourism pressures in pilot areas, February 2026).

collected the biological information needed to interpret habitat conditions. At the same time, extensive underwater photographic and video datasets were acquired using high-overlap image sequences covering the entire study area.

The imagery was subsequently processed through photogrammetric techniques to generate georeferenced point clouds and digital surface models, resulting in high-resolution three-dimensional digital replicas (hereafter referred to as Digital Twins) of the surveyed meadow. Unlike conventional photographic documentation, these models reproduce the three-dimensional architecture of the habitat, including the seagrass canopy, matte structure, bare sediment and anchoring scars, within a single integrated digital environment.

This approach substantially increased the spatial information available for ecological interpretation. Rather than relying exclusively on measurements collected along predefined transects, the methodology made the entire surveyed area measurable. Moreover, the reconstructed model constitutes a permanent digital archive that can be revisited for additional analyses without requiring further underwater operations.

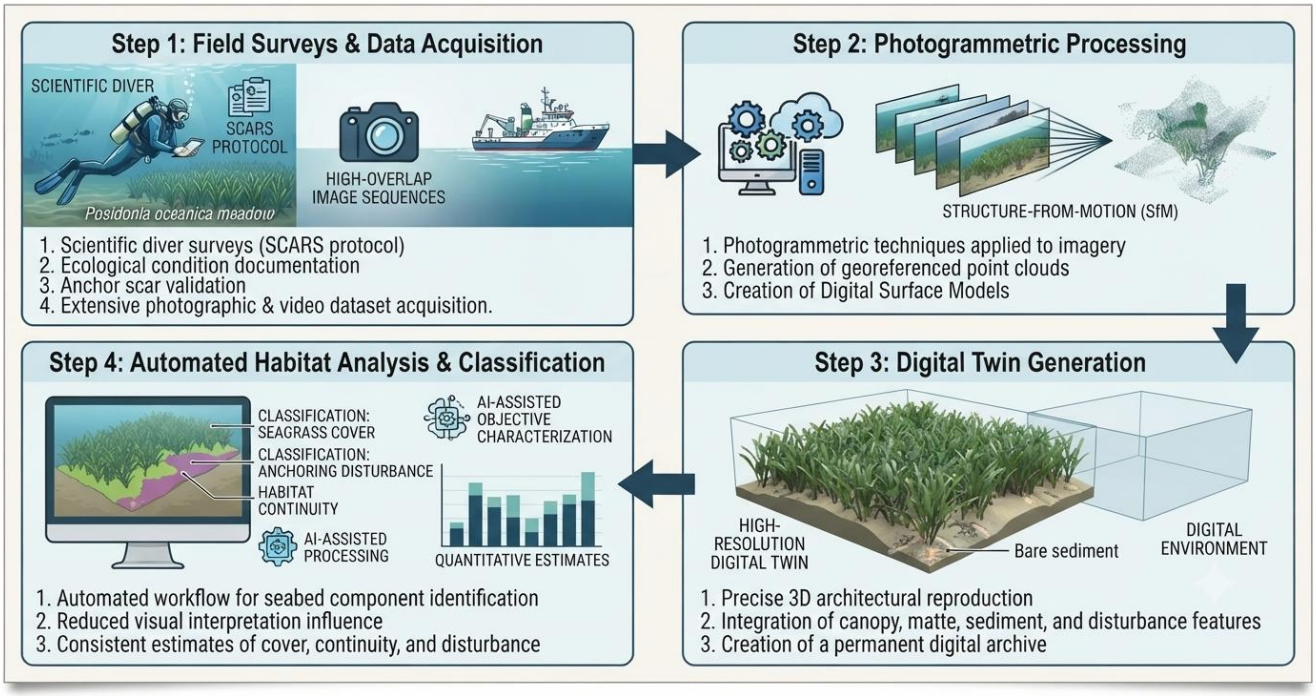


Figure 85. Workflow adopted for the generation of the Digital Twin from underwater.

To improve the objectivity of habitat characterization, the 3D models were analyzed through an automated processing workflow supporting the identification and classification of the principal seabed components (**Error! Reference source not found.** 83). By integrating image information

with three-dimensional geometry, the methodology reduced the subjectivity associated with visual interpretation and produced more consistent estimates of seagrass cover, habitat continuity and anchoring-induced disturbance.

4.2 Improving the assessment of *Posidonia oceanica* meadows

The experience gained within BIOPRESSADRIA demonstrated the potential of Digital Twin technologies to strengthen ecological monitoring of *Posidonia oceanica* meadows.

The three-dimensional reconstruction provided a far more comprehensive representation of the meadow than conventional photographic surveys. Rather than describing isolated observations, the reconstructed model enabled the habitat to be analyzed as a continuous spatial system, allowing the assessment of meadow continuity, patch morphology, scar distribution and habitat fragmentation within a single digital framework.

An additional advantage concerns the estimation of seagrass cover. Conventional underwater observations may overestimate the actual extent of living seagrass because the canopy partially obscures the underlying seabed. By integrating three-dimensional geometry with image analysis, the proposed approach more accurately represented the physical structure of the meadow, reducing this source of uncertainty and providing more objective estimates of habitat extent.

The reconstructed models also enabled quantitative measurements that are difficult to obtain through traditional field observations alone. Anchoring scars could be measured with high spatial precision, while the distribution of living seagrass and bare sediment was objectively mapped across the entire reconstructed area. These measurements provide valuable ecological indicators supporting a more comprehensive assessment of anchoring impacts on *Posidonia* meadow structure.

