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ARTEMIS

Accelerating the Restoration of Seagrass Meadows in the Mediterranean area through Innovative ecosystem-service based Solutions

Euro-MED0200867

Restoration roadmap and pilot sites report

Deliverable 1.3.1

Project acronym	ARTEMIS
Project title	Accelerating the Restoration of Seagrass Meadows in the Mediterranean area through Innovative ecosystem-service based Solutions
Project mission	Natural Heritage
Project priority	Greener MED
IMESpecific objective	RSO 2.7 Enhancing protection and preservation of nature, biodiversity and green infrastructure, including in urban areas, and reducing all forms of pollution
Type of project	Test
Project duration	01/01/2024 – 30/09/2026 (33 months)

Deliverable title	Pilot restoration reports and roadmap
Deliverable number	D.1.3.1
Deliverable type	Report
Work package number	1
Work package title	Seagrass restoration pilots for ecosystem service (ES) enhancement
Activity name	Define restoration plans
Activity number	1.3
Partner in charge	ISPRA
Partners involved	HCMR, IME-OBSAM, MEDSEA Foundation, Municipality of Monfalcone, The Green Tank, ECOACSA, BAX, PLAN BLEU,

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Introduction

Restoration is not new as a concept or practice, however, restoration has evolved and is being applied in more diverse ways serving the purposes of higher-scale policy objectives (Baker et al., 2014). Decade 2021-2030 has been declared by the UN as the 'Decade on Ecosystem Restoration' thus constituting a global call to action to support the restoration of degraded ecosystems (Osborne et al., 2021). The Global Biodiversity Framework, adopted under the UN Biodiversity Convention in 2022, includes a Target 2, which aims to restore at least 30% of all degraded ecosystems by 2030. The EU Biodiversity Strategy, adopted in 2020, includes a separate pillar on ecosystem restoration. Since 2024, the EU has also adopted the Nature Restoration Law, which aims to restore 20% of all habitats by 2030. Under this global and European framework national governments have pledged to restore millions of hectares of land and sea.

The Nature Restoration Regulation represents a key step in the EU Biodiversity Strategy and sets binding targets for the restoration of degraded ecosystems, particularly those with the greatest potential for carbon sequestration and storage, and for preventing and mitigating the impact of natural disasters. This regulation also represents a key opportunity for the protection and strengthening of ecosystems, contributing not only to the conservation of biodiversity but also to the fight against climate change. However, for restoration to be considered a scientifically credible management approach, it is essential to have a thorough understanding of the methodologies and practices to be followed, as well as adequate basic knowledge of the ecological systems to be restored, in order to implement effective actions.

Addressing the challenges associated with seagrass restoration requires close collaboration among scientists, practitioners, policymakers, managers, and other stakeholders. Such cooperation is essential for building a shared knowledge base, fostering the exchange of expertise, and promoting the adoption of innovative tools, technologies, and management approaches.

Furthermore, restoration strategies should incorporate forward-looking and adaptive measures aimed at enhancing the resilience of restored seagrass meadows to future environmental changes. By strengthening the adaptive capacity of restored populations under changing climatic and ecological conditions, these approaches can improve the long-term effectiveness, sustainability, and ecological value of seagrass restoration initiatives.

The aim of this report is to provide a comprehensive framework for the seagrass restoration process, to support the implementation of the Nature Restoration Regulation (Nature Restoration Regulation – Regulation (EU) 2024/1991 of the European Parliament and of the Council of 24 June 2024), with particular attention to active and passive restoration activities of seagrass meadows in the Mediterranean, which form part of the requirements for the implementation of the Regulation. This report also aims to provide a technical and scientific overview of the key methodologies required to develop ecological restoration projects. The various operational steps will be outlined, so that public and private bodies can correctly apply criteria, methodologies and best practices when implementing projects that have a high probability of success in the medium and long term. The workflow described will help to guide actions towards measurable and sustainable outcomes, including through the adoption of Nature-based Solutions (NBS) that promote specific ecosystem services and other innovative approaches linked to the use of technologies applicable in the field of restoration.

The structure of the document intends to be comprehensible and practical to use for active and passive restoration activities, including as support to decision-making processes at any local, regional, national, Mediterranean, and European level. Indeed, this document is also aimed at a wide range of stakeholders: public authorities, government departments, land management bodies, companies operating in the environmental management and conservation sector, as well as third-sector organisations. Its aim is to provide useful and practical support to all those involved, in various capacities, in ecological restoration projects.

Section 1 - Regulatory framework

1.1 Posidonia oceanica: European Directives, International Conventions

Ecological restoration has become an important component of international environmental policy, reflected in a growing number of legal and policy instruments that address biodiversity conservation, climate change mitigation, and sustainable use of natural resources. Provisions relevant to restoration can be found across different governance levels, from global conventions and regional agreements to European Union legislation. Each contributes to the overarching objective of not just halting but reversing ecosystem degradation.

The table below summarizes these key provisions, indicating how they refer to restoration in general and to *Posidonia oceanica* meadows in particular.

International Conventions	**Explicitly mentions *Posidonia oceanica/* Seagrass Ecosystems**	**Explicitly mentions restoration**	**Implicitly mentions restoration**
The Convention on Biological Diversity	×	✓	×
Kunming-Montreal Global Biodiversity Framework (CBD/COP/DEC/15/4 2022)	×	✓	×
Ramsar Convention (UNE, volume 996, 245, 1971)	×	×	✓
Bern Convention (UE, GU L 38, 1982)	✓	✓	×
Convention on the Conservation of Migratory Species of Wild Animals – Bonn Convention (UE, GU L 210, 1982)	✓	×	✓
United Nations Framework Convention on Climate Change (UNFCCC)	✓	✓	×
Paris Agreement (Decision, UE, 2016/1841)	×	✓	×
High Seas Treaty (BBNJ Agreement/ UNCLOS)			✓
Regional (Mediterranean) Conventions			
Barcellona Convention (UE, GU L 240, 1977)	✓	×	✓
EU policy and legislation			
The Environment Action Programme to 2030 (Decision EU 2022/591)	×	✓	×

EU Biodiversity Strategy 2030 (COM (2020) 380 final)	×	✓	×
The EU Nature Restoration Regulation (EU 2024/1991)	✓	✓	×
EU Habitats Directive (92/43/CEE)	✓	✓	×
Water Framework Directive (WFD, 2000/60/CE)	×	×	✓
Marine Strategy Framework Directive (MSFD, 2008/56/CE)	×	×	✓
The EU Nature Restoration Regulation (NRR, EU 2024/1991)	✓	✓	×
The Common Fisheries Policy (EU 1380/2013)	×	✓	×
Council Regulation (EC) No 1967/2006 concerning management measures for the sustainable exploitation of fishery resources in the Mediterranean Sea	✓	×	✓
Ocean Pact (COM (2025)555 final)	✓	✓	×
Maritime Spatial Planning (Directive 2014/89/EU)			

Section 2 - Restoration and governance of *Posidonia oceanica* meadows

2.1 Governance of *Posidonia oceanica* restoration

Ecological restoration is the "process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed" (SER, 2004).
Restoration is a demanding process, following nature's rhythms, which may be slow. It requires scientific knowledge, robust methods and tested tools in order to be successful, and possibly to be enhanced. Several of these factors are analysed in the following sections of this guideline. Alongside biophysical factors, social, economic and governance factors need to be also accounted for (Benra et al., 2024). In other words, the ability to accomplish the restoration pledges made by governments and required to recover damaging impacts of the past, is influenced by complex social-ecological factors (Benra et al., 2024) and issues connected to governance (Mansourian, 2017). The chances of success rise significantly if a restoration program integrates the various components of restoration governance presented in the following list (Sapkota et al., 2018):

- Laws, jurisdiction and Institutions
- Financial resources and adequate availability
- Collaboration and participation
- Science, technology and info

The simultaneous consideration of scale, scientific knowledge, sociocultural context, financial resourcing, and institutional tractability, can lead to long-term stewardship of a restored ecosystem (Richardson & Lefroy, 2016:1). To facilitate this integration ten principles for achieving long-lasting, resilient, and equitable ecosystem restoration, called a "Political Ecology Playbook for Ecosystem Restoration" have been developed (Osborne et al., 2021). The authors highlight that restoration goals need deep structural changes and barrier removal at local, state or national, and international scales, as listed below.

Local Arena
1. Privilege local knowledge and practices
2. Ensure participation of most impacted groups
3. Ensure social/environmental equity and justice

National Arena
4. Align restoration practices with local needs and aspirations
5. Align state policies to support restoration
6. Empower representative local decision-making authority
7. Promote regenerative interventions. (address root causes of degradation)

International Arena
8. Prioritize social and ecological benefits over financial returns
9. Ensure fair funding acknowledging ecological debts

10. Collaborate across country borders

As governance is primarily a process of making decisions, rather than prescribed outcomes, governance mechanisms should accommodate a diversity of actors, issues, and contexts. On that account, stakeholder inclusion is a reoccurring prerequisite concerning effective restoration efforts (Buitenhuis & Dieperink, 2021; Fenten Dieperink, 2024; Osborne et al., 2021; Richardson & Lefroy, 2016). Stakeholders are defined as the people and organizations who are involved in or affected by an action or policy and can be directly or indirectly included in the decision-making process (Freeman 1984).

2.1.1 Stakeholder mapping

In a *P. oceanica* restoration project stakeholders would be included, starting from the early stages of its implementation. In order to identify who the stakeholders are, what their stakes are, and how they connect to the project, a stakeholder analysis methodology has to be applied in a systematic and consistent way.

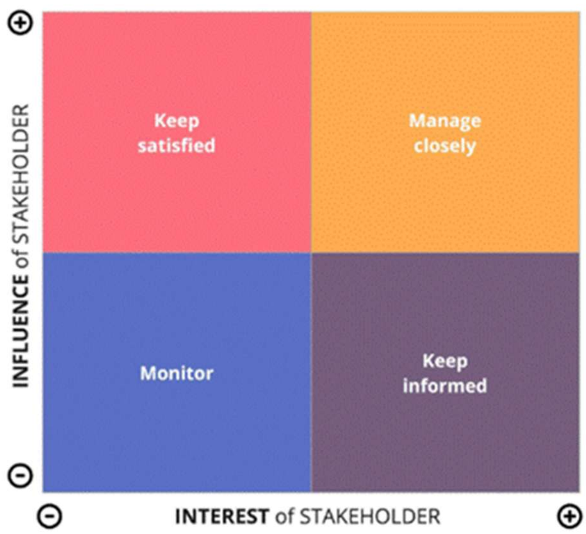
The initial step involves mapping the stakeholders, who are organized in a stakeholder table. The table is analytical (see Table 2.1.1.1), capturing numerous stakeholder characteristics to facilitate the assessment of key stakeholders. Specifically, after identifying and describing the stakeholders, whether each stakeholder is external or internal to the restoration project should be examined [blue columns]. To evaluate stakeholder importance, levels of impact, support, interest, and influence for each stakeholder using a four-level scale are assigned: High, Medium, Low, or N/A. Additionally, whether each stakeholder has decision-making authority (yes/no) is noted, as well as whether each is an expert in fields relevant to the project's objectives, and whether each has access to resources. All of these attributes are used to estimate each stakeholder's overall power. Stakeholders who score high (+3) in both interest and influence, and who demonstrate a high overall power, are considered key stakeholders.

Table 2.1.1.1: The stakeholder table

STAKEHOLDER DESCRIPTION			PROJECT RELATIONSHIP				STAKEHOLDER CHARACTERISTICS			
Name	Type	External/ Internal*	Level of Interest	Level of Influence *	Level of Impact*	Level of Support	Decision Authori	Expert	Access to Resources	Overall Power*
		External	High = 3	Medium = 2	High = 3	High = 3	Yes	Yes	Yes	High = 3
		Internal	Medium = 2	Medium = 2	Medium = 2	Medium = 2	No	No	No	Medium = 2
			Low = 1	Medium = 2	Low = 1	Low = 1				Low = 1
			N/A = 0	Medium = 2	N/A = 0	N/A = 0				N/A = 0
	European Union / International decision makers									
	National Government/ National authorities									
	Regional Government/ Regional authorities									
	Local Government/Local authorities									
	Locals/ Residents/ Civil Society Organizations									
	Local communities									
	Local - Business/ Industry									
	International- Business/Industry									
	National - Business/industry									
	National- Environmental Organizations									
	Local - Environmental Organizations									
	International - Environmental Organizations									

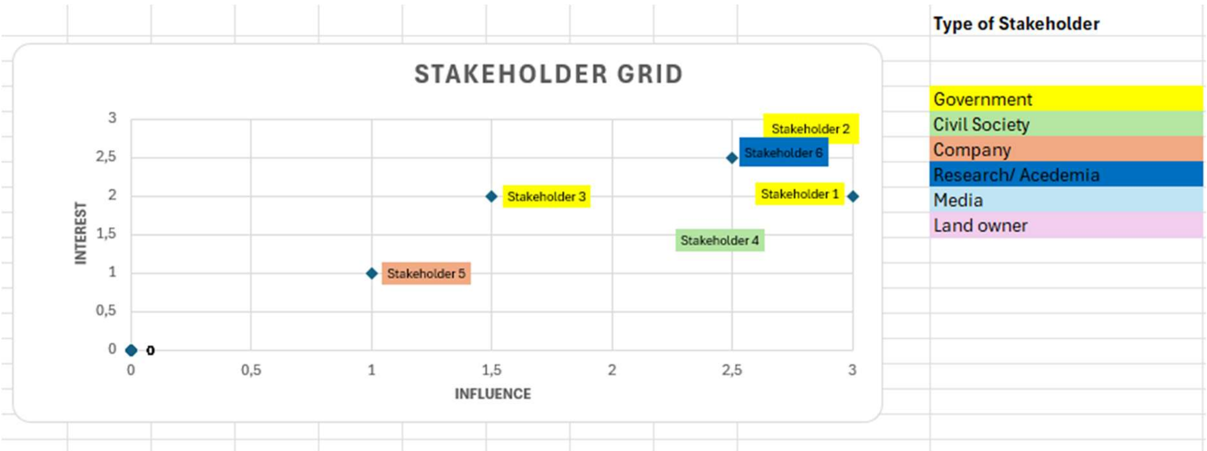
The next step is to create a stakeholder grid which is a tool that can be used to visualize, based on influence on one axis and level of interest on the other axis, the overall power of each stakeholder (Mendelow, 1991).

Table 2.1.1.2: The Mendelow influence/interest matrix



Each stakeholder is placed in a specific quadrant (see Table 2.1.1.3), which also indicates a recommended engagement strategy, ranging from managing closely to simply monitoring. Performing this step for the restoration sites facilitates the identification of key stakeholders, those with high interest and high influence. These key stakeholders are then prioritized for the development of a tailored engagement strategy appropriate for the interested restoration case study.

Table 2.1.1.3: The Stakeholder Grid



The stakeholder table also includes additional information to guide engagement with non-key stakeholders. It helps us determine and organize, for example, at which stage of the project a stakeholder should be engaged and for what purpose (e.g., business outreach, pilot site activities) (see sample in Table 2.1.1.4).

Table 2.1.1.4: The stakeholder table

KEY STAKEHOLDERS			INVOLVEMENT		
KEY for pilot s	KEY for business outreach	KEY for amplificatio	Involvement Level *	Involvement Aim *	Involvement Timing *
Yes	No	No	Collaborate/ Involve		Throughout
No	Yes	Yes	Keep Informed Keep Engaged		During - Implementation
			Closely Monitor		After - Monitoring
			Collaborate/ Involve		Beginning - Planning

Subsequently, key stakeholders can be involved through various means, including organizing meetings and conducting interviews, distributing surveys, and inviting them to workshops (Richardson & Lefroy, 2016).

Section 3 – Passive restoration

3.1 Definition and Scope of Passive Restoration

Under the EU Nature Restoration Law (NRL) and the Habitats Directive, ecological restoration is defined as any process that assists the recovery of degraded, damaged, or destroyed ecosystems by re-establishing their natural structure, functions, and resilience. The NRL distinguishes between active restoration actions and passive (or low intervention) restoration. The latter occurs when natural processes drive recovery once anthropogenic pressures have been removed and favourable conditions are restored. Passive restoration is, therefore, understood as the recovery of an ecosystem through natural regeneration and ecological dynamics following the cessation or substantial reduction of human pressures, guided by the objective of achieving favourable reference conditions.

Applied to *Posidonia oceanica*, passive restoration refers to a set of regulatory, spatial-planning, management, and surveillance measures designed to eliminate or significantly reduce the pressures causing degradation. These pressures include anchoring, mechanical disturbance, eutrophication (e.g. aquaculture), sediment alteration, coastal construction, illegal trawling and other human stressors. Removing these pressures allows natural processes to resume, including rhizome elongation, sediment stabilisation, the re-expansion of fragmented patches, and recolonisation from adjacent donor meadows.

Because *Posidonia oceanica* grows extremely slowly and has limited recolonisation capacity, restoring favourable environmental conditions is an essential prerequisite for any successful active restoration intervention. Consequently, passive restoration is the most cost-effective and immediate pathway for conservation and the necessary first step in the restoration value chain. Only once the causes of degradation are addressed can active restoration be considered effectively.

Awareness-raising and behavioural change also support passive restoration by reducing everyday pressures. When local communities, recreational users, and nautical stakeholders understand the value of Posidonia and perceive its protection as a shared responsibility, compliance increases and long-term impacts decrease. In summary, passive restoration mitigates human pressures to favour natural regeneration, making it the most ecologically robust and cost-effective approach.

3.2 Policy and Legal Framework

Passive restoration is supported by a consolidated legal basis at both EU and Mediterranean levels. The key frameworks guiding pressure reduction, conservation status and restoration objectives include: the Habitats Directive, the EU Nature Restoration Regulation, the Marine Strategy Framework Directive (MSFD), the Water Framework Directive (WFD), the Barcelona Convention, the EU Maritime Spatial Planning Directive (MSPD).

Marine Spatial Planning (MSP) provides the strategic framework to integrate Posidonia conservation needs into navigation, tourism, infrastructure and other maritime uses. Spatial prioritisation identifies areas where passive restoration has the greatest impact and ensures their incorporation into MSP zoning and decision-making. Furthermore, each national maritime spatial plans provide the legal mechanisms that operationalise these priorities. The availability of relevant datasets for MSP integration, such as updated mapping of *P. oceanica* distribution, anchoring and boating hotspots based on Automatic Identification System (AIS)-based navigation patterns, depth-based vulnerability and hydrodynamic exposure, degraded areas with recovery potential, water quality and pollution pressure criteria, spatial information from Natura 2000 management plans, and data from conservation status monitoring stations and long-term habitat assessments, allows overlay analysis to be performed to identify priority intervention zones. This ensures coherence between conservation objectives and maritime uses.

3.3 Main Passive Restoration Measures

Passive restoration relies on a coherent set of management measures tailored to specific impacts. These priority measures include (Tab 3.3.1*):*

• Regulation of anchoring and mooring practices

• Reduction, mitigation or removal of degrading pressures

• Establishment of temporary or permanent exclusion zones

• Navigation and visitor-use management in sensitive areas

• Implementation of an effective enforcement chain

Table 3.3.1: Priority measures, their purpose and specific actions that define the passive restoration framework for *Posidonia oceanica* meadows.

Measure	Purpose	Action
Implementation of an effective enforcement chain	An effective enforcement chain aimed to combine prevention, real-time information, and corrective actions, supported by consistent field presence and digital monitoring systems.	· Detection through Automatic Identification System (AIS), remote sensing, mobile apps, patrols or camera systems. · On-site inspection and verification by trained personnel. · Prevention and guidance, offering real-time information to users to avoid impacts. · Proportional sanctions when non-compliance persists, followed by administrative or judicial proceedings. · Feedback mechanisms to improve management and influence user behaviour
Regulation of anchoring and mooring practices	Effective anchoring management integrates behavioural change, digital tools, and consistent field presence allow to minimize the mechanical damage to *Posidonia oceanica*	· Prohibition or strict regulation of anchoring on *Posidonia* meadows. · Installation of eco-mooring systems. · Designated no-anchoring zones. · Real-time digital tools (apps, electronic plotters) showing *Posidonia* distribution. · Continuous communication with nautical stakeholders (marinas, charter operators, skippers). · Surveillance by trained rangers who support compliance and guide users toward no-impact behaviour. · Automatic Identification System (AIS)-based analysis to anticipate risk areas and optimize patrol deployment. · A prevention-first approach, ensuring that guidance precedes sanctioning.
Reduction, mitigation or removal of degrading pressures	Eliminating or significantly reducing the pressures that cause meadows degradation (e.g. anchoring, mechanical disturbance, eutrophication, sediment alteration, coastal construction, and other human stressors) allows natural processes to resume, including rhizome elongation, sediment stabilisation, the re-expansion of fragmented patches, and recolonisation from adjacent donor meadows.	· Relocation of aquaculture facilities located over or near seagrass meadows. · Prohibition of trawling and all towed gear. . Use of anti-trawling devices to prevent illegal fishing. · Regulation of coastal construction activities with explicit *Posidonia* avoidance criteria. · Reduction of nutrient and pollutant inputs through improved wastewater and stormwater treatment. · Minimisation and control of brine discharges from desalination plants, especially in shallow or semi-enclosed areas.
Establishment of temporary or permanent exclusion zones	Exclusion zones—temporary or permanent—protect recovering areas by preventing activities that could interrupt natural regeneration. They are effective in early recovery zones where the matte persists, fragmented meadows with re-expansion potential, or regressive borders showing initial stabilisation. Exclusion zones may also protect high-value areas hosting exceptionally dense or structurally complex meadows	Establishment of Exclusion zones where: · The matte remains intact. · Fragmented patches show recovery potential. · Regressive borders display early stabilisation. · The area holds high ecological value. · The area has recently undergone active restoration, including seagrass transplantation. · Seasonal pressure is high, and temporary closures accelerate recovery. · Operational signage, guidance and compliance are feasible. · Monitoring confirms natural recovery trajectories
Navigation and visitor-use management in sensitive areas	Navigation and visitor-use management complement anchoring regulations, particularly in regions with intense recreational boating, charter activity and nautical tourism.	· Zoning of navigation corridors to avoid shallow *Posidonia* areas. · Designated mooring fields. · Seasonal or spatial limitations in high-sensitivity zones. · Marina and harbour rules integrating *Posidonia* protection for recreational and charter vessels. · Clear signage and information systems to guide boaters and reduce unintentional impacts.

3.4 Evaluation of passive restoration measures over time

Passive restoration is fundamental to long-term ecosystem recovery and is fully aligned with EU restoration policies and Mediterranean conservation frameworks. Passive restoration delivers long-term ecological benefits and services, including the re-establishment of optimal water clarity and the recovery of biodiversity associated with *Posidonia oceanica* meadows. Furthermore, it enhances coastal resilience to climate-related stressors and improves sediment stabilisation, thereby reducing the risk of coastal erosion. Evaluating passive restoration measures is essential to confirm that the long-term restoration goals have been achieved.

In this context, management indicators can be identified to evaluate the operational performance of the passive restoration of *P. oceanica* meadows (Tab 3.4.1). At the same time, monitoring using specific ecological indicators allows the effectiveness of passive restoration measures to be assessed in terms of natural recovery and regression of the meadows (Tab 3.4.1).

Table 3.4.1: Management indicators and Ecology indicators, useful to assess effectiveness of passive restoration measures for *Posidonia oceanica* meadows.