Beyond habitat mapping, the models provide a basis for deriving indicators related to ecosystem services, including proxies associated with carbon storage potential and habitat functionality. Although these applications require further methodological validation, they illustrate how advanced digital reconstruction can contribute to linking habitat condition with ecosystem functioning and the ecosystem services provided by seagrass meadows.

Another important advantage concerns communication. Three-dimensional visualizations make underwater habitats and anchoring damage, often difficult to appreciate during field surveys, accessible to managers, stakeholders and the general public, facilitating awareness, stakeholder engagement and evidence-based management decisions (Figure 86).



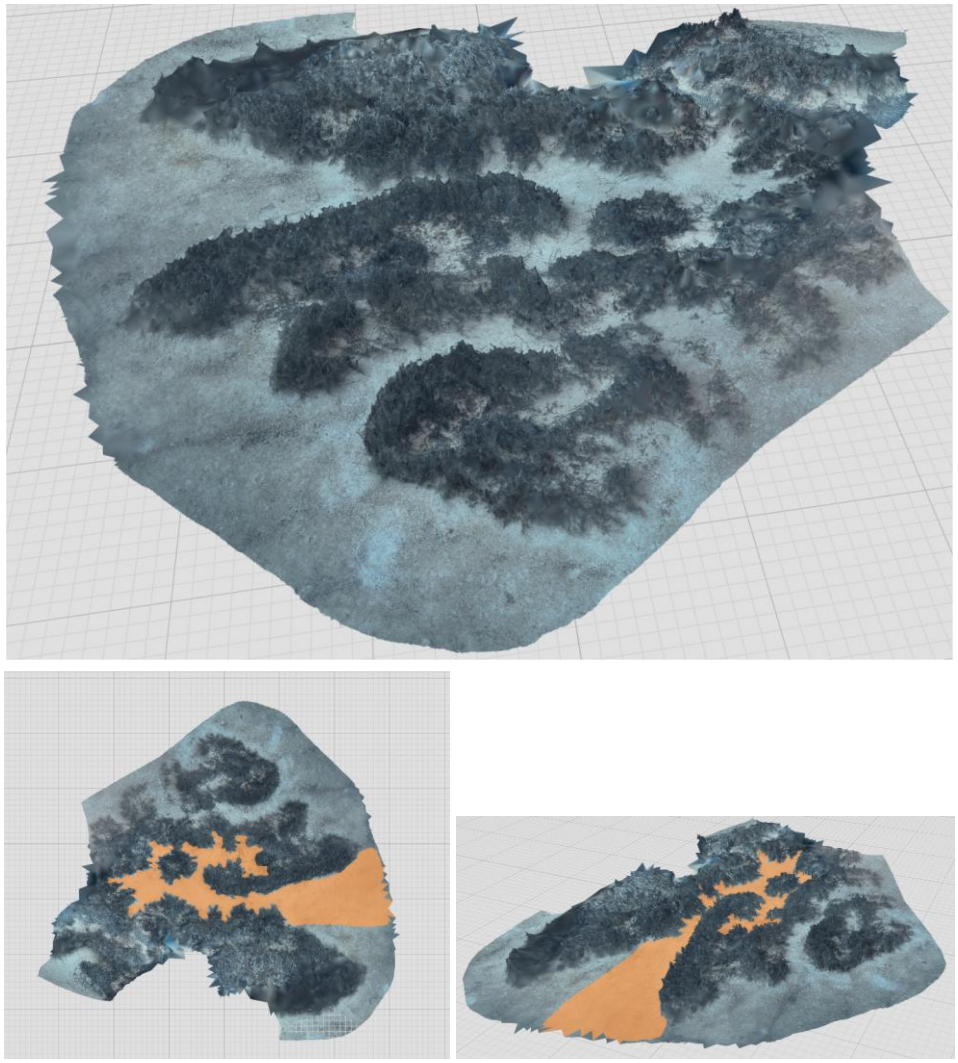


Figure 86 Three-dimensional reconstruction of a Posidonia oceanica meadow showing anchoring-induced scars highlighted in orange. The Digital Twin was generated through Structure-from-Motion photogrammetry and supports spatial quantification and visualization of anchoring impacts.

4.3 Future perspectives

The application of three-dimensional photogrammetry presented here should be regarded as an exploratory activity developed alongside BIOPRESSADRIA. Although not originally foreseen within the project work plan, this pilot study built upon the datasets and field experience acquired during the project to explore the potential of Digital Twin approaches for supporting the monitoring of *Posidonia oceanica* meadows.

The results suggest that these approaches may improve the spatial completeness of ecological surveys, support more repeatable measurements and create permanent digital records that can be revisited for future analyses. The integration of these models with complementary datasets, such as multibeam echosounder surveys or multitemporal observations, could further expand their applicability to habitat monitoring and conservation.

While additional methodological development and validation are still needed, this preliminary experience confirms the feasibility of integrating three-dimensional reconstruction with established ecological monitoring methods. Rather than replacing traditional field surveys, Digital Twin technologies can be considered complementary tools that may support habitat assessment and contribute to the future development of monitoring methodologies. More generally, this work represents an example of how the knowledge and datasets generated within BIOPRESSADRIA can provide a basis for further methodological developments beyond the project's original scope.