Management indicators	**Ecology indicators**
• Number of avoided anchoring events • Frequency and coverage of patrols and inspections • Compliance rates for recreational, charter and nautical tourism vessels • Sanctioning outcomes and follow-up • Reduction of identified pressures (anchoring, pollution, disturbance) • Improvement of water-quality parameters • Reach of awareness actions (ranger interactions, marina briefings, app usage) • Spatial reduction of anchoring scars or impact hotspots • Trends from conservation-status monitoring stations	• Shoot density • Meadow coverage and patch structure • Phenology and Lepidochronology • Upper and lower limits recovery • Reduction of anchoring scars • Sediment physical and chemical parameters • Water physical and chemical parameters • Ecological quality indices • Biodiversity of associated flora and fauna

3.5 - Assessment of ecosystem services of *Posidonia oceanica* meadows

For an assessment of the ecosystem services provided by *Posidonia oceanica* seagrass meadow undergoing passive restoration refer to section 4.2.3.

Section 4 – Active Restoration

4.1 Definition and Scope of Active Restoration

Although *Posidonia oceanica* meadows are recognised as being ecologically and economically important at an international level and are consequently protected by various national and European rules, currently significant decline in many areas of the Mediterranean is noted (Marbà et al., 2014; Telesca et al., 2015).

The diverse natural and anthropogenic causes of regression, together with the slowness of natural recolonisation processes, have led to the gradual acceptance of the idea that it may be necessary to develop transplantation techniques to support and/or speed up natural regeneration processes (Meinesz et al., 1991a). However, given that *P. oceanica* is among the species with the slowest growth rate in the Magnoliophyta, transplantation is also a slow process of recolonisation in which selected cuttings must take root and expand until, after many years, they rebuild a meadow whose characteristics can be assimilated to a natural condition. Therefore, transplantation must not be conceived as a means of achieving swift greening, as with a lawn in a terrestrial environment, but rather as a tool to promote the resilience of this habitat.

The first *P. oceanica* transplants, carried out using techniques usually employed to strengthen and improve the conservation state of meadows of other marine phanerogams, were unsuccessful. However, further experiments, including those conducted by the French school of Georges Cooper and the Jardiniers de la Mer group (Augier et al., 1996; Cooper, 1982), as well as subsequent studies primarily conducted in Italy, have gradually yielded more promising results regarding *P. oceanica* transplantation (Scardi et al., forthcoming; Calvo et al., 2021; AA.VV., 2020a). Experience gained from previous shortcomings, new discoveries about the biology of the plant and the use of new technologies, as well as the availability of long-term transplantation monitoring data, has led to increasingly effective and sustainable *Posidonia* transplants (Bacci and La Porta, 2022; Boudouresque et al., 2021; Piazzi et al., 2021; Bacci et al., 2019; Badalamenti et al., 2015).

In recent years, alongside the idea of restoring meadows that have been destroyed or damaged as a result of alterations to the marine-coastal environment (e.g. changes in coastal or climate dynamics caused by coastal works) and due to long standing impactful activities, such as illegal trawling, mooring and anchorage, aquaculture or even accidents, the transplantation of sections of *Posidonia oceanica* seagrass beds has increasingly been identified been identified in appropriate assessments under the Habitats Directives (art. 6.3 and 6.4) often included in Environmental Impact Assessment (EIA) decrees relating to the construction of coastal works as a form of compensation for the associated environmental impacts.

Regardless of the reason for active restoration, there are many factors that determine its success. The most important of these are the choice of transplantation area and the most suitable technique for the selected substrate type. However, to maximise the chances of a successful transplant, it is necessary to follow a specific process that enables each phase of the transplant to be managed correctly and all the required data for the different areas of interest to be acquired. The specific technical and scientific skills of the operators responsible for the various phases of the process are also crucial for the execution of an effective, long-lasting transplantation (AA.VV., 2020a; Boudouresque at al., 2021; Bacci and La Porta, 2022; Pergent-Martini C. et al., 2024; Pansini et al., 2025).

This section illustrates the main phases of the active restoration process: planning, implementation, monitoring and management of a transplantation. Each of these phases includes additional key steps, such as accurate environmental characterisations to select donor and recipient areas, pilot studies to select suitable restoration areas and techniques, and the selection of biological materials for transplantation. There are also appropriate and detailed monitoring plans to assess the results of restoration over time. Furthermore, even when all the good practices described are followed, a restoration action has a greater chance of success if it is managed over time and protected from anthropogenic activities that usually damage natural meadows, such as small-scale fishing, illegal trawling and mooring of leisure or commercial boats. The active restoration process can be applied to any restoration project, regardless of the specific objectives, such as the restoration of degraded meadows, or the “mending” of damaged sections meadows (e.g. due to moorings or trawling), or the compensation of areas of meadows following their complete loss due to dredging activities or seafloor sealing where *P. oceanica* meadows were present, caused by the execution of marine and coastal projects (e.g. pipelines) (Fig. 4.1.1).

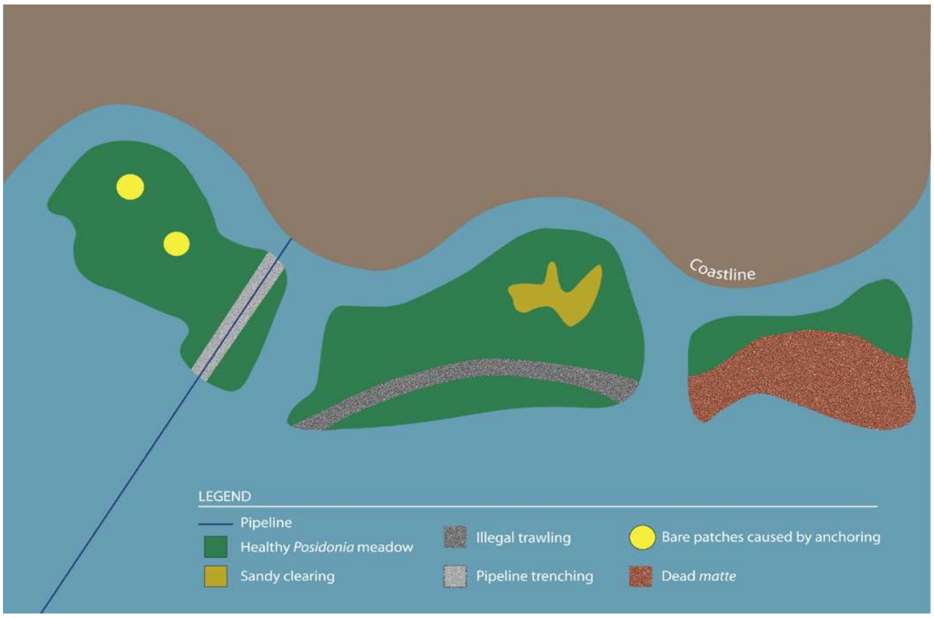


Figure 4.1.1 | Examples of degraded or damaged *Posidonia oceanica* meadows

4.2 - *Posidonia oceanica* active restoration planning

The active restoration process of *Posidonia oceanica* outlined in this section is generally a difficult and delicate operation due to the complexity of the meadows themselves. Correct management of transplantation requires specific technical and scientific skills, as well as application of a specific procedure to ensure correct management of all phases and acquisition of all necessary data in the various areas of concern (Fig. 4.2.1) (Pergent-Martini et al., 2024; La Porta and Bacci, 2022; Boudouresque et al., 2021; AA.VV., 2020a; Van Katwijk et al., 2016; Calumpong & Fonseca, 2001).

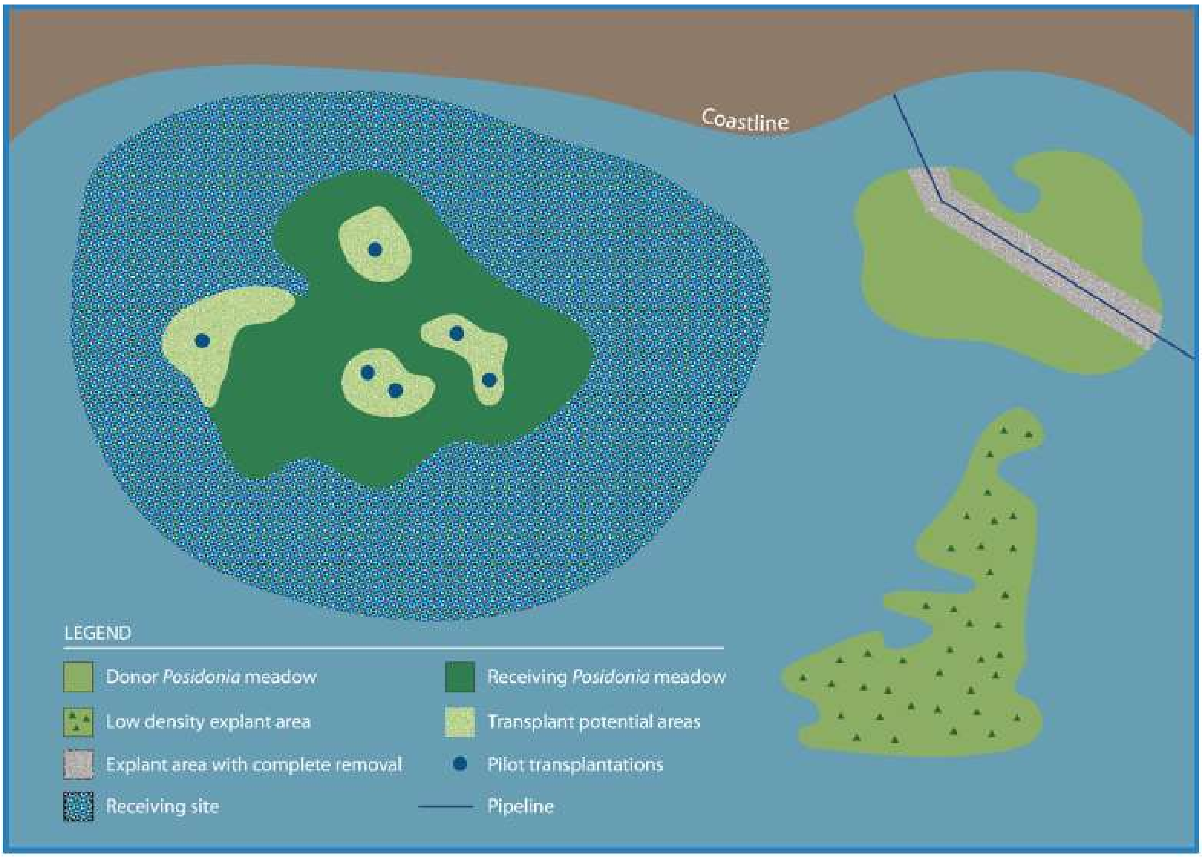


Figure 4.2.1 | Example diagram of the different areas involved in the planning, implementation and monitoring of Posidonia oceanica restoration.

4.2.1 - Characterization and assessment of donor meadows, accumulation zones of clods, cuttings and seeds.

The characterisation and assessment of the donor meadow is a critical phase in the active restoration of *Posidonia oceanica*. The 'health status' of the donor meadow, its size and the quality of the cuttings used for restoration, as well as the distance from the recipient site, are some of the main factors that can affect restoration success (Pergent-Martini et al., 2024; La Porta and Bacci, 2022; Boudouresque et al., 2021; Tan et al., 2020; Díaz-Almela & Duarte, 2008; Campbell, 2002). Clods and cuttings that have naturally become detached due to hydrodynamics or the anchoring of boats, and which are found on the seabed, should be considered as an alternative to material removed from donor meadows. Furthermore, seeds can be collected along accumulation seashore zones to be used in restoration projects after the germination in aquaria.

Table 4.2.1.1 shows the activities foreseen in characterising and assessing the donor meadow and the accumulation zones of clods, cuttings and seeds, the purpose of the activities and the types of data to be acquired in the various activities, to select the most suitable areas for collecting biological material for restoration. The collected data must be acquired according to specific reference methodologies and when required by experienced divers on *P. oceanica* samplings.

Table 4.2.1.1: Activities foreseen in characterising and assessing the donor meadow and the accumulation zones of clods, cuttings and seeds, the purpose of the activities and the types of data to be acquired in the various activities, to select the most suitable areas for collecting biological material for restoration. The collected data must be acquired according to specific reference methodologies and when required by experienced divers on *P. oceanica* samplings.

ACTIVITY	PURPOSE	REQUIRED DATA AND METHODOLOGIES
1. DONOR MEADOW		
Preliminary screening of available pre-existing data.	Provide basic information for planning subsequent characterization surveys aimed at identifying the most suitable areas for collecting biological material for restoration. If the donor area coincides with an area where portions of meadows are inevitably going to be removed, the screening will only provide environmental contextualisation data.	The historical (>20 years) and current (<20 years) distribution of the *Posidonia oceanica* meadows, its facies and the bathymetry of the meadow, as well as the meadow's structural, functional and ecological descriptors. The perimeter of any Natura 2000 network sites, as well as the presence of any Marine Protected Areas (MPAs) or other protected marine sites. The presence of recent *P. oceanica* restoration areas in the donor meadow that can influence the identification of areas for explantation.
Remote surveys	Provide data to identify the most suitable areas for collecting biological material to be used for restoration.	Morpho-bathymetric and distribution data of the meadow will be acquired mainly using side scan sonar (SSS), multi beam (MB) and video-photographic tools, as well as remotely operated vehicles (ROVs), satellite and aerial remote sensing using remotely piloted aircraft (RPAs), and autonomous underwater vehicles (AUVs). Data must be acquired according to specific reference methodologies (Rende et al., 2020; Veettil et al., 2020; Castillon et al., 2019; Gumusay et al., 2019; Mohamed et al., 2018).
Surveys in situ	Provide data on the health of the donor meadow and the quality of the cuttings to be used for restoration to maximise the chances of rooting.	Quantitative data relating to the structural, functional and ecological parameters of the donor meadow. These parameters include the density of foliar shoots, phenological and lepidochronological parameters, presence of flowers and fruits, and the abundance and composition of the associated fauna and flora. Data must be acquired according to specific reference methodologies (Bacci et al., 2020; Buia et al., 2003; Short & Coles et al., 2001) and by experienced divers on P. oceanica samplings.
Genetic variability assessment	Assess the influence of the genetic variability between the donor and receiver meadows considering the distance between the meadows.	Data on genetic structure, the plasticity, and the adaptability of populations of donor and receiver meadow. Data can be acquired according to specific reference methodologies (Litsi-Mizan et al., 2024; Procaccini et al., 2023; Pazzaglia et al., 2021; Pergent et al., 2007; Procaccini et al., 2021) and by experienced divers on *P. oceanica* samplings.

Distance of donor meadow from the restoration site	Reduce the stress for explanted cuttings during the transfer phase between the areas of explantation and restoration. Optimize the logistical and/or procedural choices for all the restoration phases.	Spatial distance between the donor and receiver meadows.

ACTIVITY	PURPOSE	REQUIRED DATA AND METHODOLOGIES
2. ACCUMULATION ZONES OF CLODS AND CUTTINGS NATURALLY DETACHED		
Preliminary screening of available pre-existing data	Identify areas where clods and cuttings naturally detached can be collected to be used in restoration projects.	Pre-existing data on the geolocalization and dimension of the accumulation zones. When no information is available, it is necessary to plan targeted preliminary surveys (i.e. analyses of available site maps (bathymetry, sediment maps, historical data, satellite or aerial images); collection of information from local users to identify areas potentially suitable for natural accumulation.
Surveys in situ	Assess the suitability of the accumulation zone, abundance and vitality of the clods and cuttings	Actual dimension and depth of the accumulation zones by video-photographic tools Estimation of clods and cuttings abundance and assessment of their vitality according to the expert opinion.
Distance of accumulation zones of clods and cuttings from the restoration site	Reduce the stress for clods and cuttings during the transfer phase between the zones of accumulation and restoration. Optimize the logistical and/or procedural choices for all the restoration phases. It is preferable to collect them from areas located as close as possible to the restoration site.	Spatial distance between the accumulation zones and receiver meadows.
3. ACCUMULATION ZONES OF SEEDS		
Preliminary screening of available pre-existing data	Identify seashore zones where seeds can be collected to be used in restoration projects after the germination in aquaria	Pre-existing data on the geolocalization and dimension of the seeds 'accumulation zones along the seashore.
Surveys in situ	Assess the suitability of the seeds 'accumulation zone, abundance and vitality of the seeds	Actual dimension of the seed's accumulation zones. Estimation of seeds' abundance and assessment of the seed's vitality according to expert opinion.
Distance of accumulation zone of seeds from the restoration site	Reduce the stress for collected seeds during the transfer phase between the zones of accumulation and aquaria. Optimize the logistical and/or procedural choices for all the germination and restoration phases.	Spatial distance between the accumulation zones and aquaria.

4.2.2 - Characterization and assessment of the receiving meadow

The selection of the restoration area is one of the main factors determining the success or failure of reforestation operations in the marine environment (Pergent-Martini et al., 2024; La Porta and Bacci, 2022; AA.VV., 2021a, 2020a; Boudouresque et al., 2021; Tan et al., 2020; Pirrotta et al., 2015; Van Katwijk et al. , 2009; Calumpong & Fonseca, 2001). During the planning phase of a restoration project, the characterisation of the recipient site and associated evaluations are expected to be conducted at both the specific areas within the meadow where the restoration project is to take place and at a broader level within the recipient Posidonia meadow.

Table 4.2.2.1 shows the activities and their purposes for characterising the site and the receiver meadow, and for assessing the most suitable areas for restoration.

Table 4.2.2.1: Activities and their purposes for characterising the site and the receiver meadow, and for assessing the most suitable areas for restoration.

ACTIVITY	PURPOSE	REQUIRED DATA AND METHODOLOGIES
1. RECEIVING MEADOW		
Preliminary screening using previous data	Exclude areas not suitable for restoration. Indicate subsequent characterisation surveys on potentially more suitable areas.	The historical (>20 years) and current (<20 years) distribution of the *Posidonia oceanica* meadows, its facies and the bathymetry of the meadow, as well as the meadow's structural, functional and ecological descriptors. Classification of the substratum, granulometry of seabed sediments, hydrology and water quality. The existence of any causes of regression of the receiving meadow related to anthropogenic pressure in the area of interest, as well as the natural dynamics of the surrounding coastal environment. Information relating to the use and constraints of the sea, e.g. port areas, dredged sediment collection areas, offshore cables and pipelines, archaeological sites and aquaculture installations. The perimeter of any Natura 2000 network sites, as well as the presence of any Marine Protected Areas (MPAs) or other protected marine sites. The presence of any pre-existing Posidonia restoration in the meadow that could hinder or facilitate the identification of suitable transplantation areas within the same meadow, based on the outcome of the pre-existing restoration. Qualitative and quantitative models have been developed to identify potential areas for marine phanerogam transplantation using previous data relating to the area in question (AA.VV., 2021a; Lanuru et al., 2018; Pirrotta et al., 2015; Campbell, 2002; Short et al., 2002).
Remote surveys	Provide data to identify the most suitable areas for restoration that are large enough to allow the transplanted areas to expand in the medium and long term.	Morpho-bathymetric and distribution data of the meadow will be acquired mainly using side scan sonar (SSS), multi beam (MB) and video-photographic tools, as well as remotely operated vehicles (ROVs), satellite and aerial remote sensing using remotely piloted aircraft (RPAs), and autonomous underwater vehicles (AUVs). The presence of elements indicating strong currents or erosive processes (such as ripple marks, erosion channels, and eroded limits in the receiving meadow) could make restoration actions difficult to carry out. Data can be acquired according to reference methodologies (Rende et al., 2025; Llorens-Escrich et al., 2021; Rende et al., 2020; Veettil et al., 2020; Castillon et al., 2019; Gumusay et al., 2019; Mohamed et al., 2018)

ACTIVITY	PURPOSE	REQUIRED DATA AND METHODOLOGIES
1. RECEIVING MEADOW		
Hydrological and water quality surveys	Provide data on the hydrological dynamics and chemical-physical characteristics of the water column that are suitable for the rooting and survival of transplanted cuttings.	Local water chemistry data is required to evaluate the supply of nutrients and inorganic carbon necessary for Posidonia photosynthesis. Hydro-dynamic data is used to identify areas with regimes that are too high or too low and are therefore not favourable for restoration activities (Koch, 2001). Chemical and physical data of the water column acquired by multi-parametric probes (e.g. light intensity, clarity, dissolved oxygen, salinity, temperature, pH, nutrient load, and suspended organic and inorganic particles) provides information on water quality and limiting factors for Posidonia growth (Larkum et al., 2006).
In situ observations of environmental criticalities	Provide information on any critical elements that could affect the implementation or outcome of the transplantation.	The presence of excessive organic debris, ripple marks, invasive and/or alien macroalgae, and 'markers' of anthropogenic pressure, such as abandoned fishing nets, traces of repeated anchorage, moorings, and debris or waste, in the potential transplantation areas, is a further limiting factor in terms of their suitability. Such data should be collected by experienced divers using visual surveys of P. oceanica.
Surveys in situ: structural, functional and ecological descriptors of the receiver meadow	Provide data to assess the health status of the receiver meadow and identify the most suitable areas for transplantation.	Quantitative data relating to the structural (density of foliar shoots), functional (phenological and lepidochronological parameters), and ecological parameters (abundance and composition of associated fauna and flora). Underwater surveys of potential transplantation areas also enable qualitative information to be acquired relating to the apparent health of the meadow, the type of limits (e.g. progressive, sharp, erosive or regressive), the type of substratum (e.g. sand or rock), and the presence and consistency of dead matte, evidence of natural recolonization. Experienced divers must acquire these parameters in the receiver meadow according to specific reference methodologies (Bacci et al., 2020; Buia et al., 2003; Short & Coles, 2001, Pergent-Martini et al., 2024).
Pilot transplantation	Testing the suitability of the identified potential restoration areas and the effectiveness of the chosen transplantation techniques through monitoring of the pilot restoration over an adequate period of time.	A pilot restoration project must (Pergent-Martini et al., 2024; La Porta and Bacci, 2022; Bacci et al., 2019; Cunha et al., 2012; Pirrotta et al., 2015; Campbell, 2000; Boudouresque et al., 1994; Pergent et al., 2024): (i) conducted on an adequate number of areas identified as potentially suitable; (ii) proportionate to the surface area of the transplantation to be carried out; (iii) conducted using an adequate but limited number of cuttings for each pilot area; (iv) monitored for at least one year to take into account both natural events (e.g. sea storm) and anthropogenic pressure (e.g. anchors), which are considered critical during the initial stages of transplantation.

4.2.3 - Assessment of ecosystem services of donor and receiving meadows

Seagrass meadows provide a wide range of ecosystem services (MA, 2005; Hein et al., 2006). Among others, these ecosystems are significant carbon sinks and contribute to effective coastal protection through sediment retention and hydrodynamic attenuation, reducing erosion caused by waves and bottom currents. They also support tourism activities and serve as biodiversity-rich habitats. These services benefit both local populations and economic sectors that rely on them, such as commercial fisheries and tourism.

Despite these benefits, seagrass meadows continue to decline across much of the Mediterranean region (Marbà et al., 2014; Telesca et al., 2015). A variety of environmental pressures are responsible for this degradation, either due to society's inability to reduce these pressures or to adequately value the importance of ecosystem contributions to the real economy (Pascual et al., 2023), particularly those provided by marine angiosperm meadows.

The economic value of these services is substantial. Depending on the author, the number of ecosystem services considered, and the geographical scope of the study, the estimated value of seagrass meadows ranges from €283/ha/year (Campagne et al., 2025) to €86,000/ha/year in high-income areas (Stamatiadou et al., 2025). Results show that the highest values are found in affluent coastal zones, driven by high local Gross Domestic Product (GDP) per *capita* and intense pressure on ecosystem services.

Nevertheless, addressing the global biodiversity crisis still implies confronting barriers to incorporating nature's diverse values into decision-making. In order to establish mechanisms that facilitate the integration of nature's values and allow for the inclusion of positive environmental externalities derived from conservation, impact reduction, or restoration activities, innovative mechanisms have been developed in recent years. These tools are known as market-based mechanisms, including Payments for Ecosystem Services (PES), Nature Credits, incentives, and environmental taxation.

PES and Nature Credits are closely related. Both aim to capture the value of environmental benefits resulting from nature-enhancing activities. However, while PES focuses on establishing payment models based on the continuous provision of ecosystem services (flows), Nature Credits emphasize the improvement of the natural assets that provide those services (natural assets).

Despite the wide array of ecosystem services provided by seagrass meadows, climate regulation (carbon sequestration) and biodiversity conservation may be considered more appropriate than others for the generation of instruments within market-based mechanisms. The selection of these services was influenced by a market appetite, driven by emerging policy frameworks (Paris Agreement and Kunming-Montreal Global Biodiversity Framework).

As a result, the quantification of Nature Credits is based on describing the state of the natural assets (seagrass meadows) through two variables: extension and condition. Extension refers to the physical surface area of the ecosystem included in the project, spatially delineated and periodically monitored. Condition reflects the ecological state of the system and is measured using standardized indices (e.g. EBQI, PREI, MediSkew) that allow the observed situation to be compared with a reference ecosystem defined as an optimal state.

The initial state of the natural assets, in terms of extension and condition, is established at the start of a restoration project, as the baseline. This baseline is accompanied by a "without restoration project" scenario, which describes the expected evolution of the ecosystem in the absence of intervention. To quantify this scenario empirically, areas outside the restoration project but ecologically comparable (or negative controls) are set and monitored. The without restoration project scenario estimates attributable changes (i.e., impacts) to restoration actions or external pressures.

During the restoration project implementation, impacts on the extension and/or condition of the ecosystem are expressed in area-adjusted condition units. Credit generation is based on the ecosystem state along the monitoring period and the minimum surface to which credits are accounted for. Effects from any potential leakage outside the project area are also deduced.

The economic valuation of credits is grounded in the monitoring of ecosystem services associated with the restored or managed ecosystem. At a minimum, carbon sequestration and biodiversity are considered. Carbon is quantified in physical units based on measurements of biomass and sediments, while biodiversity is approximated through observed changes in ecological relationships and associated biological indicators. These results are translated into monetary values using market references and natural capital accounting approaches. By aggregating the monetary values of ecosystem services, a gross value is obtained. From this value, the costs of restoration and management actions are deducted, including operational costs, monitoring costs, and amortized investments associated with the project (Fig. 4.2.3.1).

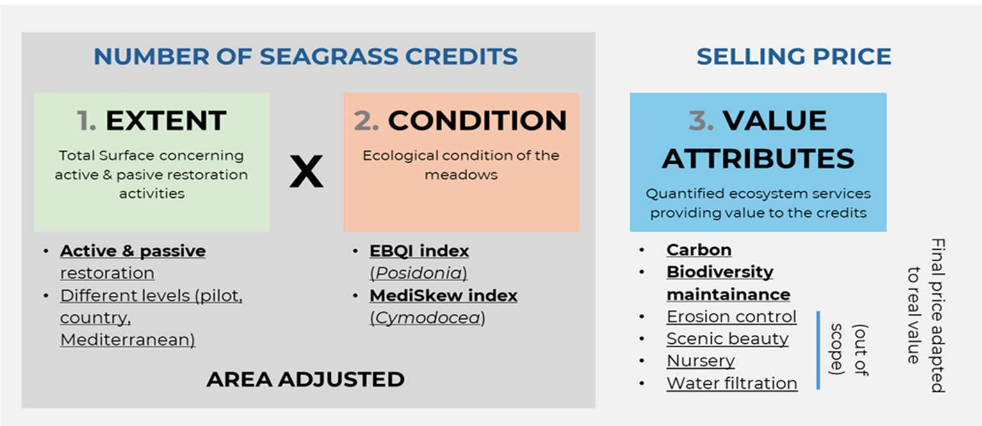


Fig. 4.2.3.1 Number of seagrass credits and selling price od *Posidonia oceanica* meadow.

4.2.4 - Characterization of Considered Ecosystem Services

Climate Regulation Service

The climate regulation service refers to the ecosystem's capacity to absorb carbon and thereby moderate local and global climate by regulating atmospheric carbon levels. This service evaluates the ability of Posidonia meadows to capture, store, and maintain carbon stocks.

The estimation follows the standard Blue Carbon methodologies outlined in "Coastal Blue Carbon: methods for assessing carbon stocks and emission factors in mangroves, tidal salt marshes, and seagrass meadows" by Howard et al., 2014. In detail:

• C org stocks (kg m^{-2}) are estimated as the cumulative mass of the corresponding element, standardized to 1 meter of sediment thickness.
• Short-term sediment accretion rate (SAR, cm yr^{-1}) is estimated from the age-depth model using ^{210}Pb dating. No fixed standardization is applied; standardization over the last 100 years is suggested.
• Long-term SAR (cm yr^{-1}) is estimated using ^{14}C dating, with suggested standardization over the last 1,000 years.
• Short-term accumulation rate of C org (g m^{-2} yr^{-1}) is calculated by multiplying the cumulative mass of C org accumulated over 100 years by the corresponding SAR.
• Long-term accumulation rate of C org (g m^{-2} yr^{-1}) is calculated similarly over 1,000 years.
• The age-depth model based on ^{210}Pb is applied to the first 20–30 cm of sediment, providing an average sediment accumulation rate using the Constant Rate of Supply (CRS) model (Appleby and Oldfield, 1978).
• The remaining core can be dated using ^{14}C analysis on dead P. oceanica sheaths, following standard procedures (Stuiver & Polach, 1977).
• Regression-based approaches can be used to upscale C org stock and Carbon Accumulation Rate (CAR) to the full extent of the meadow, as outlined by Ladd et al., 2022.

Consequently, once the amount of carbon absorbed by each meadow is calculated, it can be translated into an economic valuation. The result is obtained by multiplying the tons of carbon by a unit of carbon price. This unit's price may be derived from carbon market prices (voluntary or compliance) or abatement costs that is the costs society must bear to remove carbon from the atmosphere.

Biodiversity conservation

Biodiversity is not considered an ecosystem service. As defined in Article 2 of the Convention on Biological Diversity (CBD): "*Biological diversity means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.*"

In other words, biodiversity is a component of natural capital. Consequently, there is a relationship between the capacity of ecosystems to provide ecosystem services and the biodiversity present within them. However, this relationship does not necessarily imply that greater biodiversity results in a higher provision of services. Ultimately, although biodiversity is not a service itself, it is essential for ecosystem functioning and for the provision of all ecosystem services.

In this context, the focus can be placed on the value associated with the maintenance and conservation of biodiversity. To determine this value, the valuation procedure is based on the principle that the societal value of biodiversity is directly related to the costs incurred by society to conserve it.

The valuation method is defined by the management costs incurred for preservation, which ensure that ecological quality remains aligned with the highest standards of the recommended indices. These costs are therefore representative of an effort that may be recognized and financially supported through the purchase of a Payment for Ecosystem Services (PES). The costs considered in this assessment include:

1. Administrative/Management Costs: these include payroll costs for administrative tasks related to managing the protected area. It might refer to the preparation and implementation of management plans, which need to be tailored to the specific ecological and territorial needs of the areas.

2. Visitor Reception and Maintenance Costs: this covers information points, underwater trails, mooring areas, signs, and general upkeep of beaches and boats. It involves both investment and operational costs, along with payroll and maintenance.

3. Use Management Costs: this includes assessing site traffic, monitoring and managing fishing quotas, issuing permits for activities like recreational fishing and underwater diving, and monitoring compliance with these permits.

4. Site Monitoring Costs: this includes both coast and sea monitoring, as well as the costs associated with maintaining an alert system for sea monitoring. Monitoring costs also cover the labour required for various scientific monitoring activities, such as water quality, temperature, marine flora and fauna observation, fish stock, acoustic monitoring, and visitor traffic surveys.

5. Scientific Monitoring Costs: costs associated with both external and internal studies, including outsourcing research organizations and in-house payroll for scientific research and monitoring.

6. Educational and Public Activities Costs: expenses related to educational activities for schools and universities, summer activities, and the creation of educational documents and stories. This includes the cost of interpretive staff as well.

7. Restoration Interventions: these costs relate to specific projects aimed at restoring degraded habitats or addressing issues such as coastal erosion, which may require significant investments.

8. Conservation Projects: investments in initiatives for the protection of local fauna and flora, which may include repopulation programs or projects aimed at safeguarding endangered species.

4.2.5 - Selection of transplantation technique

The selection of the transplantation technique during the early planning phase of *Posidonia oceanica* transplantation has proven essential (La Porta and Bacci, 2022; Cunha et al., 2012; Paling et al., 2003). The main factors on which the success of *P. oceanica* transplantation depends are the choice of the receiving site and the adoption of the most suitable technique for the environmental conditions of the site. Success also depends on the specific methods of execution of the technique, which divers must scrupulously perform, and certain precautions that are sometimes crucial for effective and long-lasting transplantation. Some types of anchoring modules, such as concrete frames with metal mesh, different types of metal grids and stakes are, to date, among the most frequently used techniques for fixing *P. oceanica* cuttings to the substratum. Over time, additional anchoring methods have been tested and commonly used, such as, for example, mats and anchoring modules in bioplastic; other techniques, with greatest focus on the environmental sustainability of the technique, are also being tested (Pulcini et al, 2025; Pergent et al., 2024; Bacci and La Porta 2022; Pansini et al , 2022; Boudouresque et al., 2021;). Together with the transplantation of cuttings, additional experiences of meadow reforestation have been tested. These include the transfer of *P. oceanica* clods, comprising both plants and the underlying matte, the creation of consolidated substrata to accelerate the natural Posidonia recolonisation process and the use of seeds and seedlings as transplant material (Bacci and La Porta, 2022). For a description of the main operational techniques tested to date and commonly used in *P. oceanica* transplantation, please refer to Paragraph 4.3.3 – Transplantation techniques.

4.3- Implementation of *Posidonia oceanica* active restoration

4.3.1 - Selection of biological material for the transplantation

Cuttings intended for restoration purposes can be collected at low density from a donor meadow. Clods and cuttings that have naturally become detached due to hydrodynamics or the anchoring of boats, and which are found in the accumulation zone in the seabed, can be considered as an alternative to material removed from donor meadows. Furthermore, seedlings from seeds collected along accumulation seashore zones and germinated in aquaria can be used in restoration projects. The selection of biological material for restoration depends on the restoration objectives, e.g. restoration of degraded meadows, 'mending' of damaged meadow sections due to moorings or trawling, and compensation for partially or completely lost meadow areas due to marine and coastal project execution (e.g. pipelines). It also depends on the chosen technique and planting procedure. Some aspects of cutting management (e.g. stocking, manipulation and anchoring) are closely linked to the restoration planning phase. Furthermore, the technical expertise of the operators is also crucial when selecting and handling biological materials for restoration. Knowledge of the biological characteristics and structures and functions of *Posidonia* enables operators to select the best cuttings for restoration activities, thereby reducing the risk of unnecessary wasting of biological material.

Table 4.3.1.1 displays the main indication regarding the selection of *P. oceanica* material to be considered during the planning stages of active restoration activities.

Table 4.3.1.1: The main indication regarding the selection of *P. oceanica* material to be considered during the planning stages of active restoration activities.

BIOLOGICAL MATERIAL	NOTES AND TIPS
1. CUTTINGS COLLECTED FROM A DONOR MEADOW	
Type of cuttings (plagiotropic or orthotropic)	The choice of plagiotropic rhizomes appears to guarantee the best results in terms of the speed of vegetative growth and the survival rate. This is thanks to the plant's reserves of nutrients and antibiotic substances, which are essential for sustaining the plant during the critical post-explantation phase (Meinesz et al., 1992; Molenaar et al., 1993). However, the occasional scarcity of these rhizomes makes the selection of orthotropic rhizomes necessary. Under favourable conditions, these rhizomes also produce good growth (Bacci et al., 2024; Carannante, 2011; Meinesz et al., 1992).
Depth of cuttings extraction	Cuttings should be taken from donor meadows at a similar depth to the receiving meadow. However, cuttings taken from donor meadows at slightly greater depths adapt better during the rooting phase thanks to the new, more photosynthetically effective light conditions (Bacci & La Porta 2022; Fonseca et al., 1998; Piazzi et al., 1998; Chessa and Fresi, 1994; Genot et al., 1994; Molenaar and Meinesz, 1992).
Source of cuttings	In order to mitigate the pressure and potential adverse effects associated with excessive removal of cuttings, it is recommended that the biological material be sourced from multiple donor meadows, if they are present in the donor sites. Alternatively, the material can be obtained from different areas of the same donor meadow (Boudouresque, 2000).
Density of cuttings collection	The extraction of cuttings should be distributed over a substantial area and executed at a minimal density no more than 2 shoot/m^2 Boudouresque (2000) or 1-4 shoots/m^2 (Valiante et al. 2010) These numbers of shoots per unit area is consistent with the conservation of the donor meadow.
Period for collecting cuttings	Late autumn – early winter, period of vegetative stasis of the plant (Meinesz et al., 1992). Late spring can be the most favourable season for transplantation when meteorological conditions are favourable for the field activities and for rooting of transplanted cuttings (Pergent at al. 2024; Bacci i& La Porta 2022).
Transfer of cuttings	The cuttings should be transported in special containers (e.g. rigid mesh or jute bags), which minimise exposure to air. They should be kept constantly immersed in seawater at temperatures as close as possible to the temperature at the depth of removal, and in any case no lower than 15 °C and no higher than 25 °C (Bacci & La Porta, 2022)

2. CLODS AND CUTTINGS NATURALLY DETECTED FROM ACCUMULATION ZONES	
Type of clods and cuttings	Clods and cuttings that have naturally become detached due to hydrodynamics or the anchoring of boats.
Source of cuttings	Accumulation zones in the seabed of clods and cuttings that have been naturally detached. These zones are usually found within the donor meadows or in adjacent areas (Mancini et al., 2021).
Period for collecting cuttings	The late spring – autumn period, when there is a greater availability of clods (removed from the substratum by the anchors of pleasure boats) and of uprooted material in good condition (as a result of winter storms) (Mancini et al., 2021).
Clods and cuttings storage and transfer	Clods and cuttings must be transferred rapidly from zones of accumulation to restoration sites and can be stored underwater or in seawater containers with controlled environmental conditions. The best results were obtained when the time between harvesting and reimplantation was minimised to a few hours. The use of transplanting material collected more than three days previously is not recommended (Bacci & La Porta, 2022). To minimise stress for the clods and cuttings optimise the logistics and/or procedures for all restoration phases.
3. SEEDS AND SEEDLINGS	
Source and period for collecting of seeds	Seashore zones where seeds can be collected from accumulation zones. The collection phase takes place in late spring and usually lasts about one month (Rinaldi et al.,2024; Sutera et al., 2025)
Germination of seeds in aquaria	Vital seeds under controlled conditions in aquaria (e.g. temperature of 20-24°C, salinity of 37 ppm and a 12-hour light/dark cycle) lead to germination phase and produce seedlings (Zenone et al., 2025; Rinaldi et al., 2024; Provera et al, 2024; Bacci & La Porta, 2022).
Growing seedlings in aquaria	Growing seedlings in aquaria approximately for 3-4 months before their use for restoration (Pergent-Martini et al., 2024).
Transport of young seedlings	Reduce stress on young seedlings during transfer between aquariums and restoration areas. Optimise logistical and/or procedural choices for all stages of restoration.

4.3.2- Preparation and positioning of transplanting modules

The method of anchoring cuttings to supports for transplantation modules depends on the technique used and whether the work is carried out on the surface or underwater. Cuttings should be placed 5–10 cm apart (Molenaar & Meinesz, 1995). However, the density should never prevent sediment retention between cuttings. Various *P. oceanica* transplantations indicate that an optimal density is around 30 shoots per m², as this avoids excessive competition between shoots and promotes the rapid plagiotropic growth of rhizomes (Bacci and La Porta, 2022). In other case studies, the plants are arranged in recolonisation nuclei comprising a minimum of 20 cuttings with each more shoots, making sure that the centre of each nucleus is at least 1 meter away from all adjacent nuclei (Piazzi et al, 2021; De Luca et al., 2025).

In this phase, it is essential to have qualified underwater operators who have knowledge of marine biological and ecological systems and specific experience in handling *Posidonia* cuttings for transplantation. This will ensure better selection of cuttings and minimise stress to the plants during handling and fixing to supports. The geometric arrangement of the transplantation modules is specific to each technique. It must generally allow the growing cuttings to create nuclei that can join to form a continuous meadow over time. Therefore, the areas chosen for restoration must be sufficiently large to allow the restored meadow to expand in the medium and long term.

For an examination of the preparation and fixing of cuttings, and their positioning according to the specific technique, please refer to chapter 4.3.3 - Transplantation technique.

4.3.3 - Transplantation techniques

The main operational techniques for transplanting *P. oceanica* are described in the Table 4.2.3.1 and refers to: reinforced concrete frames with wire mesh; geomats and biomats; metal grids; biodegradable modular supports; stakes. These techniques have been tested in several case studies to date and are commonly used in restoration activities. (Boudouresque et al., 2021; Bacci & La Porta, 2022; Pergent et al., 2024). Some of these techniques are covered by patents (reinforced concrete frames with wire mesh; biodegradable modular supports). Differently, other techniques as well as metal grids and stakes, have been used in phanerogam transplantation since the early 1980s, in various shapes and sizes, for both experimental and large-scale environmental restoration projects. (Fonseca et al., 1982; Meinesz et al., 1992; Molenaar and Meinesz, 1992; Meinesz et al., 1993; Molenaar et al., 1993; Genot et al., 1994; Molenaar and Meinesz, 1995; Piazzi et al.,1998; Lepoint et al., 2004; Pirrotta et al., 2015; Pereda-Briones et al., 2018; Robello, 2019; Mancini et al., 2019; Castejón-Silvo et al., 2021).

Table 4.3.3.1 Technical information of reinforced concrete frames with wire mesh used for the restoration of *Posidonia oceanica* seagrass.

Technique	Reinforced concrete frames with wire mesh
Description of the anchoring support	The concrete frames measuring 50 cm per side, about 5 cm thick, have an inner opening of 40 cm (1,600 cm^2) and are reinforced with galvanized wire mesh with 1.5–2 cm openings.
Patent	The frames are covered by Italian Patent No. 0001360267, titled 'Anchoring Structure for Plant Organisms'.
Anchoring substratum	Soft seabeds with fine sediments and moderate hydrodynamics are ideal for placing concrete frames, typically at depths of 10–15 m with gentle slopes. Suitable transplantation areas should be medium-sized (about 100–200 m^2), sheltered by surrounding meadows, and free from erosion or sediment movement, while very small areas should be avoided to ensure effective monitoring.
Cutting type	Cuttings are obtained from the collection of predominantly orthotropic rhizomes taken from the non-margin portions of the meadow. When selecting the cuttings, consider the general state of each shoot at the surface.
Placement at the sea of anchoring support	To prevent fractures, the frames should be placed on pallets and then handled manually. It is advisable to install the transplantation modules before shoot collection to optimise operations. The anchoring supports are arranged side by side.
Fixing cuttings to the anchoring support	Divers manually plant the cuttings by inserting the rhizomes into the meshes, in contact with the sediment and tightening it to secure them, trying to space them out evenly. The modules remain independent and don't require anchoring to the seabed.
Density of cuttings/shoots	32 cuttings (each carrying one orthotropic shoot) /m^2
Environmental sustainability of the technique	The concrete frames degrade slowly, influenced by hydrodynamic action, but the process can stop once they become embedded in the matte of the transplanted seagrass meadows. Within a few months they sink into the sediment and become invisible; after about five years the habitat appears fully integrated, and after ten years the frames have almost completely disappeared (Bacci et al. 2024). In the meantime, they provide a substrate for benthic organisms typical of hard-bottom environments.

Table 4.3.3.2 Technical information of Geomats and biomats used for the restoration of *Posidonia oceanica* seagrass

Technique	Geomats and biomats
Description of the anchoring support	The technique uses "MacMat®" natural coconut fiber biomats as anchoring supports for *Posidonia oceanica* cuttings, seeds, or seedlings. The "R.E.C.S.® - Cocco" (Reinforced Erosion Control System) geocomposites, a coconut fibre net (biomat) is coupled to the double twist metal mesh. Mats varying in size between 5 m and 12.5 m in length by 2 m in width gave excellent guarantees of stability and capacity. Supplied in rolls (50 × 2 m), they are cut to size, laid on the substrate, and anchored with metal stakes 1.4 cm in diameter and 120 cm long.
Anchoring substratum	The most suitable substratum for the mats is dead *P. oceanica*, although sand can also be used if hydrodynamic stress is low. This technique can be used at any depth within the survival range of P. oceanica, with the ideal depth being between 12 and 20 metres in oligotrophic waters that are exposed to strong hydrodynamics. Substrate slopes tested are generally slight, but mats can adhere to steeper seabeds if properly secured to minimise drag. Mats should be at least 5 m long to ensure the supporting mesh has sufficient flexibility.
Cutting type	Cuttings are collected from donor meadows, including naturally uprooted material, drifting seeds, and seedlings. Both orthotropic and plagiotropic cuttings are used, preferably plagiotropic with 1–3 shoots, trimmed to ~10 using pruning shears cm.
Placement at the sea of anchoring support	The cut-to-size mats are transported on small boats and lowered to the seabed, where divers secure them with 120 cm-long metal stakes bent into an 'L' shape, which are driven in with 5 kg mallets (one per m^2). In exposed areas, stronger anchors, such as the Manta Ray system, are required. It is advisable to lay the modules before collecting the cuttings.
Fixing cuttings to the anchoring support	Cuttings are secured to mats by wedging rhizomes into the fibre weave using a dibber, while seeds and seedlings are placed manually. Plants are arranged in nuclei of at least 20 cuttings, spaced at least 1 meter apart.
Density of cuttings/shoots	20 cuttings (each carrying 1-3 shoot) /m^2
Environmental sustainability of the technique	The use of geocomposites, such as MacMat® mats and the R.E.C.S.®. , exploits the emergent property of *Posidonia oceanica* to modify the surrounding substrate. These mats support the anchoring of cuttings and seedlings, sediment retention, seabed stabilization, and algal colonization, promoting the structural and functional restoration of degraded meadows (Temmink et al., 2020; Valdez et al., 2020). The use of biodegradable materials makes the technique ecologically sustainable and suitable for large-scale projects. An advanced evaluation is also underway of bioplastics based on hydroxyalkanoates, which could replace the polypropylene filament in the MacMat® mat (Pulcini et al., 2025).