5. Annex II – Ecosystem services – perception of stakeholders

5.1 Objectives and methodology

Within the BIOPRESSADRIA project, stakeholder engagement has been carried out through several complementary methods across the pilot sites, including workshops, consultation meetings, questionnaires and participatory events. This approach aimed to promote continuous two-way communication with coastal users and institutional actors, fostering cooperation among stakeholders on both sides of the Adriatic and ensuring that project activities reflect the needs, perceptions and knowledge of local communities.

In this framework, a survey based on a structured questionnaire was developed to better understand how marine, coastal and beach "users" (including public authorities, tourism operators, nautical stakeholders and the general public) perceive seagrass meadows and the ecosystem services they provide, in order to gather insights into public awareness and attitudes toward the risks posed by coastal and nautical. All this could help to build up more effective conservation strategies tailored to the needs and knowledge of coastal users.

The questionnaire was designed to collect information on the level of awareness of these habitats, on the perceived benefits associated with them (such as biodiversity support, coastal protection and water quality improvement), and on attitudes towards the pressures affecting them, particularly those related to coastal tourism and nautical activities. The questionnaire was prepared in three languages (Italian, Croatian and English) in order to ensure broad accessibility and participation across the project's transboundary area (Figure 87).



Figure 87 Leaflet in Italian and Croatian languages.

Methodologically, the questionnaire is structured into several sections. The first section collects basic information on the respondent's profile (category, gender, age group, and geographic area). This is followed by a section dedicated to knowledge of seagrasses and the concept of ecosystem services. A central section focuses on the perceived importance of ecosystem services provided by marine habitats, such as protection from coastal erosion, carbon sequestration, improved water quality, support for biodiversity, and recreational value.

The questionnaire also includes questions regarding navigation and anchoring practices, with particular attention to boaters' behaviors in the presence of seagrass meadows and their willingness to modify these behaviors to reduce impacts on sensitive habitats. The propensity to use buoy fields as an alternative to direct anchoring on the seabed is also explored.

A final section invites participants to share qualitative observations on the marine environment, such as reporting any fauna aggregations observed near the buoy fields, as well as suggestions or proposals for improving coastal protection. The questionnaire also allows, on a voluntary basis, the uploading of photographs or videos and the option to leave an email address to receive updates on project activities or participate in future stakeholder engagement initiatives.

The questionnaire was developed online (Google Forms) and made available in more languages to ensure broad participation at the project's various pilot sites, both in Italy and Croatia. The average completion time is approximately 5–10 minutes, to encourage participation even from occasional coastal users.

During the first phase of the survey, from summer 2024 to fall 2025, the questionnaire was mainly disseminated following a *snowball sampling approach* (Goodman, 1961), starting from a network of local stakeholders and institutional contacts and progressively reaching additional respondents through their personal and professional networks. The questionnaire was shared through multiple dissemination channels, including email lists, social media, project communication materials and direct distribution during project events. A key role in the dissemination process was played by all project partners, who promoted the survey within their local stakeholder networks in the Italian and Croatian pilot areas.

Although this approach yielded an initial set of responses, the distribution among stakeholder categories was initially uneven. For this reason, the survey period was extended until spring 2026, leveraging participants already involved in the project's workshops, training courses, consultation meetings, and participatory events (such as the Venice Boat Show in May 2026). This allowed us to collect a total of 177 responses, significantly improving the representativeness of the dataset and ensuring a more balanced contribution from the various categories of coastal users.

The collected data will help to outline a comparative framework of sea user perceptions and behaviors in different contexts of the Adriatic-Ionian area, providing useful insights for developing the project's pilot actions and for defining more effective management and communication strategies to support the conservation of seagrass meadows.



Reference: Goodman, L.A. (1961). *Snowball Sampling*. Annals of Mathematical Statistics, 32(1), 148–170. https://doi.org/10.1214/aoms/1177705148

5.2 Stakeholder questionnaire: results

The socio-demographic characteristics of the respondents indicate that the sample is overall well balanced and representative of the target population (Fig. 88). The gender distribution is evenly balanced between male and female respondents, thereby limiting potential gender-related biases. Furthermore, the sample includes participants from a wide range of age groups, ensuring heterogeneous age distribution. This diversity enhances the robustness of the dataset and allows for the analysis of perceptions across different demographic segments.

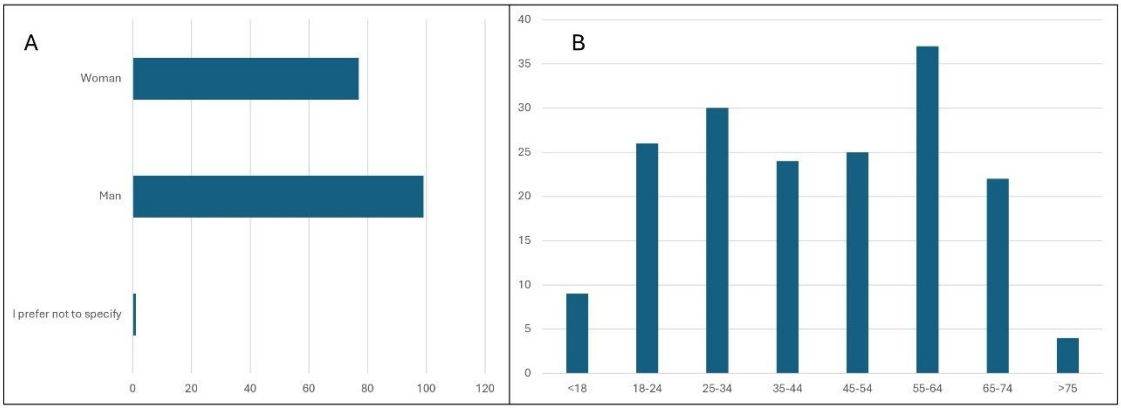


Figure 88 Distribution of respondents by gender (A) and age groups (B) (number of answers).