Table 4.3.3.3 Technical information of Biodegradable modular supports used for the restoration of *Posidonia oceanica* seagrass

Technique	**Biodegradable modular supports**
Description of the anchoring support	The anchoring system consists of a 75 cm diameter radial bioplastic structure with five arms, each holding 1–4 cuttings with at least three shoots, fixed with tear strips and anchored to the seabed via a central hub and stake. Its modular design allows adaptation for other plant organisms.
Patent	The modular anchoring system (Support system for the plantation of plant organisms in the marine environment") is covered by the following patents: • Italian patent: No. 0001400800/2013 • European design: No. 003000686-0001/2016 • Italian patent: No. 102015000081824/2018
Anchoring substratum	The modular anchoring system in bioplastic material is mainly used in transplantation on dead matte; experimentation on soft substrata (sandy seabeds with different granulometric compositions) is still lacking.
Cutting type	Cuttings are collected from rhizomes at the meadow edges or from naturally uprooted material, with a minimum length of 15 cm and at least 3 shoots.
Placement at the sea of anchoring support	Divers prepare the seabed by placing poles for anchoring the systems. Modules can be arranged individually, in rows, or in clusters of six to mimic natural meadow patches, adapting to seabed morphology and fragmentation (Marbà and Duarte, 1997).
Fixing cuttings to the anchoring support/ Preparation of the seabed	Cuttings are selected at the surface and secured to the arms with tear strips, with shoots facing upwards. Each arm holds 2–4 cuttings (10–20 per system, 30–60 shoots). The arms are attached to the central hub and kept submerged in seawater throughout the procedure to prevent dehydration.
Density of cuttings/shoots	10/20 cuttings (each carrying ~3 shoot) /m^2. The anchoring system covers about a m^2.
Sustainability of the technique	The support is made of Mater-Bi®, a starch and vegetable oil-based bioplastic that is biodegradable and non-toxic to marine microorganisms, with degradation times compatible with rooting of cuttings (Campani et al., 2020). Certified under the ETV pilot program, its modular design allows flexible seabed coverage, application to various plant species, simplified anchoring, and improved installation efficiency.

Table 4.3.3.4 Technical information of Metal grids supports used for the restoration of *Posidonia oceanica* seagrass

Technique	Metal grids
Description of the anchoring support	Among different types of grids used in seagrass transplantation projects, small electro-welded metal grids can be suggested. The use of larger grids is equally feasible but makes it more difficult to deploy them at sea. (e.g. in Pirrotta et al., 2015: 1 x 1 electro-welded metal grid, with Ø 2 mm, 50 x 50 mm mesh, weighing 1.3 kg; fixed on matte by means of ~70 cm long iron hooked starters).
Patent	-
Anchoring substratum	The metal grid anchoring system is effective for transplantation on *dead* matte, but it is unsuitable for sandy substrates (Scardi et al., 2014) and poorly documented for rocky substrates.
Cutting type	Cuttings collected from donor meadows or plants naturally uprooted have been used. (e. g. in Pirrotta et al., 2015: cuttings at least 15 cm long and have three or more shoots are taken from the rhizomes of plants at the edges of donor meadow).
Placement at the sea of anchoring support	If the grids are small enough, they are deployed at sea after the cuttings have been secured. Otherwise, with larger grids, the cuttings must be secured to the grids after they have been positioned at sea. The grids can be arranged in rows, quincunx, or patches to mimic natural meadow colonization and restoration (Cunha et al., 2012; Calvo et al., 2021).
Fixing cuttings to the anchoring support	Plant cuttings are selected and attached to a metal grid using wires or biodegradable strips. The shoots are positioned facing upwards to simulate their natural orientation on the seabed after detachment from the meadow (Meinesz et al., 1992). Each grid of 1 x 1 m can hold up to 20 cuttings (Pirrotta et al., 2015).
Density of cuttings/shoots	20 cuttings (each carrying ~3 shoot) /m^2 (Pirrotta et al., 2015).
Environmental sustainability of the technique	The electro-welded metal grid is lightweight, cost-effective, easy to handle and adaptable to various substrates. Its small size enables it to disintegrate completely within 4–5 years (Pirrotta et al., 2015), which is sufficient time for it to anchor cuttings and rhizomes. Additionally, biodegradable tear strips enhance its environmental sustainability. The use of small grids reduces the need for divers, since most of the activities are carried out ashore.

Table 4.3.3.5 Technical information of Stakes supports used for the restoration of *Posidonia oceanica* seagrass

Technique	Stakes
Description of the anchoring support	Among different types of stakes used in seagrass transplantation projects, some models that have yielded used successfully are described. e.g. in Mancini et al. 2021: iron stake with diameter of 0.6 cm; tensile strength, measured underwater with a spring dynamometer, is 6 kg (59.5 N), 20 cm long (for use with matte) or 50 cm long (for sandy or soft seabeds) and 10 cm wide, with each semicircle measuring 5 cm in width and 8 cm in length. Since 2020, comparable U-shaped iron stakes (around 17 × 3 cm) have been routinely employed (www.medseafoundation.org) in several Mediterranean Posidonia restoration projects, demonstrating reliable performance on dead matte and ease of handling during underwater operations.
Patent	-
Anchoring substratum	Stakes have proven to be effective tools for transplanting *Posidonia oceanica* on dead matte on gently sloping seabeds between 8 to 30 m. Compact matte, minimally degraded, and partially covered by coarse sand, with a rich algal community, providing an ideal substrate for rhizome anchoring. Tests on coarse sand (60–98% gravel) showed that long stakes ensure good rhizome stability (Mancini et al 2021), although literature evidence on this substrate is limited. This technique is particularly suitable for fragmented meadows, where dead matte is often interspersed with patches of living Posidonia, creating a heterogeneous mosaic of substrates that requires adaptable anchoring solutions. (Pulcini et al., 2025).
Cutting type	Cuttings collected from donor meadows or plants naturally uprooted can be used. Cuttings primarily from naturally detached clods have been used both in large spatial scale restoration (Mancini et al., 2021), and in several smaller ones (www.medseafoundation.org). The optimal material consisted of 10–30 cm plagiotropic rhizomes bearing two to four healthy foliar shoots and roots. However, orthotropic shoots were also used.
Placement at the sea of anchoring support/ Preparation of the seabed	To ensure the anchoring supports are positioned uniformly at sea and to improve the management of subsequent monitoring activities, the seabed can be prepared in advance by dividing the entire transplantation area into 10 x 10 m squares marked off with ropes fixed to the substratum and georeferenced (Mancini et al, 2021). Delimiting the seabed is not always useful, especially when dealing with different transplant geometries (e.g. patchy).

Fixing cuttings to the anchoring support	Transplantation involves fixing cuttings to stakes and inserting them into the substrate simultaneously. Divers manually anchor each cutting with one or two stakes, using a small hammer if necessary and taking care not to damage the rhizome. For a homogeneous placement at the sea of anchoring supports (Mancini et al., 2021) operators work inside a 1 x 1 m portable aluminium frame within a pre-marked 10 x 10 m area to ensure full coverage, moving the frame sequentially and placing cuttings randomly but evenly spaced. For a patchy placement (www.medseafoundation.org), operators place the cuttings while maintaining an approximate distance of 1 m between the centres of adjacent nuclei, ensuring adequate spacing for rhizome expansion and allowing flexible deployment in fragmented or heterogeneous meadows.
Density of cuttings/shoots	5/9 cuttings (each carrying ~2-4 shoot) /m^2, corresponding to an average of 23-28 shoots/m^2 (Mancini et al., 2021). In other transplants (www.medseafoundation.org), cuttings are typically transplanted at densities of 10–12 cuttings/m^2, ensuring a minimum coverage of approximately 20 shoots/m^2.
Sustainability of the technique	The iron stakes corrode quickly in seawater. In Mancini et al., (2021) after 4 years, they have lost 20% of their thickness, with the most exposed parts losing up to 50%. They are expected to fully disintegrate within eight to 24 years, which minimises their environmental impact. Once planted, the stakes are almost invisible, concealed by rhizomes and algae, and they do not alter the landscape or habitat of the meadow. Advantages of this method include the ease and speed with which it can be implemented underwater, without the need to move heavy materials or construct structures above or below the water. The removal of the stakes after the successful anchoring and establishment of the cuttings is also possible and can further reduce the presence of non-natural materials in the restored area. However, this operation must be carefully evaluated on a case-by-case basis and avoided whenever it may cause damage to the cuttings themselves (Pulcini et al., 2025).

4.4 - Monitoring the *Posidonia oceanica* active transplantation

4.4.1 - Verification of transplantation success

In the case of engineer species with slow growth such as *Posidonia oceanica*, it might be useful to distinguish between "transplantation success" and a "restoration success. Monitoring that highlights the transplantation success must be carried out at regular, predefined intervals, especially during the period following completion of the transplantation process. The monitoring period must be long enough to allow for the growth rates of the plant to be evaluated. Differently, the long-term monitoring that highlights the restoration success would imply the recovery of habitat structure, species composition, ecological functioning or ecosystem services that had been lost at a specific site.

Table 4.4.1.1 shows the monitoring periods and their purposes for a transplantation operation.

Table 4.4.1.1: Monitoring periods and their purposes for a transplantation operation.

Monitoring Period	Purpose
Short-term monitoring (≤ 2 years)	Assess the rooting of the biological material and any non-survival due to natural mortality or mechanical damage (e.g. storms, fishing activities, or anchoring). Activities aimed at quantifying transplantation success.
Medium-term monitoring (2 < years ≤ 5)	Assess the growth trajectory of the transplantation as a balance between initial losses and the subsequent phase of growth and expansion, leading towards ecological stability. Activities aimed at quantifying transplantation success.
Long-term monitoring (> 5 years)	Assess the achievement of transplantation maturity and the acquisition of structural and functional characteristics comparable to those of a natural meadow. Activities aimed at quantifying restoration success.

To effectively verify the outcome of a restoration, it is important to define an appropriate monitoring plan according to the restoration surface, technique used, and local environmental conditions. Essential aspects to guarantee the effectiveness of monitoring include:

- selecting a significant number of monitoring areas in both the transplanted area and the control receiver meadow;
- selecting a significant number of sample units for the various sample monitoring areas identified;
- labelling of the sample units, which takes place at the same time as their selection, and periodic maintenance must be provided.

Table 4.4.1.2 shows the metrics and parameters that best describe the status and growth dynamics of the restoration during the different monitoring phases.

Table 4.4.1.3 shows the monitoring plan for a restoration operation using cuttings. The parameters to be investigated and the frequency of surveys in the characterisation phase before restoration operation and the monitoring phase after restoration are illustrated.

Table 4.4.1.2 Metrics and parameters that best describe the status and growth dynamics of the restoration during the different monitoring phases.

Monitoring time scale	Metrics and parameters for restoration verification	Technical specifications
Short-medium term monitoring	Temporal trend of the average number of shoots per sample unit (Ym) in relation to the initial number of shoots (Y0) (expressed as multiplier factor = Ym / Y0)	The total number of shoots per sample unit includes both transplanted shoots and new shoots originating from them.A sample unit is a sampling surface on which the total number of foliar shoots is counted. This can be represented by an anchoring module or by standard surfaces within which the transplanted cuttings are anchored.
	Temporal trend of the number of sample units lost in relation to the total number of sample units monitored (expressed as %)	The number of sample units lost includes those with no shoots.
	Temporal trend of the coefficient of variation calculated on the number of shoots per sample unit.	The coefficient of variation is an effective indicator of transplant stability, identifying the point at which shoots mortality no longer affects growth, which becomes balanced regardless of the density level in the sample unit (AA.VV., 2020a).
	Coverage of the area colonised by transplanted shoots of *Posidonia oceanica.*	The coverage is expressed as the substratum surface area colonised by the *Posidonia* cuttings in relation to the initial surface area transplanted, once a significant monitoring surface has been defined as representative of the total transplantation area. Underwater photogrammetric technologies are recommended (Pergent et al. 2024; La Porta & Bacci 2022).
Long-term monitoring	Average absolute density (expressed per m2) of the transplantation area and the surrounding natural meadow.	The average absolute density, as measured by the methodologies employed in natural Posidonia oceanica meadows (Bacci et al., 2015; Pergent et al., 1995; Panayotidis et al., 1981; Giraud, 1977), provides an accurate representation of long-term restoration dynamics and enables comparison with neighbouring natural meadows (Calvo et al., 2021; Bacci et al. 2024).
	Coverage of the area colonised by transplanted *Posidonia oceanica*.	Coverage is an effective indicator of the long-term outcome of the transplantation process, highlighting the level of development of the transplant and any surface area lost. Underwater photogrammetric technologies are recommended (Pergent et al. 2024; La Porta & Bacci 2022).
	Phenology and Lepidochronology	Phenological and lepidochronological analyses reflect the level of maturity that the restoration has reached over time compared to the adjacent natural meadow (Calvo et al., 2021; Bacci et al. 2024).

Table 4.4.1.3. Summary diagram showing the parameters and sampling frequencies to be adopted for monitoring a *Posidonia oceanica* transplant intervention.

		Characterization Monitoring	**Short/Medium term Monitoring**		***Long-term Monitoring***
Surveyed area	**Parameter**	**Frequency (Freq)**	**Freq Year I and II**	**Freq Year III to V**	**Freq from Years VI to X**
Donor meadow	Coverage of the meadow	Once (before explantation)	Based on the purpose of the research		
	Shoot density				
	Phenology				
	Lepidochronology				
	Associated flora and fauna				
Site (near the receiver meadow)	Temperature		On the basis of the specific site conditions and the purposes of the research		
	Salinity				
	Water clarity				
	Light intensity				
	pH				
	Oxygen				
	Nutrient load				
	Particle suspension				
	Sedimentation rate				
	Sediment granulometry				
	Organic substance content				
	Local hydrodynamic regime				
Receiver meadow	Coverage of the meadow		At least once	At least once	At least twice
	Shoot density				
	Phenology				
	Lepidochronology				
	Associated flora and fauna				
Transplantation area (in the receiver meadow)	Survival rate of cuttings	-	Every 3/6 months	–	–
	Root production				
	Rhizome elongation			Every 6/12 months	
	Leaf elongation				
	Coverage of the area colonised by the cuttings				Every 12/24 months
	Formation of new shoots				
	Shoot density		Based on the purpose of the research		
	Phenology				
	Lepidochronology				
	Associated flora and fauna				

4.5 - Management of *Posidonia oceanica* restoration

4.5.1 Integration between the active and passive measures of restoration

Both active and passive restoration require the adoption of best practices, as well as constant synergy between research, government action, and the active participation of citizens, in order to guarantee the protection and recovery of marine habitats, and the ecosystem services they provide. For example, the adoption of restoration protection measures such as anti-trawling devices and mooring buoys near the restored area serve to ensure the integrity of the transplant modules over time.

When restoration is carried out as a compensatory measure for damage due to human activity, the most preferred option may be to locate the compensation area within or in proximity to the nearest Natura 2000 site where the conditions are suitable for the measure to be successful. However, this is not always possible, so a range of priorities should be applied when searching for locations that meet the requirements of the Habitats Directive. Providing the same contribution to the ecological structure and/or network function, compensation outside the Natura 2000 site concerned, both in a common or different topographical or landscape unit, is feasible. The new location can be in another Natura 2000 site or in an undesignated area. In the latter case, the location may be designated as a Natura 2000 site and be subject to all the requirements of the Nature Directives, as specified in the Guide to the interpretation of Article 6 of Directive 92/43/EEC, 2019/C 33/01.

4.5.2 Temporary prohibition of fishing, shipping and anchoring in restoration areas

To protect restoration sites in areas subject to high anthropogenic pressure, the competent authorities should issue specific ordinances to temporarily ban activities such as recreational and trawl fishing (the latter of which is illegal in *Posidonia* meadows) and the anchoring of pleasure boats. These ordinances should also provide for regular surveillance by the authorities throughout the restoration process and monitoring period. Failure to regulate these areas and prevent significant damage to anchoring modules and transplanted plants threatens the success of the restoration process (AA.VV., 2021c, 2020a).

4.5.3 Replacement of failures

Small 'repairs', performed to compensate for the loss of transplanted cuttings, help to ensure the success of the restoration process, particularly in the early years. A plan for replacing non-surviving plants must be envisaged during the restoration planning phase and implemented as soon as monitoring shows excessive loss of cuttings due to natural death and/or environmental conditions or human activity damaging the transplantation during the early years. The replacement frequency and duration must be defined according to the technique used and should not be less than two years after transplantation.

4.5.4 Appreciation of the restoration

Posidonia oceanica transplantation is not merely a technical intervention but a complex social-ecological and governance process. Its appreciation and long-term success depend on transparent communication on costs, benefits and opportunities, transparent governance, and active participation and buy-in by local stakeholders. Developing an information and communication strategy in collaboration with relevant actors from the outset is therefore essential to ensure shared understanding and support throughout all phases of restoration.

Active interventions such as transplantation must be complemented by passive measures including habitat protection, continuous monitoring, and community stewardship. While transplantation can deliver ecological benefits, its sustained impact relies on local ownership, institutional alignment, and adaptive management.

Effective engagement requires dialogue across all stages: prior to implementation to build trust and co-define objectives; during implementation to maintain visibility and participatory roles; and after implementation to communicate monitoring outcomes and reinforce adaptive management. Inclusive and transparent processes can transform externally imposed regulations into socially supported and locally valued practices.

A systematic stakeholder analysis designed to inform future consultation activities is an essential structured approach that lays the groundwork for more in-depth consultation, ensuring that restoration planning and market development are informed by a comprehensive understanding of stakeholder perspectives and capacities. For further details related to stakeholder engagement see Section 2 - Restoration and governance of *Posidonia oceanica* meadows.

Insights from private-sector engagement further emphasise that investment and long-term commitment depend on credible governance frameworks, measurable ecological outcomes and the protection of ecosystem integrity. Aggregating restoration projects at a landscape scale, standardising monitoring approaches and maintaining transparent communication enhances confidence among stakeholders and investors alike.

Ultimately, appreciation of restoration emerges when ecological, social, and financial dimensions are integrated from the outset. By embedding communication, governance, adaptive management, and stakeholder participation alongside active restoration, local initiatives can evolve into replicable and sustainable models that strengthen both ecological outcomes and institutional resilience.

4.5.5 Decommissioning of the active restoration

If the active restoration is unsuccessful, the seabed affected by the operation must be cleared of all materials used, such as transplant modules, fixing pegs and mats. A decommissioning plan must be envisaged in the restoration planning phase and carried out as soon as monitoring reveals the failure of the operation for adverse weather-marine events or anthropogenic action, with the aim of avoiding the accumulation of foreign materials and waste in the sea.

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Accelerating the Restoration of Seagrass Meadows in the Mediterranean area through Innovative ecosystem-service based Solutions

Euro-MED0200867

Restoration roadmap and pilot sites report

Deliverable 1.3.1 _ Annex 1: *Posidonia oceanica* restoration: description of restoration plan and methodologies adopted at pilot sites

Annex 1 - *Posidonia oceanica* restoration: description of restoration plan and methodologies adopted at pilot sites

Annex 1 shows the restoration initiatives undertaken at the four pilot sites of the Artemis Project. In the three case studies of Atzikiari, Siteia (Crete, Greece), Capo Testa Punta Falcone (Sardinia, Italy) and Cala Blanca, Ciutadella (Menorca, Spain) transplants of *Posidonia oceanica* were carried out. The case study of Panzano Bay (Monfalcone, Italy) describes a restoration initiative involving *Cymodocea nodosa* that preceded the Artemis Project. In the first three case studies, the activities were carried out, albeit with the necessary adaptations to each local conditions, in accordance with the Road Map presented in deliverable D1.1.3. The activities at the various pilot sites of the Artemis Project were therefore useful to verify the methodologies developed and their implementation, as outlined in the road map presented.

1 - Restoration plan and methodologies adopted at the Atzikiari pilot site, Siteia (Crete), by the Hellenic Centre for Marine Research.

1.1 Local Stakeholders mapping

A comprehensive stakeholder mapping was conducted for the Greek pilot site in Atzikiari, Siteia (Crete), identifying a total of 126 stakeholders. These were systematically categorized across a wide spectrum of sectors, including public authorities, scientific and academic institutions, civil society organizations (NGOs), private sector actors, and local governance bodies. Each stakeholder was assessed based on their relevance, level of influence, knowledge, and involvement in activities related to *Posidonia oceanica* restoration, as well as their connection to the ARTEMIS Interreg EURO-MED project.

From this broader pool, 17 key stakeholders were selected for in-depth interviews, based on their institutional mandate, influence on policy or implementation, and direct or indirect role in restoration governance. The semi-structured interviews were based on a discussion guide that had been prepared beforehand. The interview results were thematically analyzed across three main axes: (1) awareness and understanding of *Posidonia oceanica* and its ecological value; (2) the current governance and restoration framework; and (3) awareness and attitudes toward Payment for Ecosystem Services (PES). While there was a high level of awareness regarding the ecological importance of Posidonia, significant gaps were identified in restoration-specific knowledge, clarity of institutional responsibilities, and familiarity with PES mechanisms. These gaps present key barriers, but also strategic opportunities for targeted interventions under a national restoration roadmap.

Crucially, all stakeholders expressed support for the development of a realistic and context-sensitive restoration framework. They highlighted the importance of a centralized institutional roadmap, underpinned by clear restoration guidelines, enhanced inter-agency coordination, and localized benefit-sharing mechanisms (e.g. retaining revenues from environmental penalties within the local community). The findings underline the need to clarify institutional mandates, strengthen monitoring and enforcement, and provide a comprehensive and mandatory set of restoration guidelines, in order to secure the best possible outcomes and ensure consistent, comparable results across sites. These findings highlight the importance of the Guidelines provided through this project.

1.2 *Posidonia oceanica* restoration planning

1.2.1. Site characterization

The pilot restoration activity was conducted in Atzikiari Bay, Eastern Crete (NATURA 2000 site GR4320006), which hosted a fish farm from 1996 to 2017 producing over 1,000 tons of gilthead sea bream and sea bass. Environmental assessments took place in 2008, 2019, and 2023. In 2008, the bay was heavily polluted with organic matter from the farm, creating anoxic seabed zones, bacterial mats, and severe degradation of *P. oceanica* meadows near the cages. By 2019, two years after farm removal, sediments remained degraded (organic carbon 11.92 mg/g, seven times higher than a reference site), bacterial mats persisted, and the exotic seagrass, *Halophila stipulacea*, had spread, while *P. oceanica* was largely absent except in distant areas. Solid waste maintained anoxic conditions.

The 2023 assessment showed water column parameters returned to normal seasonal levels. Sediment organic carbon halved since 2019 but remained elevated, indicating partial recovery. Bacterial mats disappeared, while *H. stipulacea* continued to expand across the bay. *P. oceanica*, although showing signs of recovery in the more exposed parts of the bay, has not recolonized the areas near the former fish farm cages, where only dead *P. oceanica* matte remained.

1.2.2 Characterization and assessment of the donor and receiving meadow

The donor meadow extended in the southern-central part of the bay, between 15 and 22 m depth, covered a total of 1.1 ha and had “Good” ecological status (EQR = 0.739), based on the wePOSI. In the inner bay, at depths 5 and 15 m, continuous dead matte formations prevailed. Along the outer margins, at depths of 10 – 22 m, mixed habitats of P. oceanica and dead matte were observed, covering 2.2 ha and having a “Moderate” ecological status (EQR = 0.479). Overall, the ecosystem status of *P. oceanica* meadows of Atzikiari bay, based on the EBQI, was classified as "Bad" (EBQI = 3.1; CI = 4).

1.2.3 Assessment of ecosystem services of donor and receiving meadows

The biodiversity survey of the Cretan pilot site revealed a strong ecological link between *P. oceanica* meadows and their associated communities, dominated by planktotrophic fish and the bryozoan *Pentapora ottomulleriana*. The degradation caused by fish farming has led to a sharp decline in these specialized species, replaced by opportunistic and non-indigenous taxa such as the thermophilic goatfish *Parupeneus forsskali*, which dominate in degraded or dead matte areas. Similarly, macrofaunal assemblages shifted from diverse Posidonia-associated species to gastropod grazers, reflecting structural simplification and ecosystem decline. Seagrass loss also affected carbon storage: vegetative carbon stocks were five times lower in impacted stations than at the control, while sedimentary carbon was higher (231 ± 12 Mg ha-1 and 153 ± 17 Mg ha-1 at the top meter of impacted and control station, respectively) due to enrichment from fish farm discharges and geomorphology of the bay. The spatial installation of the fish farming facility in relation to the natural distribution of the meadow in the area and the geomorphology and resulting hydrodynamics in the bay resulted in higher sedimentary carbon storage in dead matte and loss seagrass cover areas. However, the carbon stored in the impacted stations, although high in amount, derived mainly from allochthonous sources, accounting for 65 %, on average, of the organic matter pool, representing a more labile carbon pool and therefore a less permanent carbon sink.

1.2.4 Selection of restoration technique

The restoration plan employed a mixed approach tailored to different implementation phases. For pilot testing, U-shaped metal staples were selected to secure cuttings in small groups across different areas and depths, based on their lightweight design, rapid underwater deployment capability, minimal material transport requirements, and demonstrated effectiveness on compact matte substrates (Mancini et al., 2021; Castejón-Silvo et al., 2021). This initial phase assessed technique effectiveness and survival rates before proceeding to full-scale implementation. For full-scale restoration, two distinct anchoring techniques were employed: metal staples and coconut-fiber mats. This experimental design leveraged the complementary strengths of both methods. Metal staples provided deployment speed and simplicity, while coconut-fiber mats enhanced sediment retention, seabed stabilization, and large-scale efficiency by exploiting *P. oceanica*'s capacity to modify surrounding substrate and support algal colonization (Temmink et al., 2020; Valdez et al., 2020).

Both techniques utilized biodegradable materials to ensure temporary anchoring during establishment followed by natural elimination. The selected techniques proved effective in the target depth range (7-12 m) on matte substrates and well-suited to the conditions at Atzikiari Bay. The dead matte at both restoration depths provided suitable substrate for implementation, being compact, minimally degraded, and partially colonized by macroalgae. The gentle seabed slopes and moderate hydrodynamic regime, with the inner bay positioning reducing displacement risk, made both techniques appropriate for the site conditions.

1.3Implementation of *Posidonia oceanica* restoration

1.3.1 Passive

As an initial step in the restoration work at Atzikiari Bay, HCMR, in collaboration with the Greek NGO Aegean Rebreath, carried out an underwater and coastal clean-up to remove remnants of the fish farm that closed in 2017. The collected material included plastic tubes, nets, rubber tires and other material found on the seafloor at depths of up to 25 meters, along with significant plastic waste washed up on the shore. This intervention is important for promoting the ecological recovery of the bay and creating a healthier foundation for the upcoming transplantation activities.

1.3.2 Selection of biological material for the restoration

Material source selection

Natural fragments (detached shoots) were not available in sufficient quantities at Atzikiari bay, making selective pruning of cuttings from the living meadow the only viable option for obtaining transplantation material. This approach required careful management to avoid donor meadow degradation and allowed access to high-quality plant material with intact rhizomes and active growth potential. Cuttings were collected at low density from the healthiest part of the meadow (Fig. 1.1), following established guidelines to balance restoration needs with donor meadow conservation.

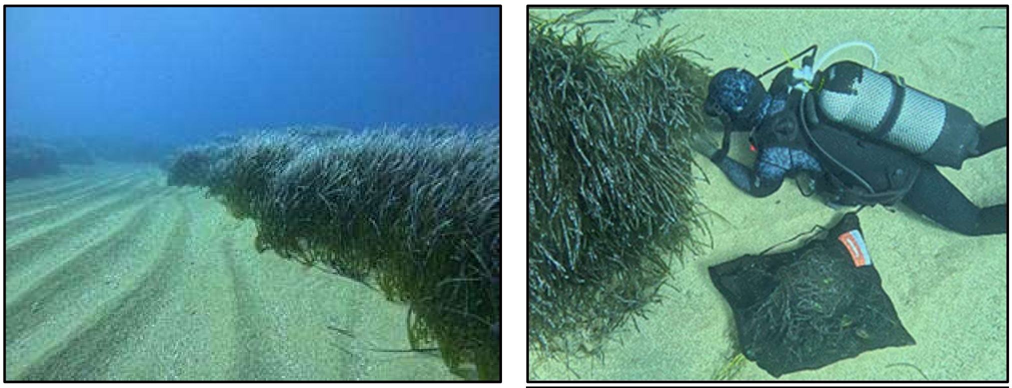

Figure 1.1 (A) Donor meadow where cuttings were collected; (B) HCMR's scientific diver selecting and collecting cuttings from meadow edge.

Cutting type selection

Only cuttings from the meadow edges were collected for transplantation. The preferred cuttings consisted of both plagiotropic and orthotropic shoots, ideally comprising at least 1 plagiotropic/apical shoot and 2-4 orthotropic shoots (Fig. 1.2). While plagiotropic rhizomes are preferred due to their superior survival rates and faster vegetative growth thanks to greater nutrient reserves, under the favorable conditions at Atzikiari bay (cuttings transplanted from deeper donor sites to shallower, higher irradiance areas; short transfer distance; good water quality), orthotropic cuttings were also expected to produce good growth results.

Figure 1.2 (A) Underwater view of a suitable cutting immediately after collection showing intact rhizome and healthy shoots; (B) Cutting prepared for attachment on coconut-fiber mat.

Depth selection rationale

Cuttings were collected from the donor meadow at 14-16 m depth and transplanted to restoration areas at 8-10 m depth. This depth differential was advantageous, as cuttings from greater depths adapt better during the rooting phase due to improved photosynthetic conditions at shallower depths (Bacci & La Porta, 2022; Fonseca et al., 1998).

Collection strategy and density

To mitigate pressure on the donor meadow, cuttings were collected in a distributed pattern across suitable areas rather than through concentrated extraction from a single location. Collection density did not exceed 1 cutting/m², ensuring conservation of the donor meadow (Boudouresque, 2000).

Transfer protocol

The short distance between donor and restoration sites (300-500m) enabled same-day collection and transplantation, minimizing stress on cuttings. Cuttings were transported in mesh bags maintaining constant seawater immersion, with water temperature kept as close as possible to the donor depth temperature within the 20-25°C range. Gentle handling throughout the process avoided rhizome damage, with cuttings kept in shaded seawater containers aboard the small boat during surface transport.

Quality criteria

Cutting selection was based on apparent shoot health, rhizome integrity, and presence of visible roots (Fig. 1.3). This quality control at the collection stage maximized the probability of successful establishment.

Figure 1.3 Cuttings during their inspection and quality control based on shoot health, rhizome integrity, and root presence.

1.3.3 Preparation and positioning of restoration modules

Site preparation

Prior to module installation, debris removal from restoration areas was completed. The dead matte surface was inspected for substrate consistency and suitability. The restoration areas (Area-1 and Area-2) were identified and photographic documentation recorded pre-restoration conditions for comparison during monitoring phases (Fig. 1.4).

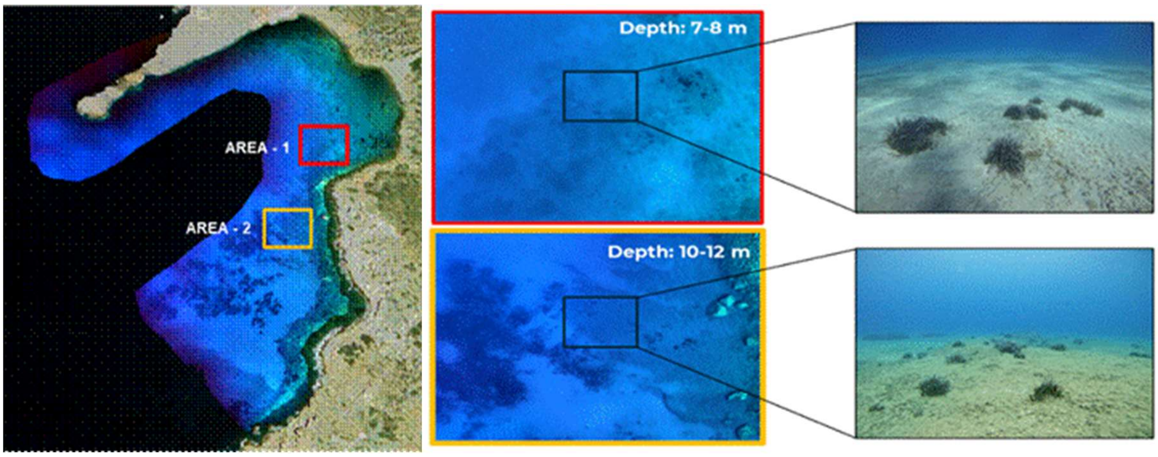

Figure 1.4 Transplantation areas (Area-1 and Area-2) identified on dead matte substrate following site inspection.

Pilot trial design

The pilot phase deployed a small number (50) of cuttings collected from the best-preserved meadow sections, arranged in small groups of five cuttings (nuclei) across three trial areas at depths of 5-8 m. These pilots used U-shaped metal staples as an anchoring technique. The objective was to test technique effectiveness and optimize procedures before full-scale deployment.

Full-scale restoration design

For full-scale implementation in both recipient areas, the design incorporated 20 units of 1 m^2 each, arranged in a chessboard pattern within a 7 × 7 m area (Fig. 1.5). This created a transplanted surface of 20 m^2 within a total restored meadow surface of 50 m^2. The chessboard arrangement (alternating 1 m^2 planted units with 1 m^2 gaps) was designed to create recolonization nuclei that could merge over time to form a continuous meadow, following the principle that restored areas must be sufficiently large to allow meadow expansion in the medium and long term.

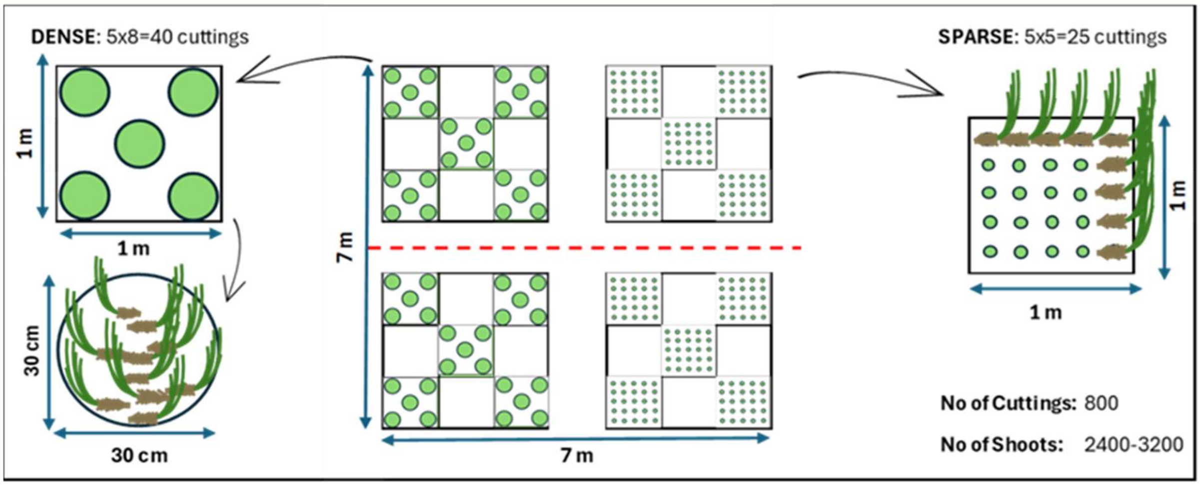

Figure 1.5. Chessboard pattern design showing 20 units of 1 m² arranged within a 7 × 7 m area, creating 20 m² transplanted surface within 50 m² total restored meadow surface.

Two distinct anchoring techniques were employed across the restoration units (Fig. 1.6): metal staples and coconut-fiber mats, applied in equal proportions (50% each). Within each technique, two planting density treatments were tested to evaluate optimal spacing for establishment success.

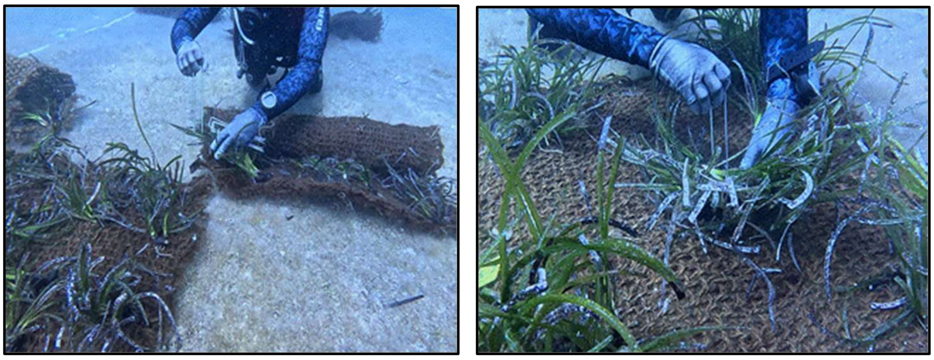

Figure 1.6. View of underwater activities during coconut mats fixation on the substrate.

Cutting spacing and arrangement

For low-density plantings, cuttings were arranged in a linear 5 × 5 grid pattern with 10-15 cm spacing between cuttings, resulting in 25 cuttings per 1 m² unit (Fig. 1.7 A-B). For high-density plantings, cuttings were arranged in 5 nuclei of 8 cuttings each following a quincunx pattern (four corner nuclei plus one central nucleus), resulting in 40 cuttings per 1 m² unit (Fig. 1.7 C-D). This experimental design allowed comparison of sparse versus clustered planting configurations and their respective effects on survival, growth rates, and sediment retention under different anchoring methods.

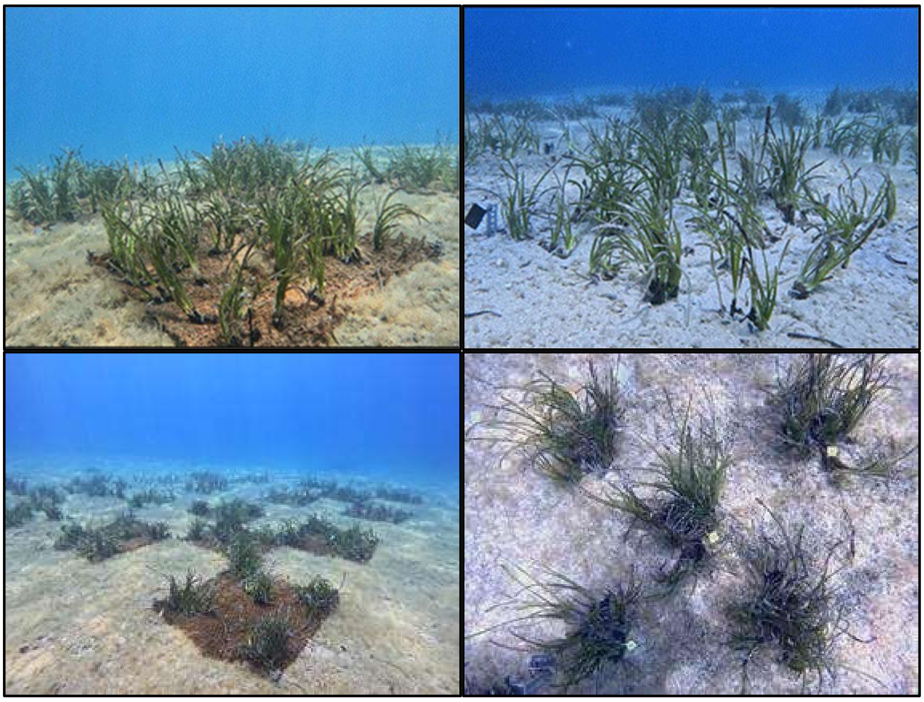

Figure 1.7 Planting density treatments: (A-B) Low-density configuration with 25 cuttings in 5 × 5 grid pattern; (C-D) High-density configuration with 40 cuttings in quincunx pattern (5 nuclei of 8 cuttings each).

1.4 Management of *Posidonia oceanica* restoration

1.4.1. Integration between the active and passive measures of restoration

Fish farm removal in 2017 eliminated the primary degradation pressure, initiating natural environmental recovery. However, natural *P. oceanica* recolonization has not occurred in areas close to former cages after 7 years. Currently, no significant pressures are recorded except marine litter accumulation. This recovery trajectory, combined with NATURA 2000 site protection (GR4320006), created conditions suitable for active intervention.

Passive restoration measures supporting active intervention include NATURA 2000 legal protection framework, ongoing natural environmental recovery processes continuing sediment quality improvement, targeted marine litter removal from restoration sites, and stakeholder engagement through ARTEMIS project fostering community stewardship and compliance.

Active restoration targets specific areas to accelerate natural recovery that is ongoing but progressing slowly, while passive measures ensure protection of transplanted units and continued improvement of surrounding habitat conditions. Success depends on sustained passive protection (enforcement of management measures, prevention of new pressures) combined with active intervention and adaptive management based on monitoring results.

1.4.2 Temporary prohibition of fishing, shipping and anchoring in restoration areas

Currently, no specific temporary prohibitions on fishing, shipping, or anchoring have been established for the restoration areas in Atzikiari Bay. However, the site operates within the NATURA 2000 framework (GR4320006), which provides a legal basis for implementing protective management measures if deemed necessary.

1.4.3 Replacement of failures

A replacement strategy has been integrated into the restoration plan to compensate for cutting losses during the critical early years.

Trigger thresholds

Replacement intervention will be triggered if the Year 1 monitoring reveals: >30% unit loss or >50% cutting loss within any restoration area; or complete loss of contiguous units (e.g., an entire row in the chessboard pattern) regardless of overall loss percentage.

Implementation

Assessment of replacement needs will be conducted following the Year 1 monitoring, with primary intervention (replacement and replanting activities) during late spring optimal season. Replacement approaches may differ from initial techniques based on lessons learned: if mat displacement occurs, enhanced anchoring methods will be used; if certain depths show higher success, replacement will focus on optimal depth ranges.

Additional cuttings will be collected from the donor meadow following the same low-density protocols (1 cutting/m^2) used for initial transplantation, conducted during optimal season (late spring), with complete documentation of locations, cutting numbers, techniques used, and reasons for initial failure to inform adaptive management.

1.4.4 Appreciation of the restoration

A comprehensive stakeholder mapping identified the key stakeholders across public authorities, scientific institutions, NGOs, and private sector actors. Key stakeholders exhibited high awareness of *Posidonia oceanica* meadows' ecological importance but significant gaps in restoration-specific knowledge and institutional coordination.

An awareness campaign was planned to promote understanding of restoration activities in Atzikiari Bay. Given the site's aquaculture history (1996-2017), communication emphasized how active restoration accelerates natural recovery and restores lost ecosystem services. Activities included public information sessions prior to implementation of transplantation activities by the HCMR team.

The restoration operates within the NATURA 2000 governance framework, addressing identified knowledge gaps and institutional coordination needs to transform conservation regulations into locally supported practices and provide a replicable model for future restoration efforts.

1.4.5 Decommissioning of the restoration

A decommissioning plan has been established to ensure removal of restoration materials if the intervention does not achieve expected outcomes.

Failure criteria

Restoration will be considered unsuccessful if monitoring at Year 3 post-trasplantation reveals >70% transplant loss despite replacement efforts conducted following Year 1 assessment, or complete failure across restoration area.

Decommissioning procedures

For metal staples, early-stage failures will be retrieved by divers, while significantly corroded staples (expected after 3+ years) may be left to complete natural degradation. For coconut-fiber mats, intact or partially degraded mats if decommissioning is required after Year 3+ will be retrieved by divers and removed to the surface. Significantly degraded mats (>50% decomposition) will be left to complete natural biodegradation.

Implementation

Decommissioning decisions will be made after the Year 3+ assessment and replacement attempts, conducted during optimal diving season (summer), with completion within 6 months post-decision.

Reporting

Although both metal staples and coconut-fiber mats have minimal long-term environmental impact due to natural degradation, their removal will be planned to ensure full environmental responsibility and prevent any potential habitat alteration in the case of restoration failure. If necessary, all decommissioning activities will be documented and reported to NATURA 2000 site managers and Greek environmental authorities.

2 - Restoration plan and methodologies adopted at the Capo Testa Punta Falcone pilot site, Sardinia, by MEDSEA Foundation

2.1 Local stakeholder mapping

A stakeholder mapping exercise was conducted at the Capo Testa Punta Falcone MPA, the Sardinia pilot site. During this process, 68 stakeholders were identified and categorized based on their sector (e.g. public authorities, scientific and academic institutions, civil society organizations (NGOs), private sector actors, local governance bodies etc.). Each stakeholder was then assessed based on their level of interest and of influence, knowledge, and involvement in activities related to *Posidonia oceanica* restoration and to the ARTEMIS Interreg EURO-MED project.

Based on these considerations, a smaller group of stakeholders was selected to be interviewed through a questionnaire structured with the following three axis:

1. *Posidonia oceanica*: status, level of knowledge, awareness of restoration initiative, including ARTEMIS, at pilot site level
2. Conservation and Restoration Governance Framework
3. Awareness of *Posidonia oceanica* Ecosystem Services (ES) and Payment for Ecosystem Services (PES) Schemes

The questionnaire was created using Google Form and initially distributed to six relevant stakeholders to the pilot site Capo Testa Punta Falcone MPA, who are directly or indirectly linked to *Posidonia oceanica* restoration. These stakeholders included:

- Representatives of national authorities and key agencies operating at the national or regional level, including the Ministry of the Environment and Energy Security (MASE) and the Italian Institute for Environmental Protection and Research (ISPRA)
- Representatives of the regional and local authorities, including the Region of Sardinia, the Municipality of Santa Teresa Gallura, the Capo Testa Punta Falcone MPA, and the La Maddalena Coast Guard.

In addition, during an on-site awareness-raising event organised by the Capo Testa Punta Falcone MPA, the questionnaire was shared with a broader group of local stakeholders, including fishermen, environmental associations (Plastic Free, CRAMA), private actors, local media, and citizens.

In total, **31 stakeholder responses** were analyzed using a thematic analysis approach, with thematic categories corresponding to the three main axes of the questionnaire.

Results from the 31 stakeholder interviews were analyzed and led to the following considerations:

Stakeholders demonstrated a generally high level of knowledge about *Posidonia oceanica*, with good awareness of existing restoration projects, including the ARTEMIS actions. There is also a broad understanding of the main anthropogenic pressures affecting *Posidonia oceanica* meadows and of the effectiveness of both active and passive restoration efforts.

From a regulatory perspective, conservation legislation and institutional frameworks are in place but are perceived differently across stakeholder categories: while some consider them clear and adequate, the majority regards them as vague, incomplete, and poorly implemented. The only restoration framework explicitly mentioned across all stakeholder groups is linked to the Nature Restoration Law, while a clear national framework for planning and implementing restoration actions is still lacking. Key challenges identified for restoration initiatives include high costs, limited funding for surveillance and long-term monitoring, the need to address the root causes of *Posidonia* decline through effective site protection, and slow bureaucratic procedures.

In terms of economic aspects, stakeholders showed broad awareness of the ecosystem services provided by *Posidonia oceanica*, but limited knowledge of Payment for Ecosystem Services (PES) schemes, particularly those related to this habitat. This gap in PES awareness was consistent across both institutional and non-institutional stakeholders. Stakeholders believe that restoration funding should primarily come from public sources such as the State or the EU. Nonetheless, there is growing interest in PES as an innovative financing mechanism. Given the high costs of restoration, stakeholders emphasized the importance of involving multiple entities and organizations. Therefore, private funding should also contribute to conservation and restoration efforts, although non-profit sources are generally perceived as more reliable to ensure public-benefit outcomes.