The distribution of respondents across stakeholder categories shows that the largest share of participants consisted of tourists (more than 50 per cent of whom declared to be daily visitors), including both beach visitors and recreational boat users (Figure 89). This reflects the relevance of these groups as primary users of coastal and marine environments, whose perceptions are particularly important for assessing public awareness of seagrass meadows. A substantial number of responses was also collected from representatives of local authorities and from the fishing sector, ensuring that the survey captures the perspectives of key stakeholders directly involved in the management and use of coastal ecosystems. The participation of these different stakeholder groups contributes to a comprehensive understanding of perceptions and attitudes towards seagrass meadows within the BIOPRESSADRIA project area. Regarding the respondents' country of origin, the majority (71%) declared Italy as their country of residence, while a further 20% originated from

Croatia. The remaining responses were distributed among other countries, reflecting the cross-border dimension of the BIOPRESSADRIA project area.

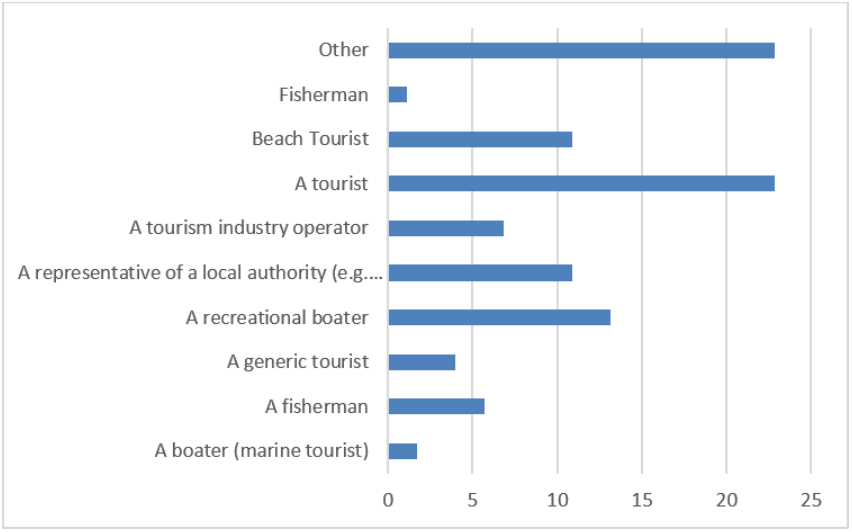


Figure 89 Distribution of questionnaire respondents by activity category (number of answers).

The analysis of the areas where respondents reported carrying out their recreational or professional activities (Figure 90) shows that, among Italian participants, respondents are evenly distributed between the two pilot sites at Porto Cesareo and Panzano Bay, just as it is evenly distributed amongst the pilot sites on the Spalmadori and Kornati islands.

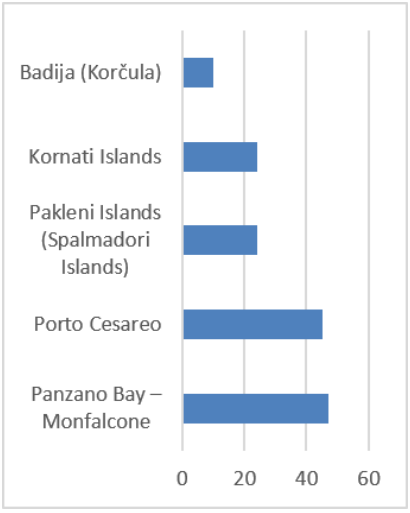


Figure 90 Distribution of questionnaire respondents by geographical area of activity (number of answers).

In addition to the socio-demographic characteristics of the respondents, the survey also allowed for an analysis of the stakeholder categories represented within each of the main areas reported by participants as their area of origin or activity (Figure 91). The distribution of stakeholder groups varies across the different locations, reflecting the specific characteristics and uses of each coastal area. In Panzano Bay (Monfalcone), respondents are relatively evenly distributed among beach tourists, recreational boat users, and fishers, providing a diversified representation of coastal users. In Porto Cesareo, the majority of respondents belong to the general tourist category, highlighting the prevalence of recreational coastal use. Similarly, the Kornati Islands are mainly represented by tourists, with considerable contribution from recreational boat users, consistent with the importance of boating activities in the area. In the Spalmadori Islands, alongside tourists, responses were also collected from representatives of public administration, providing an institutional perspective on marine area management. Finally, in Badija, the sample is mainly composed of tourists, with additional contribution from fishers. This distribution highlights the different socio-economic profiles of the surveyed areas and provides a broader understanding of the perspectives represented in the questionnaire.