2.2 *Posidonia oceanica* restoration planning

2.2.1 Site and donor meadow characterization and assessment

The Sardinia pilot site is the Capo Testa Punta Falcone Marine Protected Area, located in the northern part of the island (Fig.2.1).

Established by Ministerial Decree in 2018, the MPA is entirely managed by the Municipality of Santa Teresa Gallura (SS) and divided into four zones of different protection levels. The MPA is also part of the Nature2000 network, as it includes the marine SCI and SPA site “da Capo Testa all’Isola Rossa” (ITB013052).

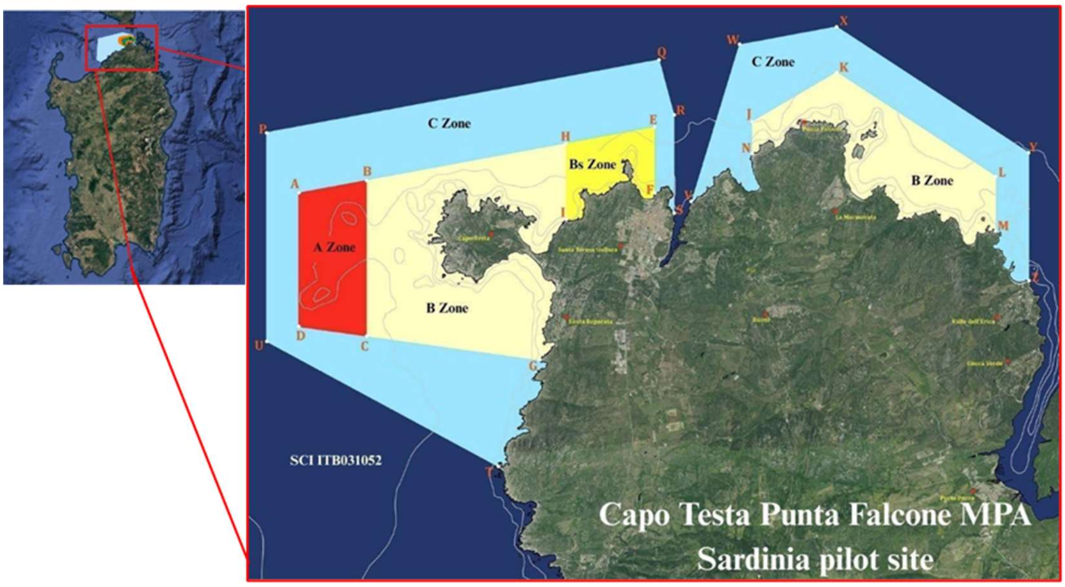

Figure 2.1 Map of the Sardinia pilot site: Capo Testa Punta Falcone MPA.

The site is characterized by an extensive *Posidonia oceanica* meadow (1120* habitat) of exceptional natural and conservation value, recognized as a priority habitat under the EU Habitats Directive (92/43/EEC). Covering approximately 294.47 ha, the meadow is generally in good conservation status. However, in the eastern part of the MPA, unregulated boat anchoring, probably prior to its establishment, caused significant fragmentation. In particular, MPA mapping data produced by Aera in 2021 identified several zones where *Posidonia oceanica* meadows showed signs of damage or fragmentation (Fig. 2.2.). Building on this data, targeted underwater SCUBA surveys were carried out in March 2023 across the entire La Marmorata Bay. Surveys were performed along linear transects and complemented by systematic photo documentation. Depth data were recorded with dive computers, while the precise coordinates of both non-impacted, named control, and impacted meadows were collected using GPS devices. These surveys provided a more accurate characterization of the meadow and a clearer definition and localization of impacted patches. In particular, impacted areas were tested using metal pegs to verify both substrate type and thickness. The extent of dead matte areas was measured using a measuring wheel. This process allowed the identification of the most suitable restoration area: an approximately 200 m² of continuous dead matte located at a depth of 20–25 m within a fragmented 2 hectare *Posidonia oceanica* meadow (Fig. 2.3.), which was selected as the site for the planned restoration activities.

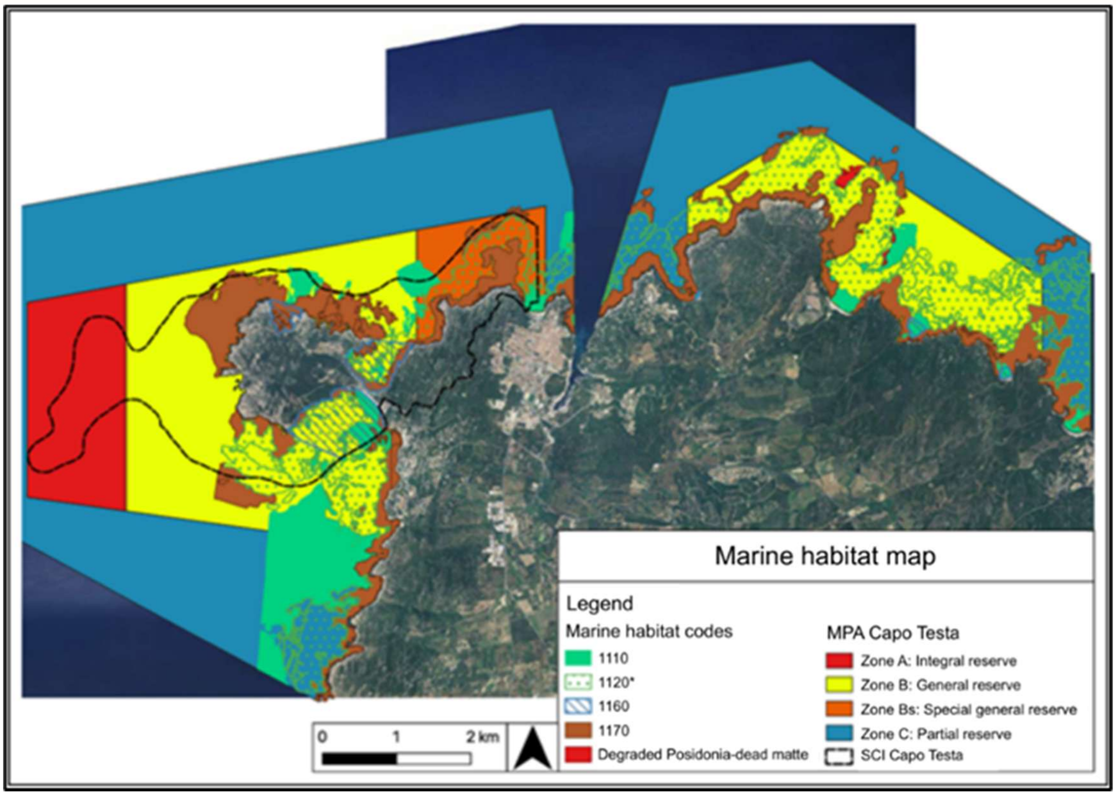

Figure 2.2 Biocenotic map of the Capo Testa Punta Falcone MPA

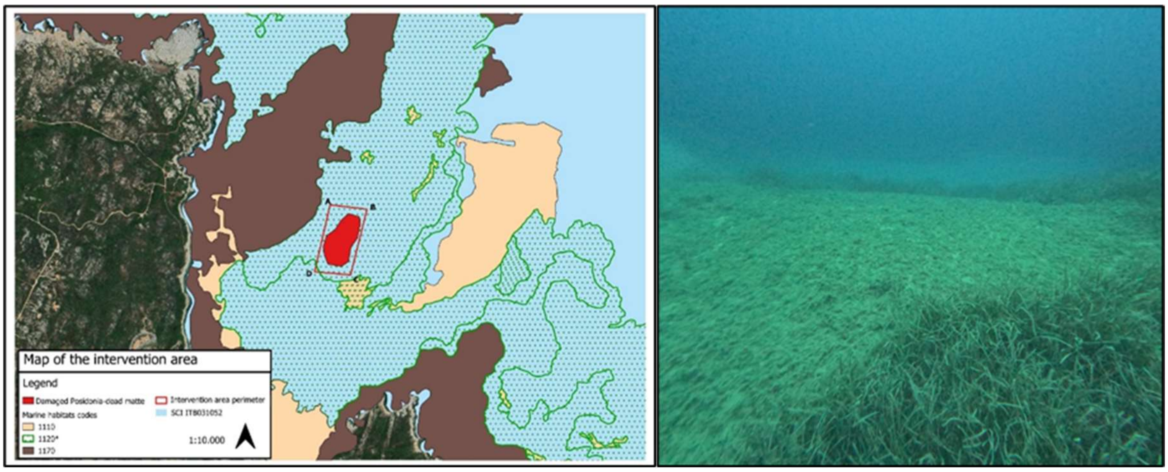

Figure 2.3. site selected for the restoration activities

In line with the conservation objectives of the MPA, no donor meadow was selected for the collection of transplant material. Instead, the restoration activities were based exclusively on naturally detached *Posidonia oceanica* cuttings or clods. These were collected and carefully selected in areas immediately adjacent to the intervention site. This approach avoided removing material from healthy meadows within the protected area, thereby preventing additional, even if limited, impacts on the ecosystem. To support this strategy, an assessment of the availability of naturally detached material was carried out during the preliminary surveys, which allowed the identification of suitable collection zones nearby the restoration area.

2.2.2. Characterization and assessment of the receiving meadow

The receiving meadow is characterised by a markedly degraded and fragmented seagrass meadow. The area includes a continuous patch of dead matte of approximately 200 m^2 located at 20–25 m depth. The percentage cover was considerably low (40.3 ± 4.2%), while shoot density (263.7 ± 1.5 shoots m^{-2}) was comparable to that of the control meadow, indicating a compromised but not yet collapsed structural condition. From a functional and ecological perspective, the associated communities were depauperated, and the EBQI assessment confirmed the degraded condition of the area, with a score of 2.97 corresponding to a “Bad” ecological status. Regarding blue carbon, sedimentary organic carbon stocks in the impacted area remained comparable to those of the control site, indicating that disturbance has not yet resulted in measurable carbon loss. However, the marked coarsening of sediments and the reduced vegetative biomass suggest a declining long-term capacity for carbon retention, reflecting a weakened and less resilient carbon-sink function.

2.2.3 Assessment of ecosystem services of donor and receiving meadows

For the Capo Testa Punta Falcone MPA site, the assessment focused on the two ecosystem services selected within the ARTEMIS framework: biodiversity maintenance and blue carbon storage. As no donor meadow was selected for transplantation, the assessment presented here focused solely on the receiving meadow (impacted site). In this area, both ecosystem services showed signs of functional decline: although species richness remained comparable to the control meadow, community structure shifted toward opportunistic taxa, reflecting reduced habitat quality. Similarly, sedimentary organic carbon stocks in the upper 40 cm remained substantial, but reduced vegetative biomass and sediment coarsening indicated a weakened and less resilient carbon-sink function. Overall, the receiving meadow currently supports lower biodiversity and diminished long-term carbon retention, reinforcing the need for restoration actions.

2.2.4 Selection of restoration technique

Given the environmental and structural characteristics of the receiving meadow, specifically the presence of a continuous dead matte patch within an otherwise extensive *Posidonia oceanica* meadow, the U-shaped metal peg technique was selected for the restoration intervention. This methodological choice was made to ensure minimal disturbance to the protected habitat while maximising transplant stability and survival (ISPRA, 2014; Bacci & La Porta, 2022). The technique is recognised for being easy to apply, having a low environmental impact, and ensuring high survival rates of transplanted shoots (Molenaar et al., 1993; ISPRA, 2014). It also offers several operational advantages: it is particularly suited to fragmented areas and small restoration patches, can be deployed rapidly in the field, and uses stakes that corrode naturally over time. Once inserted, the stakes remain invisible and do not alter the seagrass landscape, and no persistent foreign materials remain if the transplant fails. Stakes can also be removed after root anchoring, further reducing the ecological footprint of the intervention.

2.3. Implementation of *Posidonia oceanica* restoration

2.3.1. Selection of biological material for the restoration

At the Capo Testa Punta Falcone MPA site, the biological material used for transplantation consisted exclusively of *Posidonia oceanica* cuttings naturally uprooted and accumulated in underwater areas near the restoration site (Fig. 2.4. A). This choice was fully consistent with the conservation objectives of the MPA, as no donor meadow was selected and no material was removed from healthy meadow. The use of naturally detached cuttings is linked to the fact that these shoots are naturally uprooted and dispersed during winter storm events, providing material that can be safely used for restoration.

For this technique, plagiotropic cuttings rhizomes were preferentially selected, as these ensure higher vegetative growth rates and improve survival during the critical post-transplantation phase thanks to their greater reserves of nutrients and antibiotic compounds (Meinesz et al., 1992; Molenaar et al., 1993; Piazzi et al., 2021; Frau et al., 2023), although orthotropic rhizomes can also be used. Only well-preserved cuttings were retained for transplantation, ensuring the highest possible quality of the biological material introduced into the restoration site.

Cuttings were collected by MEDSEA scientific divers and brought to the surface for processing (Fig. 2.4 B). On board, they were kept in seawater tanks and carefully cleaned, with damaged or necrotic portions removed. After processing, the cuttings were placed back into scuba nets and transported underwater for transplantation within a few hours of collection.

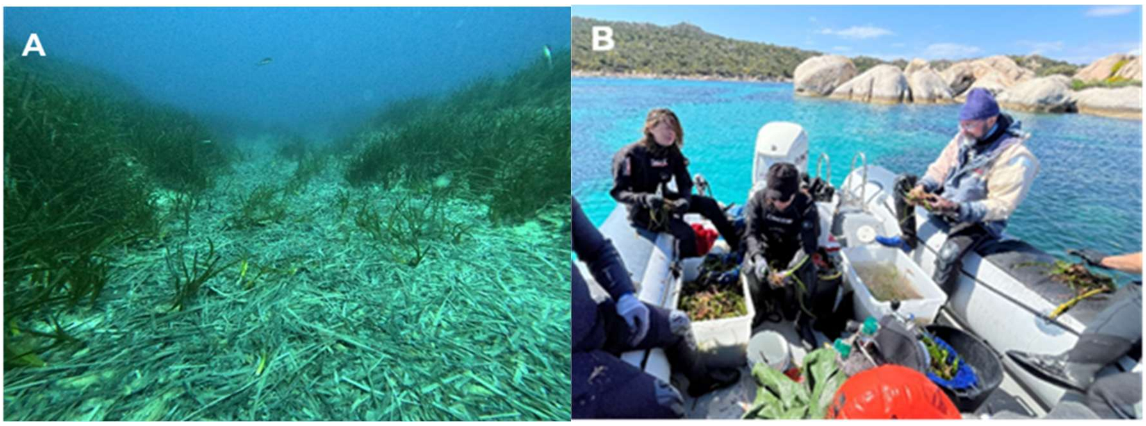

Fig. 2.4: Accumulation area of naturally detached cuttings (A); The MEDSEA scientific team selecting and processing cuttings on board (B).

2.3.2. Preparation and positioning of restoration modules

For the technique adopted at Capo Testa Punta Falcone MPA, no preparation of restoration modules was required. The metal pegs were transported underwater in scuba nets with the processed cuttings and positioned directly at the restoration site. The transplantation activities were carried out by the MEDSEA scientific team, highly specialised in *Posidonia oceanica* restoration operations, completing the full restoration set-up in April 2025.

The restoration intervention was carried out over a 200 m^2 area of continuous dead matte. A total of 2,000 cuttings, each bearing at least two leaf shoots, were selected, processed, and transplanted at the restoration site. The cuttings were fixed to the dead matte using the U-shaped metal pegs, arranged in small nuclei (1 nucleus per m^2) with a planting density of 10 cuttings/m^2 and ensuring a minimum density of 20 shoots/m^2 (Fig. 2.5. A, B). This configuration provided adequate initial coverage and stability, promoting the establishment and early development of the transplanted shoots.

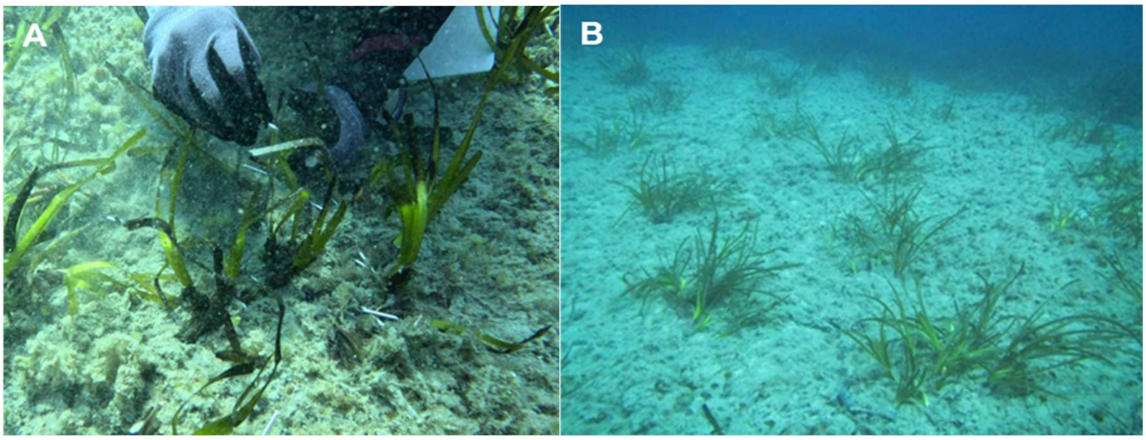

Fig. 2.5: Securing cuttings with U-shaped metal pegs (A); Transplanted nuclei on the restoration site (B).

2.4 Management of *Posidonia oceanica* restoration

2.4.1. Integration between the active and passive measures of restoration

The active restoration measures carried out by the MEDSEA scientific team as part of the Interreg Euro-MED "ARTEMIS" project are complemented by passive restoration actions implemented by the MPA management through national funds (PNRR). These measures included the installation of a network of eco-friendly mooring buoys designed to prevent destructive free anchoring on

Posidonia oceanica meadows. The buoys are made of environmentally friendly materials and feature internal cavities, interstices, and small depressions that can act as microhabitats, supporting the development of small benthic organisms. In summer 2025, approximately 150 buoys were positioned across the MPA, from Licciola to Santa Maria Reparata, of which 27 were installed in La Marmorata Bay.

Together, active transplantation and passive anchoring control form an integrated restoration strategy: while transplantation aims to regenerate the impacted meadow, the mooring system and anchoring regulations reduce ongoing mechanical impacts and enhance the long-term effectiveness and resilience of the restored habitat.

2.4.2. Temporary prohibition of fishing, shipping and anchoring in restoration areas

The restoration site is located within Zone B (general reserve) of the MPA, where anchoring on *Posidonia oceanica* meadows is strictly prohibited and fishing activities are regulated according to the MPA's Regulation:

- Small-scale artisanal fishing and pescatourism are permitted exclusively for fishing enterprises (individual or cooperative) registered in the municipality of Santa Teresa Gallura.
- Recreational fishing is allowed only for residents of Santa Teresa Gallura, using rod and line, and requires prior authorization from the managing authority.
- Mooring is permitted exclusively within designated buoy fields positioned to ensure effective protection of the seabed.

Violations of anchoring prohibitions and other infractions, such as unauthorized anchoring, navigation within restricted zones, or free anchoring on *Posidonia oceanica* are subject to administrative sanctions. The MPA applies fines exceeding €1,000 for unauthorized anchoring on *Posidonia oceanica* meadow, reinforcing compliance and contributing to the protection of the restoration area.

2.4.3. Replacement of failures

A replacement strategy was planned to address potential losses among the transplanted cuttings, as identified during the ex-post monitoring activities. If the survival rate of the cuttings is found to be below 70% six months after the transplant set-up, additional naturally detached *Posidonia oceanica* cuttings will be introduced to restore the intended planting density and ensure the full functionality of the restoration area. The need for replacement will be evaluated during the scheduled monitoring surveys, allowing timely intervention and maximising the long-term success of the restoration action.

2.4.4. Appreciation of the restoration

An awareness-raising campaign was planned to promote understanding and appreciation of the restoration activities carried out in La Marmorata Bay. The initiative aims to inform visitors, local stakeholders, and the wider community about the ecological importance of *Posidonia oceanica* meadows and the benefits of the restoration intervention, strengthening public support and fostering responsible behaviour within the MPA. Educational materials, outreach actions, and communication tools will be used to increase visibility of the project and enhance community engagement in the protection of the restored habitat.

2.4.5. Decommissioning of the restoration

A decommissioning procedure was planned to ensure the removal of all restoration materials in the event that the intervention does not achieve the expected outcomes. If monitoring activities reveal that the transplant has not been successfully established, and replacement actions are not sufficient to restore the intended functionality of the meadow, any remaining pegs will be removed to avoid leaving non-functional structures on the seabed.

Although the metal pegs used have a minimal environmental impact, since they naturally dissolve over time, their removal is still foreseen to ensure full environmental responsibility and to prevent any potential long-term alteration of the habitat should the restoration fail.

3 - Restoration plan and methodologies adopted at the Cala Blanca, Ciutadella (Menorca) pilot site, Spain - IME-OBSAM

3.1 Local Stakeholders mapping

A stakeholder mapping was conducted for the Menorca pilot site in Cala Blanca, Ciutadella (Menorca), identifying 131 stakeholders. These were systematically categorized across a wide spectrum of sectors, including public authorities, scientific and academic institutions, civil society organizations (NGOs), private sector actors, and local governance bodies. Each stakeholder was assessed based on their relevance, level of influence, knowledge, and involvement in activities related to Posidonia oceanica restoration, as well as their connection to the ARTEMIS Interreg EURO-MED project.

From this broader pool, a subset of key stakeholders was selected based on their knowledge, experience, and field of activity. These were invited to participate in an online survey adapted to the Menorca context. The survey was completed by 44 participants, representing 30 different entities across the public administration, research, private sector, and civil society.

The survey explored several dimensions of perception, governance, and awareness related to *Posidonia oceanica* conservation and restoration.

Regarding the level of awareness and understanding all respondents reported knowing what *Posidonia oceanica* is, indicating a highly informed and environmentally aware sample. Nearly all participants were familiar with multiple seagrass meadow locations across the Balearic Islands and other Mediterranean regions. The perceived conservation status was mixed: about half indicated that conditions "depend on the site," while a smaller portion (≈15%) considered the meadows to be in regression, and very few perceived them as "generally good." This reflects heterogeneous and locally variable perceptions of meadow condition.

In relation to the importance of conservation and priority actions all participants were aware of ongoing conservation efforts. The most valued actions included: control of boat anchoring and increased surveillance, installation of ecological moorings and regulation of sensitive zones, control of land-based pollution sources (e.g. wastewater discharge), scientific monitoring of meadow health and environmental communication and education campaigns. These responses highlight a clear preference for combining regulatory and technical measures with awareness-raising and scientific monitoring.

About the knowledge and attitudes toward Payments for Ecosystem Services (PES) a half of respondents (52%) had previously heard of PES, while 41% had not. Overall, three-quarters (75%) expressed a positive or open attitude toward PES, though with some uncertainty regarding their practical implementation. This reflects moderate awareness but strong conceptual acceptance of PES as an innovative funding tool.