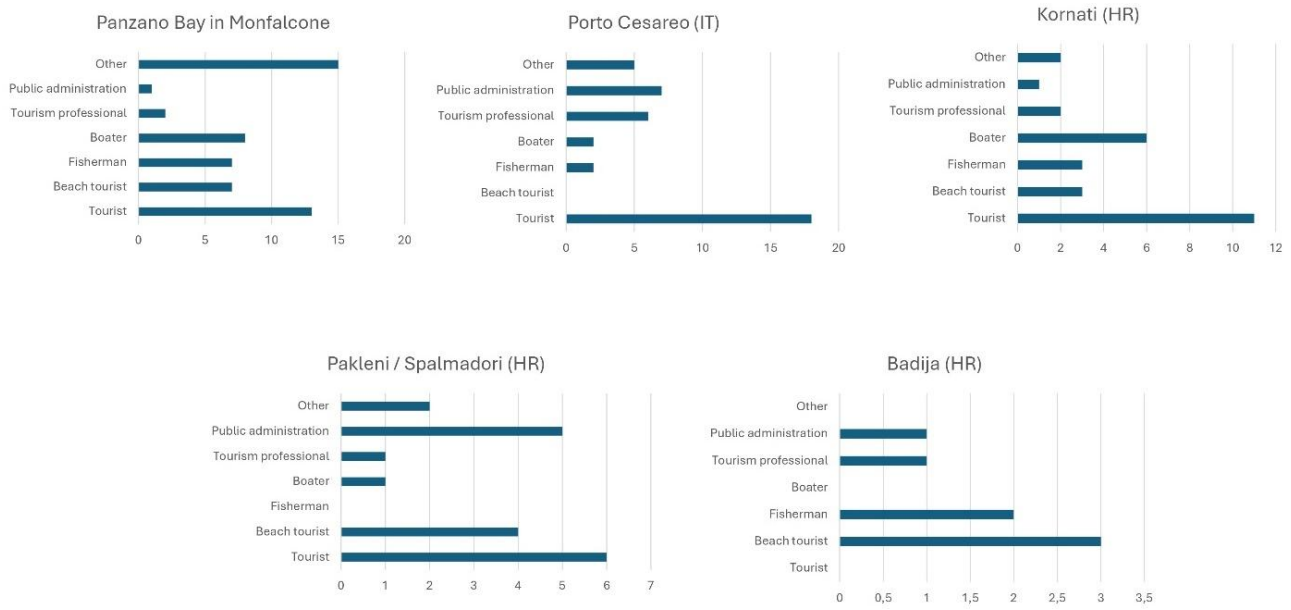


Figure 91 Distribution of stakeholder categories across the different survey sites (number of answers).

The survey results indicate a moderate to high level of awareness of seagrass meadows among respondents. Approximately 40% of participants reported being familiar with seagrass meadows, while 35% stated that they had heard about them but did not possess a thorough understanding. The remaining 25% declared that they were not familiar with seagrass meadows at all (Fig. 89A).

A similar pattern emerged with regard to awareness of ecosystem services. Nearly half of the respondents indicated that they were familiar with the concept and the benefits provided by coastal and marine ecosystems, whereas around 20% reported having no knowledge of ecosystem services. The remaining respondents expressed only partial familiarity with the concept, suggesting that, although awareness is relatively widespread, there is still scope for improving public understanding of the ecological functions and benefits associated with seagrass meadows (92 B).

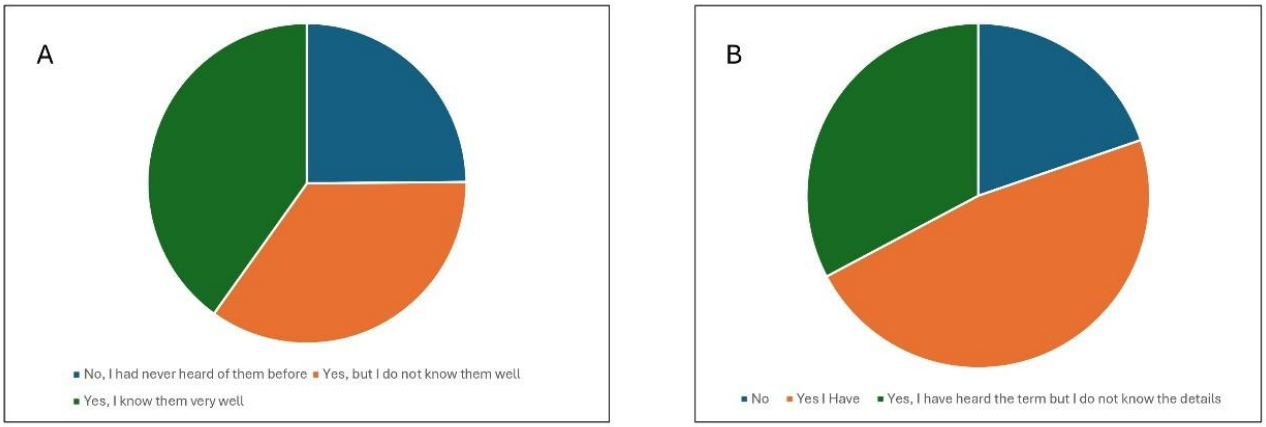


Figure 92 Percentage distribution of respondents' awareness of seagrass meadows (A) and ecosystem services (B).

The following section of the questionnaire explored respondents' perceptions of the importance of seagrass meadows in providing a range of ecosystem services. As illustrated in the Figure 93, the ecosystem services most frequently perceived as being highly important are oxygen production, coastal erosion protection, biodiversity enhancement, and the improvement of water quality. These findings indicate that respondents generally recognize the key ecological functions of seagrass meadows, particularly those associated with environmental regulation and the maintenance of healthy coastal ecosystems.