In relation to the perception of governance and existing legal framework, a majority (57%) perceived that a legal framework for *P. oceanica* conservation exists, though only one-third (32%) believed that a clear framework also exists for restoration. Open responses identified key governance barriers such as lack of inter-administrative coordination, bureaucratic complexity, insufficient stable funding, limited technical capacity, and conflicts between economic and conservation interests.

When asked about ecosystem services valuation, respondents rated regulating and supporting services as the most important—particularly climate regulation and CO_2 capture, coastal protection, biodiversity maintenance, and water quality. Provisioning and cultural services, such as tourism and fisheries, were rated as moderately or variably important.

Finally, about financing mechanisms, preferred funding sources included public funds (EU, national, regional), public-private partnerships, earmarked taxes on impactful activities (e.g. tourism, anchoring), and shared responsibility mechanisms whereby ecosystem beneficiaries contribute to conservation.

Overall, the findings reveal a highly aware and environmentally committed stakeholder community in Menorca, with strong consensus on the need to strengthen protection, clarify restoration governance, and develop innovative financing approaches such as PES. However, the results also underscore persistent challenges related to regulatory complexity, coordination gaps, and limited technical and financial capacity—key aspects to be addressed under a coherent national and regional restoration roadmap.

3.2 *Posidonia oceanica* restoration planning

3.2.1. Site characterization

The area of the ARTEMIS project is located at about 1 km south-west of Ciutadella, in the island of Menorca, Spain. The entire area is located within the Natura 2000 Site ESZZ16002 Canal de Menorca. The site is characterized by rocky shorelines with extensive *Posidonia oceanica* meadows located between 2 to >30 m water depth. The seagrass meadows grow on medium to coarse sandy bottoms intertwined with coarse sandy patches and rocky reefs.

In 2010, the construction of a desalination plant to supply water to Ciutadella resulted in the loss of 1,808 m2 of *P. oceanica* meadows near Cala Blanca, located at a depth of 20 meters, owing to the direct impact of the construction of the tower to collect water (170 m2) and the incidental spill of bentonite during construction that decimated the surrounding meadows (1,638 m2). Although the desalination plant was built in 2010, desalination operations only started in 2019, and the plant has been operating at 30% capacity since.

Figure 3.1. Posidonia clones in the area affected by a bentonite spill in Menorca prior to restoration

The substrate in the area impacted by the construction of the desalination plant consisted of bare coarse sands with very few small and sparse clumps of *P. oceanica* across the relatively homogenous and even area of bare sand that was vegetated previous to the impact.

3.2.2. Characterization and assessment of the donor and receiving meadow

The project is conducted in two areas within continuous *P. oceanica* meadows; one area impacted by the construction of the desalination plant, and another area (control) located about 300m north of the desalination plant that was not impacted by its construction.

The benthic habitats of the restoration area were characterized by a rocky bottom fringe colonized by photophilic algae down to a depth of approximately 8 m, followed by a continuous *P. oceanica* meadow extending from the rocky coastal margin to around 34 m depth. This seagrass belt encircled nearly the entire coastline of the island, only interrupted by drainage channels associated with coves and bays. Beyond the *Posidonia* meadow, sandy bottoms occurred, hosting maërl communities.

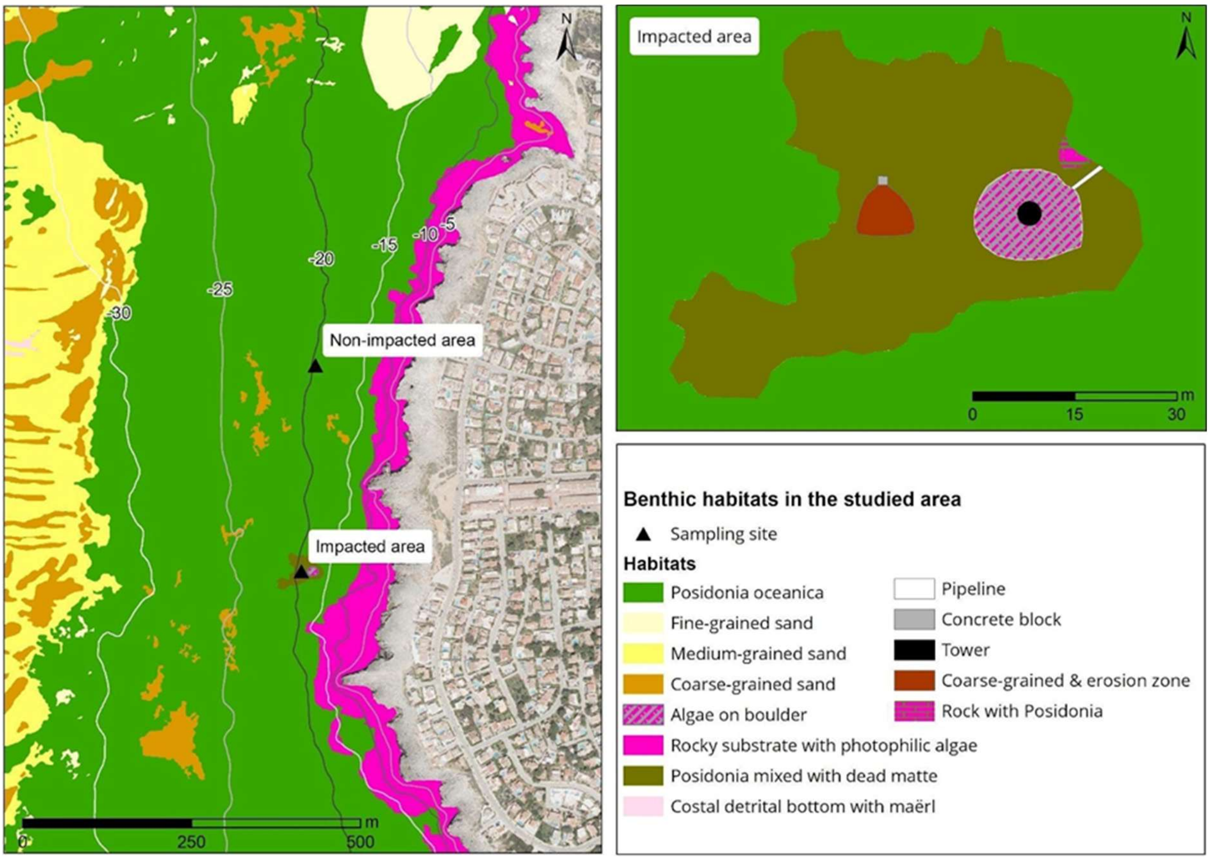

Figure 3.2. Benthic habitats within the study area and the surrounding region and location of the impacted area and control. It includes elements of the restoration zone that may influence plantation activities, such as the intake tower, pipeline, and the degraded area caused by the chain and the existing buoy mooring.

Within the specific restoration zone, the mapped habitats included dead *P. oceanica* matte interspersed with scattered patches of regenerating seagrass (1,742.4 m^2), rocky bottoms corresponding mainly to the riprap surrounding the intake tower (161 and 9.7 m^2) and sandy areas.

3.2.3. Assessment of ecosystem services of donor and receiving meadows

As agreed among the partners of the ARTEMIS project, the ARTEMIS pilot site located in Cala Blanca has mainly assessed the status of two of the ecosystem services provided by *P. oceanica* meadows: biodiversity and blue carbon.

As this pilot project does not have a seagrass bed to donate biological material, but instead plans to collect naturally detached bundles from the nearby Posidonia seagrass bed, the baseline for these two ecosystem services has been assessed in the impacted seagrass bed and in the seagrass bed identified as a control.

The *Posidonia oceanica* meadows at Cala Blanca show clear structural contrasts between impacted and control areas, reflecting the long-term legacy of the 2010 bentonite spill during the desalination plant construction. In the non-impacted zone, seagrass canopies are dense, tall (0.5–1 m), and characterized by interspersed sandy channels typical of highly hydrodynamic environments. In contrast, meadows surrounding the lost seagrass area display reduced cover and shoot density, scattered clones of *P. oceanica* still persist in the affected area, indicating limited but detectable recovery potential. Therefore, restoration actions are proposed with the aim of accelerating the natural regeneration process of the meadow.

The Ecological Biodiversity Quality Index (EBQI) classified both impacted and control sites within the 'poor' category (EBQI < 3.5), differing only slightly (2.9 vs. 3.1). Although the shoot density within the vegetated patches was comparable (514 versus 630 shoots·m^2), meadow cover differed drastically (11% vs. 88%), resulting in an overall density nearly ten times higher at the control (≈555 vs. 57 shoots·m^2). This pattern indicates extensive fragmentation and habitat loss in the impacted area.

From a functional perspective, the impacted site lacked filter feeders/suspensivores, had lower wrack accumulation, and was dominated by holothurians, suggesting simplification and a shift toward sandy-bottom communities. No fish compartments were observed at either site, likely reflecting regional fishing pressure. Therefore, EBQI results should be interpreted as relative indicators of ecological degradation and recovery potential rather than absolute quality metrics.

Species richness and abundance were consistently higher at the control site (44 species and 488 individuals) compared to the impacted area (36 and 262). The epifaunal community on rhizomes was particularly affected (S_total = 10 and H' = 1.56 at the control site versus S_total = 1 and H' = 0 at the impacted site), evidencing ecosystem degradation and loss of habitat complexity. In the canopy and matte compartments, differences were less pronounced, but the overall diversity patterns confirmed the structural impoverishment of the impacted meadow.

With regard to the blue carbon ecosystem service, analyses of soil carbon stocks and biomass revealed that, although the total organic carbon (C_org) content in the top 40 cm was not significantly lower at the impacted site, the composition of carbon stocks had been altered.

The isotopic signatures of ^{13}C, the ^{210}Pb profiles and the granulometric analyses indicate partial erosion and replacement of seagrass soils by bentonite and reworked sand following disturbance. The presence of fine sediments rich in bentonite limits interstitial water exchange and oxygen diffusion, conditions that are unfavourable for *Posidonia oceanica* recolonisation.

Average soil organic carbon stocks in the control meadow (22 ± 5 Mg C_org ha^{-1}) were lower than regional averages (> 60 Mg C_org ha^{-1}), reflecting the hydrodynamic and non-depositional nature of the west coast of Menorca. Estimated soil C_org accumulation rates (1.05 ± 6.13 Mg C_org ha^{-1} yr^{-1}) were, however, comparable to or higher than Mediterranean averages, though potentially overestimated due to ^{210}Pb mixing.

3.2.4. Selection of restoration technique

The main objective of the intervention is to accelerate the natural recovery of the *Posidonia oceanica* meadow affected by the installation of the outfall pipe of the Ciutadella desalination plant. The selected methodology consists of the manual planting of live rhizome fragments, a technique that has proven effective in the "El Bosque Marino de Red Eléctrica" project carried out in the Bay of Pollença (Mallorca), where survival rates above 85% have been recorded six years after planting.

The choice of manual planting is based on its ability to restore *Posidonia* cover in degraded areas where the substrate remains suitable. This technique allows fragments to be placed on patches of exposed dead matte, which, due to their structure and thickness, provide favourable conditions for rhizome anchoring and horizontal growth. In addition, the ordered arrangement of fragments facilitates individual monitoring over time, which is essential for evaluating the ecological development of the restored area.

The project plans to plant a total of 1,048 fragments, a figure obtained by applying the reference density used in Pollença (0.64 fragments/m^2) to the suitable affected surface (1,638 m^2). Fragments will be spaced 20 cm apart and at least 20 cm from the edges of the dead matte, ensuring full coverage of the selected planting areas.

Finally, once planting has been completed, 20% of the installed fragments (209 in total) will be monitored. These will be randomly selected within 13 permanent 1 × 1 m monitoring plots to be established in the restored area. This monitoring will make it possible to assess the success of the intervention and the structural evolution of the meadow in the following years.

3.3 Implementation of *Posidonia oceanica* restoration

3.3.1. Selection of biological material for the restoration

The plant material used for planting must consist of live rhizome fragments with a horizontal growth habit. Each fragment must present at least one apical group of living leaf bundles and at least two additional vertical leaf bundles. These characteristics ensure that the fragments have growth capacity and a higher probability of survival after planting.

It should be noted that fragments will not be taken from donor meadows, in order to reduce the impact of the restoration on these habitats. Only fragments that have naturally detached due to marine dynamics—particularly after strong storms—and are found loose on the seabed will be used. Collection will be carried out manually by divers equipped with autonomous breathing systems, placing the fragments in mesh bags and avoiding any damage during handling and transport.

Once collected, the fragments will be transported the same day to the maintenance area in the port of Ciutadella (cala en Busquets), where they will be kept under natural temperature, light, and salinity conditions. The fragments will remain submerged, suspended from the pontoons inside closed plastic boxes with mesh lids to prevent losses. During this phase, final selection will also be performed, discarding damaged fragments and prioritising those with active apical growth.

Prior to planting, 10% of the material (105 fragments) will be characterised by recording the number of apical and non-apical leaf bundles of each fragment. This information will be digitised to provide reference data for interpreting the evolution and performance of the restoration process.

3.3.2. Preparation and positioning of restoration modules

Each selected fragment must be fixed to an individual anchoring system to ensure proper establishment. The anchoring system consists of a U-shaped metal staple made from 6-mm diameter corrugated iron rod, with a central segment of 20 cm and two legs of 20 cm. The segment where the rhizome is attached is coated with beeswax to minimise corrosion and prevent damage to the plant tissue.

Planting is carried out manually by divers between January and March, the period in which fragment availability is highest and environmental conditions are most favourable for rooting. Fragments are placed on the selected dead-matte areas, maintaining a spacing of 20 cm between them and avoiding zones where the matte thickness is less than 10 cm, as well as areas occupied by infrastructures such as the outfall pipe or the associated rock mound. The orientation of each fragment must ensure that the foliar apex remains in contact with the substrate and parallel to the surface of the dead matte.

Finally, 13 permanent monitoring plots (1 × 1 m) are established using metal rods driven into the corners, each identified. In each plot, the number of leaf bundles present and the planted fragments within it are recorded, and the fragments selected for monitoring are subsequently placed there. This control system ensures a detailed evaluation of the restoration success in the years following the intervention.

3.4 Management of *Posidonia oceanica* restoration

3.4.1. Integration between the active and passive measures of restoration

The area designated for active restoration is already located within a clearly delineated and signposted no-anchoring zone, established due to the presence of the seawater intake tower of the Ciutadella desalination plant, as explained in the following chapter. Moreover, this is an open-sea environment with strong currents and no natural shelter, meaning that vessels do not typically stop there and anchoring pressure on the seabed is practically non existent. Should any occasional incident arise, the Posidonia surveillance service—operational in the Balearic

Islands for many years—would ensure adequate monitoring and response to prevent potential impacts.

For these reasons and given the lack of additional threats associated with nautical or fishing activities in the area, no further passive restoration measures are considered necessary to ensure the survival of the *Posidonia oceanica* plants introduced through the active restoration project.

3.4.2 Temporary prohibition of fishing, shipping and anchoring in restoration areas

The restoration area is located within the SCI Canal de Menorca, where the Management Plan, currently being drafted, will regulate activities and establish any necessary restrictions. This plan will define the measures needed to ensure the protection of the site's natural values, including temporary limitations on fishing, navigation and anchoring in areas undergoing ecological restoration.

Additionally, the restoration zone overlaps with the safety area surrounding the seawater intake tower of the Ciutadella desalination plant, where anchoring is already strictly prohibited. This zone is clearly marked with a buoy to prevent vessel interference and avoid damage to the seabed infrastructure.

Anchoring restrictions established by Decree 25/2018, of 27 July, on the conservation of *Posidonia oceanica* in the Balearic Islands, also apply. The decree prohibits anchoring on Posidonia meadows or engaging in activities that could uproot or degrade them, requiring vessels to anchor only on areas free of seagrass. In line with these regulations, fishing, navigation and anchoring will be temporarily restricted within the restoration area to avoid disturbance and ensure the success of the restoration works.

3.4.3 Replacement of failures

A contingency strategy has been established to compensate for any potential losses among the transplanted *Posidonia oceanica* fragments, based on the results obtained during ex-post monitoring.

Follow-up and monitoring activities are planned for the years following the restoration to evaluate the evolution of the *Posidonia* meadow. If, during the monitoring carried out one year after planting, survival rates are found to be below 80%, a new replanting operation will be conducted, applying the same density criteria used in the initial restoration.

New naturally detached fragments will be added to recover the planned planting density and maintain the ecological functionality of the restored area. The need for these reinforcements will be assessed during the scheduled monitoring surveys to allow prompt action and maximise the long-term effectiveness of the restoration effort.

3.4.4 Appreciation of the restoration

An awareness-raising initiative has been developed to promote understanding and appreciation of the restoration actions carried out in Menorca. The campaign aims to inform visitors, local stakeholders and the broader community about the ecological significance of *Posidonia oceanica* meadows and the benefits derived from their restoration, thereby fostering public support and encouraging responsible behaviour within the marine environment. As part of this effort, public presentations have been organised to explain how the restoration works are implemented and to share the project's progress. These activities, together with educational materials and other outreach tools, are intended to increase the visibility of the project and strengthen community engagement in the protection and long-term conservation of the restored habitat.

3.4.5 Decommissioning of the restoration

No decommissioning actions were foreseen or required for the restoration site in Menorca.

4 – Restoration plan and methodologies adopted at the Panzano Bay (Monfalcone) pilot site, Italy - Municipality of Monfalcone

4.1 Local Stakeholders mapping

From 2020 to 2022, restoration activities in Panzano Bay (Monfalcone pilot site) was carried out under the SASPAS project, which promoted coordinated action among regional and local stakeholders for coastal and marine habitat protection. Consultations involved recreational boaters, marinas, fishing communities, and maritime infrastructure authorities.

Although the COVID-19 pandemic hindered direct engagement, the project's concept, focused on underwater vegetation transplants and buoy fields, was generally well received. A constructive partnership was formed with the Harbour Master's Office in Monfalcone, under the Trieste Maritime Directorate and the Ministry of Sustainable Infrastructure and Mobility (MIMS).

4.2 *Cymodocea nodosa* restoration planning

4.2.1. Site and donor meadow characterization and assessment

The Monfalcone pilot site lies in Panzano Bay, a shallow sedimentary embayment (average depth 1–5 m) influenced by freshwater discharges from the Isonzo River and by seasonal "Bora" winds. The seabed is primarily composed of fine, well-oxygenated sands and hosts natural seagrass meadows, predominantly dominated by *Cymodocea nodosa*, followed by areas with lower coverage of *Zostera noltei* and *Ruppia* species, particularly in the innermost and more brackish zones.

The area includes two Natura 2000 sites:

- *IT3330007 – Cavana di Monfalcone (SAC)*
- *IT3330005 – Foce dell'Isonzo – Isola della Cona (SPA/SAC)*

The donor area was located in the central part of Panzano Bay, on a shallow sandy bottom about 1.2 m deep (Figure 4.1). The site has stable, well-oxygenated sediment, moderate water movement, and generally clear water during calm weather. It hosts a dense and healthy *Cymodocea nodosa* meadow, typical of the natural seagrass habitats in the bay. The meadow had almost continuous coverage, with only small bare patches and strong rhizome networks that helped keep the sediment in place. Epiphytes were present but not excessive, and no signs of eutrophication or macroalgal overgrowth were observed.

Only a few traces of human impact, such as possible anchor marks, were visible. Divers observed many young shoots along the edges of the meadow, showing that the plants were actively growing. The sediment was compact and stable, with no signs of erosion. Overall, the donor meadow was in good condition and suitable for collecting plant material for transplantation without causing damage to the habitat.

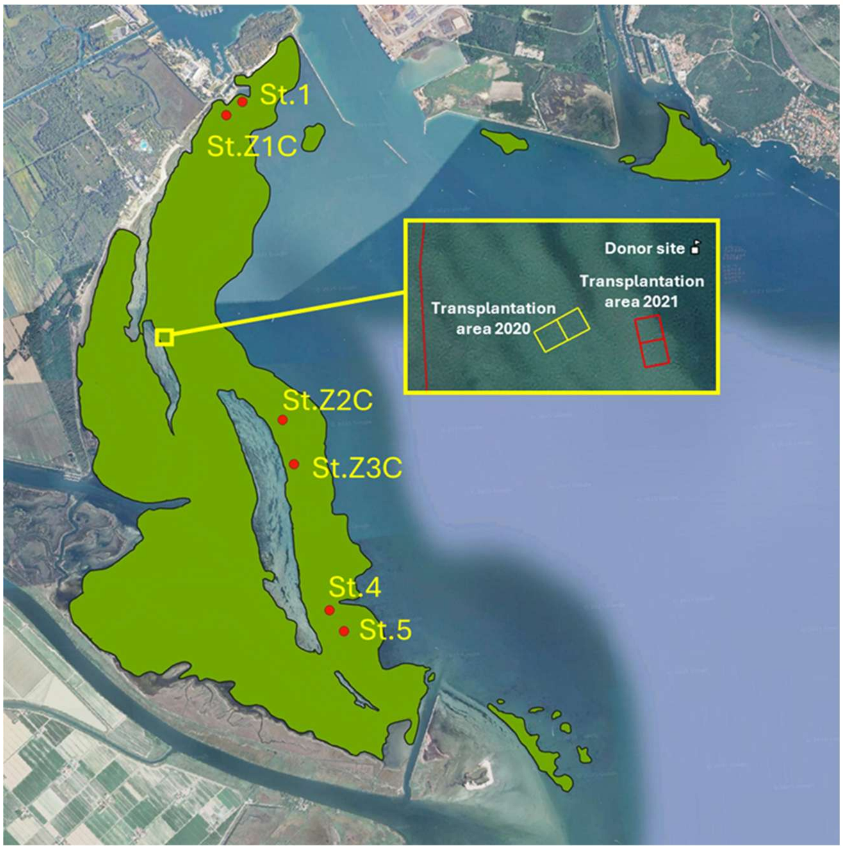

Figure 4.1 | Location of *Cymodocea nodosa* donor and transplantation areas in Panzano Bay (Monfalcone) under the SASPAS project. The map highlights the donor site and the 2020 (yellow) and 2021 (red) transplantation plots, together with nearby reference monitoring stations (St. Z1C, Z2C, Z3C, 4, 5).

4.2.2. Characterization and assessment of the receiving meadow

The receiving area was located on a nearby sandy flat in the central part of Panzano Bay, at a similar depth to the donor meadow (around 1.2 m) (Figure 4.1 and Figure 4.2). The seabed consists of fine, compact, and well-oxygenated sand, moderately exposed to waves and currents. During windy periods, short episodes of sediment resuspension may occur. These environmental conditions are typical of the central part of Panzano Bay, influenced by freshwater inputs from the Isonzo River and by seasonal winds.

The sediment in the transplant area was characterized by the near-total absence of seagrasses and consisted of well-aerated, fine sands with stable granulometry and no signs of organic enrichment or anoxic layers, providing suitable conditions for *Cymodocea nodosa* rooting and growth. During calm weather, water transparency was sufficient to ensure adequate light penetration for photosynthesis within the expected colonization depth.

Overall, the receiving site was classified as environmentally suitable for restoration, combining stable physical conditions, moderate hydrodynamic exposure, and sediment characteristics comparable to those of natural *C. nodosa* meadows in Panzano Bay.

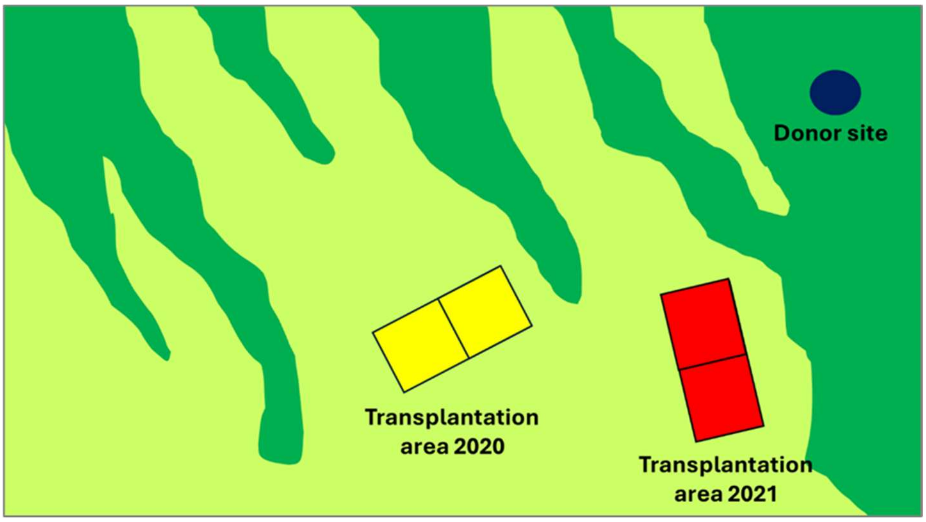

Figure 4.2 | Schematic representation of the *C. nodosa* restoration area in Panzano Bay (Monfalcone). In green: natural *C. nodosa* meadows; in light green: sandy seabed with very sparse or no seagrass cover; in yellow and red: 2020 and 2021 transplantation plots, respectively (each plot comprising two 10 × 10 m subplots); in blue, the donor site.

4.2.3. Assessment of ecosystem services of donor and receiving meadows

The *Cymodocea nodosa* meadows of Panzano Bay, including those from the donor site used for transplanting, provide a wide range of ecosystem services that significantly contribute to coastal ecological functioning and climate regulation. Among these, Blue Carbon storage and biodiversity support stand out as the most relevant services, both in terms of scientific interest and management implications.

Blue Carbon storage

The seagrass meadows of *Cymodocea nodosa* play a crucial role in organic carbon sequestration, both in living biomass and in the underlying sediments. Measurements obtained in the SASPAS–ARTEMIS framework indicate a mean organic carbon stock of approximately 2.16 kg Corg m^{-2}, including 0.127 kg Corg m^{-2} in aboveground biomass and 2.03 kg Corg m^{-2} in the top 20 cm of sediment. Although this storage capacity is lower than that of *Posidonia oceanica* meadows, *C. nodosa* compensates with higher productivity rates, rapid colonization, and fast sediment turnover, which allow for quicker carbon accumulation after disturbance or restoration.

Sediment analyses from the Monfalcone pilot site reveal well-oxygenated, fine-grained sands that facilitate the trapping and burial of organic detritus derived from seagrass litter and epiphytic communities. The proximity to the Isonzo River delta also enhances organic matter deposition, further supporting carbon retention. Over time, restored *C. nodosa* seagrass meadows are expected to become stable carbon storage areas, supporting blue carbon assessments in the northern Adriatic coastal region.

Biodiversity

The *Cymodocea nodosa* meadows of Panzano Bay represent key biodiversity hotspots within the shallow infralittoral zone, sustaining a wide variety of flora and fauna. Before assessing ecological quality, it is important to note that the Ecological Biodiversity Quality Index (EBQI), although applied at other ARTEMIS pilot sites dominated by *Posidonia oceanica*, is not applicable to *C. nodosa* systems. EBQI integrates structural and functional attributes specifically calibrated for *Posidonia* and currently lacks reference thresholds or adaptation for *C. nodosa* meadows. For this reason, biodiversity assessment in Panzano Bay relied on direct biological indicators, such as species richness, shoot density, and faunal assemblage composition, together with ecological indices. These included MediSkew, which describes the structural condition of the *C. nodosa* canopy, and M-AMBI, which evaluates the ecological quality of the benthic macrofaunal community. The combined interpretation of these metrics provides a more comprehensive understanding of the habitat's structural and functional integrity.

The assessment of ecological quality based on these indices classified the adjacent natural *C. nodosa* meadows as having Good to Moderate ecological status (M-AMBI 0.69; MediSkew 0.42). These values indicate balanced benthic communities dominated by sensitive taxa (Groups I–II) and the absence of opportunistic or stress-tolerant species, confirming the overall good environmental condition of the donor and nearby reference sites.

Functionally, *C. nodosa* meadows provide safe areas where many marine animals can feed and grow. They host fish families such as sea breams (Sparidae), mullets (Mugilidae), pipefish (Syngnathidae), and soles (Soleidae), together with many small invertebrates like crustaceans, polychaetes, and small gastropods. The dense leaves and rhizomes give shelter and food, helping young fish and small animals survive.

Monitoring under SASPAS confirmed that *C. nodosa* meadows host significantly higher species richness and abundance compared to adjacent unvegetated areas.

Additional ecosystem services

In addition to their role in carbon storage and biodiversity enhancement, *Cymodocea nodosa* meadows contribute to:

- Sediment stabilization and wave energy attenuation, through an extensive rhizome–root network that reduces sediment resuspension and mitigates coastal erosion.
- Water quality improvement, by trapping suspended particles and absorbing dissolved nutrients, leading to clearer waters and improved light penetration.

These supporting services reinforce the ecological and socio-economic importance of seagrass restoration in Panzano Bay, complementing the primary functions of carbon sequestration and habitat provision.

4.2.4. Selection of restoration technique

Within the SASPAS project, two manual transplantation techniques were tested and compared to evaluate their effectiveness under the local environmental and sedimentary conditions of Panzano Bay. The selection of the methods was based on previous experience with *Cymodocea nodosa* restoration in the Adriatic Sea and on the need to minimize disturbance to both donor and receiving areas while ensuring adequate mechanical stability of the transplanted material.

1. Vegetated plug (sod) method

This approach involved the transplantation of intact vegetated plugs (or sods) containing *C. nodosa* shoots, rhizomes, roots, and a portion of the surrounding sediment (Figure 4.3). The plugs were extracted manually by divers using stainless-steel coring cylinders of approximately 25 cm in diameter and 20–25 cm in depth, ensuring the preservation of the natural sediment structure and the associated microbial and faunal components. Each sod was inserted into a pre-dug hole in the receiving area at the same depth as the surrounding seabed to maintain continuity of the sediment surface. To enhance stability and reduce erosion, the plugs were placed inside biodegradable jute bags, which allowed sediment cohesion during the initial establishment phase and gradually decomposed within a few months.

This method aimed to replicate small self-sustaining “islands” of seagrass capable of expanding laterally through rhizome growth. The sods were positioned in calm weather conditions, ensuring precise placement and minimal sediment disturbance.

Figure 4.3 | Pilot transplantation procedure by plugs (or sods): a) identification of the donor meadow; b) harvesting of plugs; c, d, e) temporary storage of plugs and their transport to the site to be reforested; f, g) plugs planting into the substrate by means of jute bags (SASPAS, 2022).

2. Sprig (bare root) method

The second method tested was the transplantation of bare-root rhizome fragments, or sprigs, consisting of one to three apical shoots with short rhizome sections and basal roots (Figure 4.4). The sprigs were inserted directly into the sediment and fixed using U-shaped stainless-steel staples, designed to hold the shoots in place until new roots developed and natural anchorage occurred. This method used less donor material and made it possible to apply the restoration over large areas quickly, although it provided less initial sediment stability than the vegetated plug technique.

Figure 4.4 | Pilot transplantation procedure by sprigs: a) temporary storage of sprigs and their transport to the site to be reforested; b, c) sprigs attachment to staples; d) sprigs planting into the substrate by means of staples (SASPAS, 2022).

4.3 Implementation of *Cymodocea nodosa* restoration

4.3.1. Selection of biological material for the restoration

Biological material was harvested from a nearby donor meadow selected to ensure similar environmental and sedimentary conditions. Both sods and sprigs were collected manually by divers, from the donor meadow margins to avoid damage to dense central patches, kept consistently moist to prevent desiccation, and transplanted shortly after collection to reduce stress. The short distance between donor and transplant sites (only a few tens of meters) allowed rapid transfer and reduced handling time, minimizing potential damage to the plants.

4.3.2. Preparation and positioning of restoration modules

Transplantations were carried out in the central sector of Panzano Bay, at depths between 1 and 1.5 m on gently sloping sandy bottoms. In each campaign, two 10 × 10 m plots (approximately 200 m² total) were established in the selected restoration site: one planted with about 100 vegetated plugs (sods) and the other with roughly 100 bare-root rhizomes (sprigs), arranged in a regular 30–40 cm grid to ensure uniform spacing and allow rhizome expansion (Figure 4.5). This setup enabled a direct comparison between the two transplantation techniques under identical environmental conditions.

Operations were conducted under calm sea and clear-water conditions, avoiding periods of high turbidity or strong winds. Two campaigns were completed: an initial trial in autumn 2020 to test operational feasibility, and a second in spring 2021, aligned with the natural growth period of *C. nodosa*, with higher success and survival rates.

Each plot was clearly marked with poles and small surface buoys, positioned at the corners and along the perimeter to allow relocation during monitoring and to prevent accidental disturbance by small boats. The markers were left in place throughout the monitoring period and periodically checked by divers to ensure stability and visibility.

Particular attention was paid to the anchoring and stabilization of the transplanted material. Sods were placed within biodegradable jute bags, which acted as temporary containers to maintain sediment compactness and reduce erosion in the early stages of settlement. The jute material provided both mechanical protection and surface roughness, promoting natural sediment deposition and microbial colonization around the transplanted shoots. Over time, the fabric gradually decomposed, allowing full integration of the sods into the surrounding seabed and the lateral expansion of rhizomes.

This simple but effective stabilization system proved particularly valuable during strong wind events typical of Panzano Bay, when increased wave motion could cause sediment resuspension. By enhancing the cohesion of the upper sediment layer, the jute-bagged sods helped maintain transplant stability and prevented uprooting, even under moderate hydrodynamic stress.

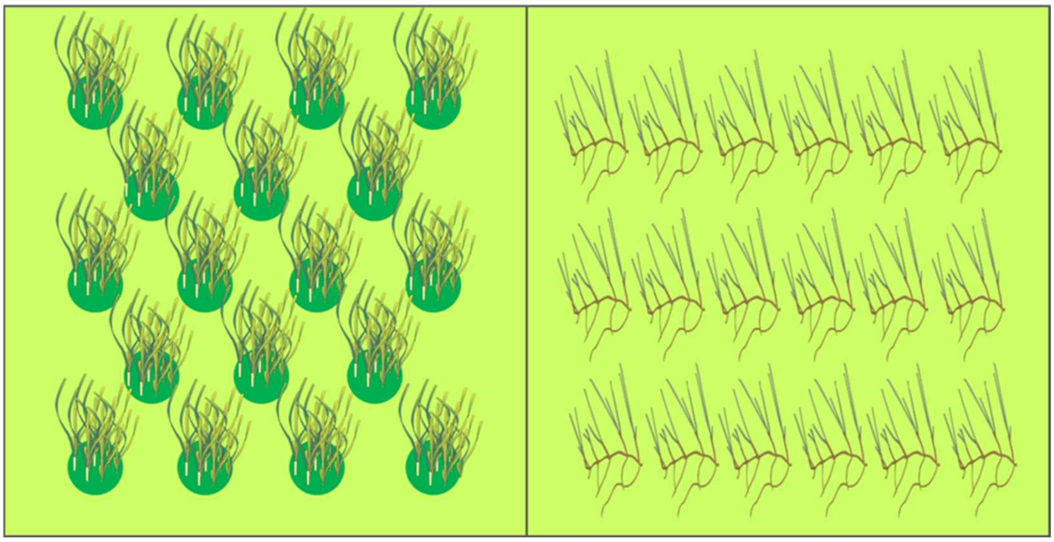

Figure 4.5 | Layout of the two *Cymodocea nodosa* transplantation plots in Panzano Bay (Monfalcone pilot site). Left: vegetated plug (sod) plot. Right: sprig (bare root) plot. Each 10 × 10 m plot contained about 100 transplants arranged in regular rows for comparative monitoring.

4.4. Monitoring of *Cymodocea nodosa* restoration

A dedicated post-transplantation monitoring program was implemented to verify the short- and medium-term evolution of the restored plots and to document the establishment and persistence of the transplanted *C. nodosa* shoots. Given the pilot and experimental nature of the intervention, the monitoring approach was qualitative and descriptive, aimed at minimizing disturbance while ensuring a continuous visual assessment of plant development and sediment stability.

4.4.1. Monitoring approach

Field inspections were carried out by divers several times during the first year following transplantation, under calm sea and clear-water conditions. The 10 × 10 m plots established during both campaigns were revisited periodically to document plant vitality, sediment status, and the progression of the restored patches. Observations focused on:

- Presence and condition of the transplanted shoots (leaf colour, production of new leaves, rhizome elongation).
- Sediment stability and the integrity of jute-bagged sods.
- Signs of lateral expansion and coalescence between neighboring transplants.
- Early faunal and epiphytic colonization, indicative of habitat functionality.

No destructive sampling was conducted, and permanent markers facilitated consistent relocation of the plots throughout the monitoring period.

4.4.2. Observations and qualitative results

The first transplantation campaign (Autumn 2020) was conducted in October 2020 during a period of relatively calm conditions. Initial survival of the vegetated plugs (sods) was very high (about 95%), and the plants appeared well rooted and stable within a few weeks after placement. During the following winter months, several episodes of intense hydrodynamic stress typical of the northern Adriatic caused localized sediment erosion and partial uprooting of transplants. After 12 months, about half of the sods remained alive, while most sprigs suffered heavy losses, with survival dropping below 10% (Figure 4.6).

Figure 4.6 | May 2022: sods of *C. nodosa* transplanted in September 2020.

The second campaign (Spring 2021) was implemented in May 2021, coinciding with the start of the active growth season for *C. nodosa*. Initial survival of sods reached 100%, and plants quickly developed new shoots and elongated rhizomes expanding beyond the original plot boundaries. After one year, around 90% of sods remained alive and well established, forming small continuous patches. Sprigs survival also improved markedly, reaching about 50% after one year, with several individuals showing new root emission and successful anchorage (Figure 4.7).

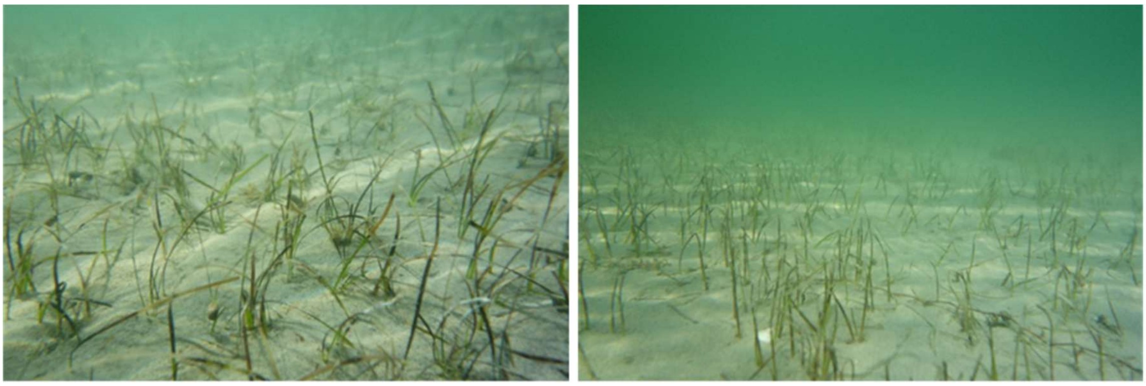

Figure 5.4.7 | May 2022: sods of *C. nodosa* transplanted in April 2021.

Sediment within the plots remained stable, and the biodegradable jute bags gradually decomposed without leaving residues, allowing full integration of the sods into the natural seabed. Divers reported the appearance of small invertebrates (amphipods, polychaetes, small bivalves) and a light epiphytic cover, suggesting early stages of faunal recolonization and ecological functionality. No opportunistic macroalgal blooms or organic accumulation were observed. Even though monitoring was mainly qualitative, the results indicate a positive recovery trend, with sod transplants showing long-term viability and the capacity for gradual expansion.

Recent follow-up observations conducted within another project (Interreg BIOPRESSADRIA, 2025; https://www.italy-croatia.eu/web/biopressadria) have confirmed the persistence of the vegetated plug (sod) transplants, which have now developed into small expanding patches of *C. nodosa* (Figure 4.8). On the contrary, the bare-root (sprigs) transplants experienced significant losses due to intense storm events a few months after installation. These recent observations provide valuable feedback on the long-term performance of the two transplantation techniques under the hydrodynamic conditions of Panzano Bay.

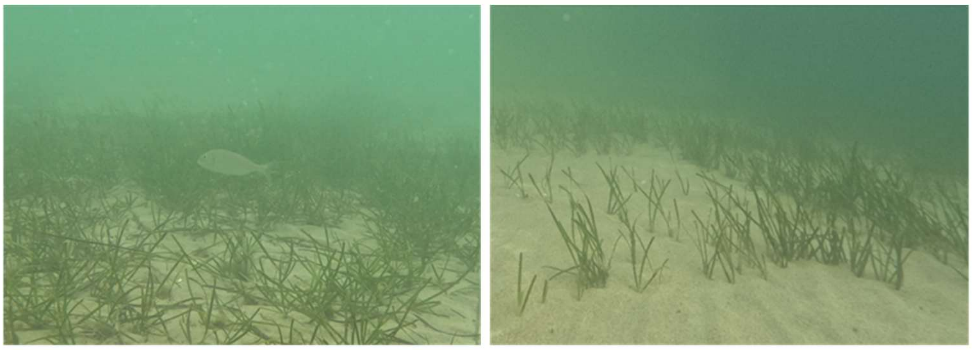

Figure 4.8 | July 2025: small expanding patches of *Cymodocea nodosa*.

4.5 Management of *Cymodocea nodosa* restoration

4.5.1. Integration between the active and passive measures of restoration

The restoration activities in Panzano Bay were conceived as part of a broader management framework aimed at the protection and recovery of *C. nodosa* meadows. The active intervention carried out under the SASPAS project (2019–2022), consisting of the transplantation of seagrass using sods and sprigs, was implemented in an area already subject to passive protection actions, such as the establishment of ecological mooring fields designed to prevent anchoring impacts on sensitive habitats.

This combination of active and passive approaches contributed to reducing potential mechanical disturbance in the restoration area and to creating favorable conditions for the natural expansion of *C. nodosa*. The spatial proximity between restoration plots and protected zones allowed for the integration of the pilot actions into the wider management strategy for Panzano Bay, promoting long-term habitat stability and ecological continuity.

4.5.2. Temporary prohibition of fishing, shipping and anchoring in restoration areas

No formal temporary prohibitions on fishing or navigation were established during the SASPAS restoration period. However, to safeguard the transplanted plots and the adjacent *C. nodosa* meadows, preventive management actions were implemented in coordination with local authorities, including the Harbour Master's Office of Monfalcone and the Friuli Venezia Giulia Region.

These actions consisted of discouraging anchoring and mechanical disturbance in the immediate vicinity of the transplant sites and promoting the use of designated ecological mooring areas as part of the broader passive protection strategy in Panzano Bay. Such measures, although voluntary in nature, were communicated through awareness campaigns and local outreach initiatives, in collaboration with diving associations, recreational users, and citizen groups, aiming to reduce physical pressures on shallow seagrass habitats and to foster a culture of responsible marine use.

4.5.3. Replacement of failures

No large-scale replanting or replacement of lost sods was required after the SASPAS transplantation campaigns. Nevertheless, the comparative evaluation between the two trials carried out in autumn 2020 and spring 2021 clearly demonstrated the influence of seasonal timing on transplant success. The first campaign, implemented during late autumn, showed higher post-winter losses due to hydrodynamic stress, while the second, performed in late spring under calmer and warmer conditions, resulted in a markedly higher establishment rate.

This outcome confirmed that transplantation timing, preferably between late spring and early summer, when *C. nodosa* exhibits active growth, plays a crucial role in promoting rhizome settlement and minimizing mortality. These operational findings can be used to refine methodological recommendations for future restoration actions in the northern Adriatic, ensuring that similar efforts can replicate the most effective conditions observed in Panzano Bay.

4.5.4. Appreciation of the restoration

Awareness and communication activities were an important part of the restoration work in Panzano Bay and complemented the technical actions carried out under the SASPAS project. These activities aimed to improve public understanding of seagrass ecosystems and to build cooperation with local communities and maritime users identified during the stakeholder consultations described in Section 5.4.1.

Outreach actions focused on the pleasure boating sector, marinas, and both professional and recreational fishers, to raise awareness about the ecological value of *Cymodocea nodosa* meadows and the need for careful navigation and anchoring to avoid physical damage.

Information materials and meetings explained the role of seagrass in supporting biodiversity, stabilizing sediments, and storing blue carbon, helping people understand how these habitats protect and improve the coastal environment. Educational and visual materials produced within SASPAS were shared through local channels and public events, encouraging active participation and responsible behavior at sea.

These awareness activities continue under the ARTEMIS project, ensuring long-term communication and policy support for the Monfalcone pilot site.

4.5.5 Decommissioning of the restoration

No decommissioning actions were foreseen or required for the restoration sites in Panzano Bay. During the restoration activities, materials as environmentally friendly and biodegradable as possible were used (e.g., jute bags), in order to minimize environmental impact and ensure the full ecological compatibility of the interventions.

The transplanted plots established under the SASPAS project were designed as permanent demonstration and observation areas, representing a long-term reference for assessing restoration success and the natural expansion of *Cymodocea nodosa* meadows. The plots are still visible and periodically checked during other projects' follow-up activities.

The data and experience gained from these sites have been used in the ARTEMIS project to update and integrate regional knowledge on seagrass restoration and habitat conditions in Panzano Bay and the Gulf of Trieste.

4.6.6 Other transplantation and restoration of *Cymodocea nodosa* meadows in the Gulf of Trieste (since 2022)

Since 2022, several coordinated projects have been carried out in the Gulf of Trieste to restore *C. nodosa* meadows, using common methods and sharing experience among different organizations. The first large-scale effort, the REPLANT Project (Marevivo, 2022–2023; https://marevivo.it), aimed to repopulate degraded seabed at Miramare MPA and Punta Sottile by testing various transplantation techniques. Results showed full survival of sods and lower, site-dependent survival of sprigs, emphasizing the importance of maintaining native sediment to support rooting and reduce stress.

Building on these findings, the SIRENS Project (2024–2026; https://www.progetto-sirens.it) introduced biodegradable 3D-printed supports designed to anchor rhizomes collected from naturally detached material. Monitoring in 2025 recorded about 80% survival, vigorous leaf growth, and stable anchoring, confirming the ecological and practical benefits of these innovative materials.

In parallel, the Eco2Smart Project (Interreg Italy–Slovenia, 2023-2025; https://www.ita-slo.eu/en/eco2smart) tested metallic support frames near Duino–Aurisina to recreate a lost meadow and enhance coastal stability. Finally, the Water Defender Alliance initiative (Mareblu, 2025–2026; https://www.mareblu.it/water-defenders-alliance) applied the SIRENS methods in Miramare's protected zone, transplanting around 2,000 shoots over 100 m^2 using biodegradable supports developed through previous research. Early monitoring indicated high survival, structural stability, and promising site resilience.

These recent interventions contribute to a broader regional dataset, improving knowledge on *C. nodosa* restoration feasibility, sediment dynamics, and blue carbon potential under different environmental settings. They complement and expand upon the earlier SASPAS pilot actions in Panzano Bay.