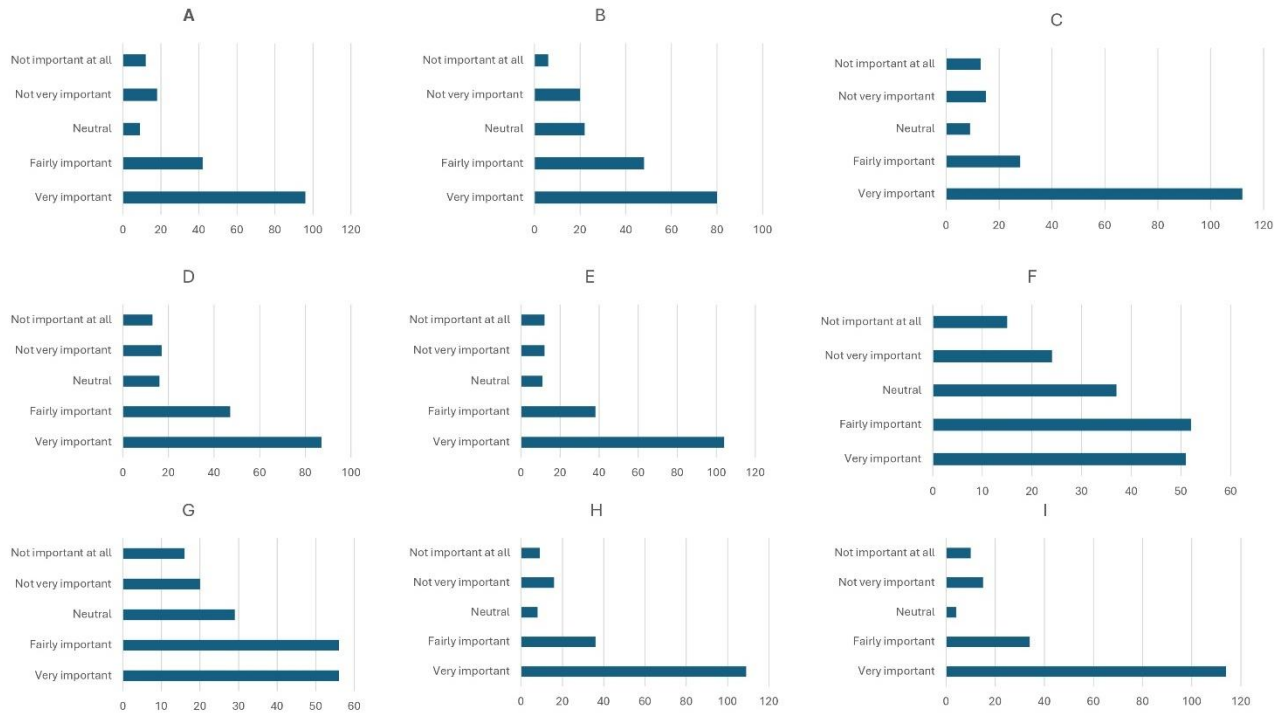


Figure 93 Respondents' perception of the importance of ecosystem services related to marine habitats, with reference to the ecosystem services associated with seagrass meadows: A) protection from coastal erosion, B) carbon sequestration, C) oxygen production, D) increased water clarity, E) water filtration and improved water quality, F) aesthetic value, G) opportunities for snorkeling, H) refuge and nourishment for marine fauna, and I) increase in biodiversity (number of answers).

Respondents were also asked to assess the extent to which seagrass meadows provide specific ecosystem services. Overall, the results (Figure 94) indicate a stronger perception of the contribution of seagrass meadows to regulating and supporting ecosystem services, particularly those related to ecological processes and environmental quality. By contrast, lower scores were assigned to cultural ecosystem services, especially with regard to their aesthetic value and their role in providing opportunities for recreational activities such as snorkeling. These findings suggest that the ecological functions of seagrass meadows are generally better recognized than the cultural and recreational benefits they can provide.

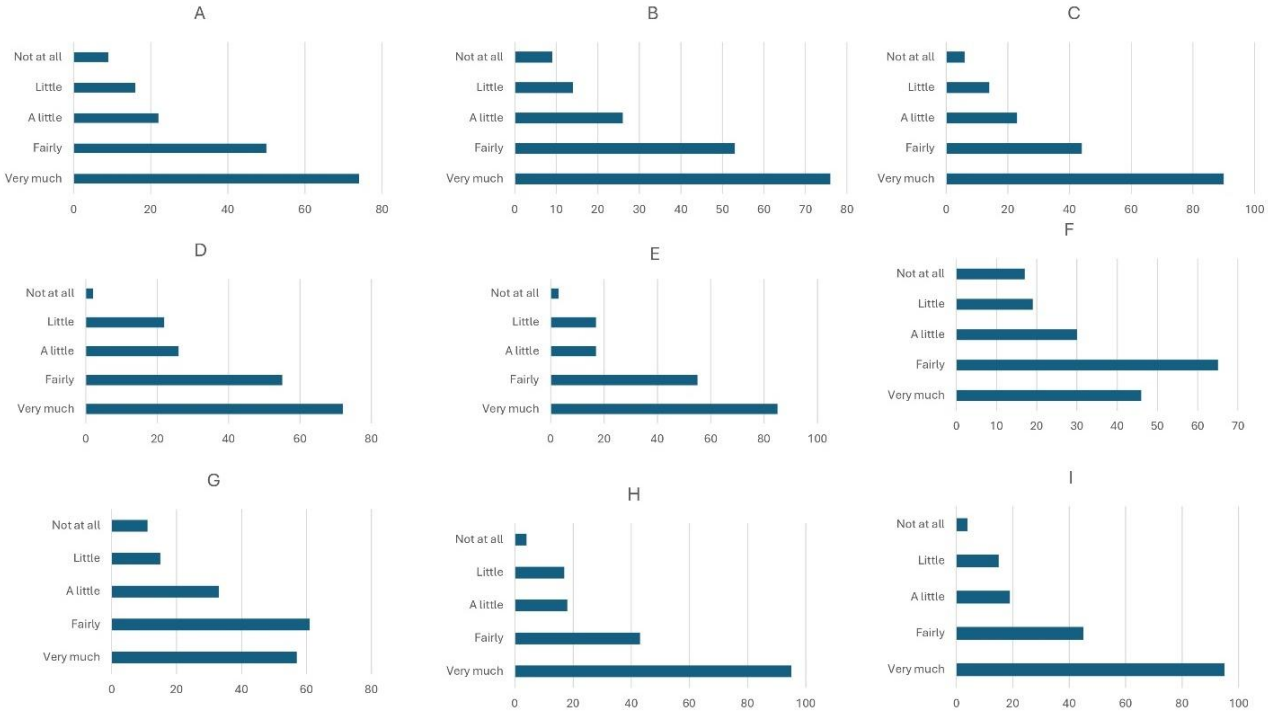


Figure 94 Respondents' perception of the extent to which seagrass meadows provide different ecosystem services: A) protection from coastal erosion, B) carbon sequestration, C) oxygen production, D) increased water clarity, E) water filtration and improved water quality, F) aesthetic value, G) opportunities for snorkeling, H) refuge and nourishment for marine fauna, and I) increase in biodiversity (number of answers).

With regard to perceptions of the conservation status of seagrass meadows, respondents expressed differing views. Approximately 50% of the sample considered seagrass meadows to be degraded, although with varying degrees of severity, while more than 30% perceived them to be in a good conservation status (**Error! Reference source not found.**5). These results suggest that public perception of the current condition of seagrass meadows is not uniform, reflecting different levels of awareness and direct experience with these habitats.

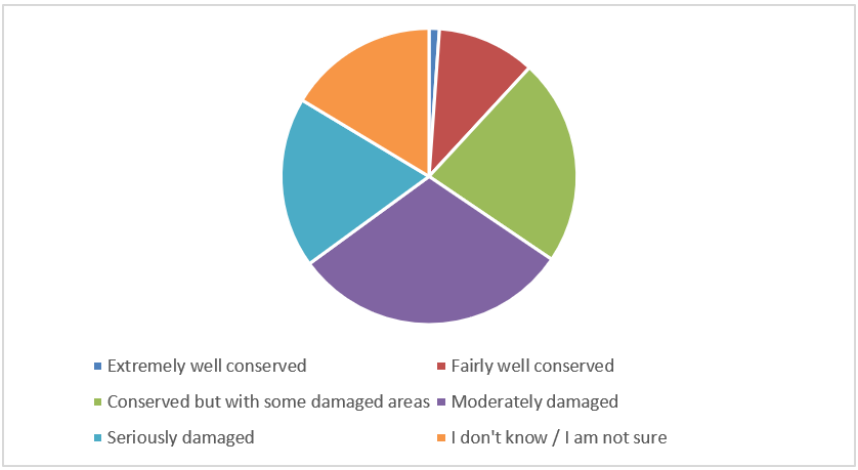


Figure 95 Respondents' perception of the conservation status of seagrass meadows in the areas they visit (%).

The questionnaire also investigated the perceptions and behaviors of respondents who use recreational boats (Figure 96 and Figure 97). The vast majority stated that, when seagrass meadows are present, they avoid anchoring on vegetated seabeds by selecting unvegetated areas and, where available, by using mooring buoys. Similarly, almost all respondents indicated that they would be willing to refrain from anchoring on seagrass meadows in order to support their conservation.

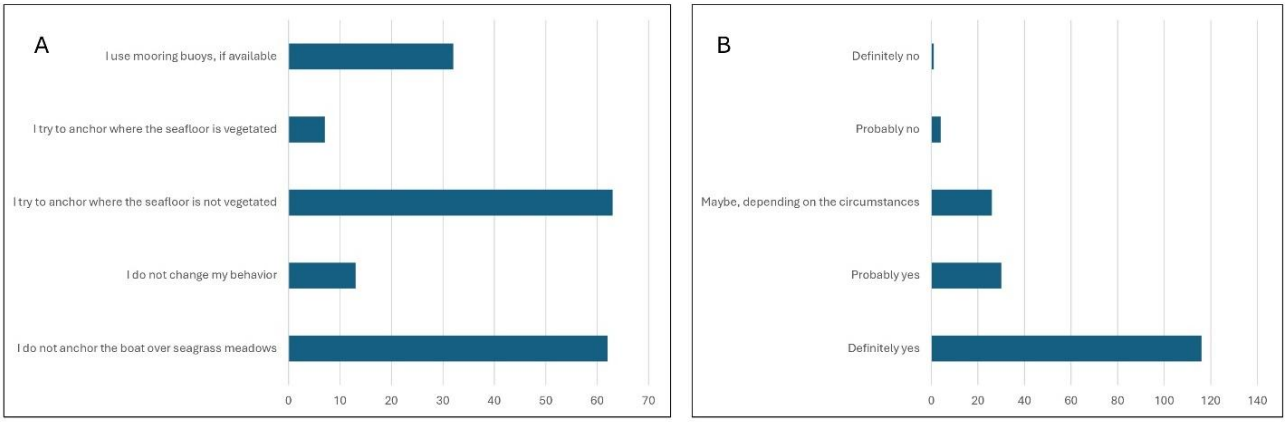


Figure 96 Respondents' reported behavior when anchoring in areas where seagrass meadows are present (A) and respondents' willingness to give up anchoring over seagrass meadows to support their conservation (B) (number of answers).

A similarly positive attitude emerged regarding the use of mooring buoy fields, with most respondents expressing their willingness to use such facilities when available (Figure 95). Nevertheless, a small proportion of participants reported that they would not use mooring buoys under these circumstances. This finding highlights the continued need for targeted awareness-raising and communication activities aimed at increasing public understanding of the ecological importance of seagrass meadows and promoting responsible boating practices that contribute to their long-term conservation, as is also evidenced by the fact that those who stated they were familiar with ecosystem services and seagrass meadows are also the ones who attribute the highest value and importance to them.

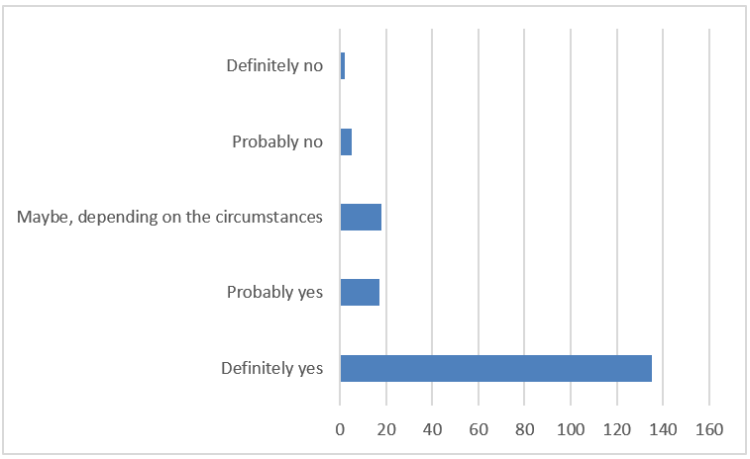


Figure 97 Respondents' willingness to use mooring fields instead of direct anchoring to support seagrass meadow conservation (number of answers).

Regarding the perceived impact of each stakeholder category on seagrass meadows, as shown in Table 28, the results highlight differences in the way respondents evaluate their own contribution to the conservation or degradation of these habitats. Tourists, both beach users and recreational boat users, generally perceive their impact as neutral, with no significant positive or negative effects identified. This suggests that these groups do not strongly associate their activities with either beneficial or detrimental consequences for seagrass meadows, although their interaction with coastal environments may still play an important role in shaping conservation outcomes.
Among fishers, the prevailing perception is that of a mostly positive impact, reflecting the recognition of their potential contribution to the sustainable management and protection of marine ecosystems. A similar perception emerges among public and local authorities, which identify their role as ranging between positive and neutral, likely reflecting their responsibilities in terms of planning, regulation, and implementation of conservation measures. Tourism operators also perceive their impact as

mainly positive or neutral, indicating an overall awareness of the potential compatibility between tourism activities and the conservation of seagrass habitats. These results highlight a generally positive self-perception among key stakeholder groups, while also emphasizing the importance of continued engagement and awareness activities to strengthen the role of all users in seagrass meadow conservation.

Table 28 Stakeholders' perceived impact on seagrass meadows and their role in habitat conservation (number of answers).

Stakeholder category	Very positive	Fairly positive	Slightly/ Neutral	Fairly negative	Very negative
Beach Tourists	5	9	40	7	7
Boaters	3	6	14	2	1
Fishers	3	4	2	2	1
Tourism operators	3	2	7	0	0
Others / Public authorities	9	15	24	7	4

5.3 Stakeholder questionnaire: conclusions

As part of the BIOPRESSADRIA project, a questionnaire survey involving 177 respondents was conducted to assess respondents' perceptions of seagrass meadows, with particular attention to their level of awareness, about the ecological importance, and the provided ecosystem services. The survey represents a key activity within the project, supporting the assessment of public perception and providing an evidence base for subsequent analyses and project actions.

Overall, the results of the questionnaire provide valuable insights into stakeholders' perceptions, awareness, and behaviors regarding seagrass meadows within the BIOPRESSADRIA project area. The composition of the sample, which includes different stakeholder categories and a balanced distribution in terms of gender and age, allows for a broad understanding of the current level of knowledge and attitudes towards these valuable marine habitats.

The findings indicate that seagrass meadows are generally recognized for their ecological importance, particularly in relation to key regulating and supporting ecosystem services such as oxygen production, coastal protection, biodiversity enhancement, and water quality improvement. However, the results also highlight that knowledge gaps remain, especially regarding the full range of ecosystem services provided by seagrass meadows and their cultural and recreational values. This suggests the need to continue promoting communication and awareness-raising activities aimed at strengthening public understanding of the multiple benefits associated with these habitats.

The responses also show a generally positive attitude towards conservation measures, particularly among recreational boat users, who largely demonstrate willingness to adopt more sustainable



practices, such as avoiding anchoring on seagrass meadows and using designated mooring areas where available. Nevertheless, the presence of a small proportion of respondents with lower awareness or willingness to adopt such practices confirms the importance of targeted information campaigns and stakeholder engagement initiatives.

Overall, the survey highlights a widespread recognition of the ecological value of seagrass meadows and the need for collaborative efforts among citizens, marine users, local authorities, and economic stakeholders to ensure their long-term conservation. The results provide a useful baseline for the BIOPRESSADRIA project, supporting the development of effective strategies aimed at increasing awareness, promoting sustainable behaviors, and enhancing the protection of seagrass ecosystems across the Adriatic region.

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