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Deliverable 3.1 - Shared Guidelines for the Recognition, Classification and Conservation Status Assessment of Target Mediterranean Habitats

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Abstract (for dissemination)	These Guidelines provide a harmonised methodological framework for the recognition, classification and conservation status assessment of Mediterranean coastal habitats targeted by the LIFE terrAmare project, including dune habitats and Posidonia oceanica meadows. The document integrates structural, functional and pressure-related indicators consistent with the Habitats Directive (Art. 17), combining expert-based monitoring approaches with simplified citizen science methodologies to support habitat conservation, monitoring and management across Mediterranean Natura 2000 sites..

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1. INTRODUCTION

1.1 Purpose and objectives of the document

These Guidelines define a methodological framework aimed at supporting the recognition, classification and conservation status assessment of Mediterranean coastal habitats.
The framework builds upon existing national approaches and EU reference standards and is structured to facilitate progressive harmonisation across different Mediterranean contexts.

The document responds to the need to harmonise criteria, terminology, and indicators already adopted at the national level in Italy, Greece, and Spain, integrating them into an approach consistent with the Mediterranean biogeographical scale. The Guidelines do not introduce new classification systems; rather, they consolidate and standardise existing methodologies in order to enable a comparable interpretation of habitat conditions across the different territorial contexts involved.

In particular, the document pursues the following objectives:

- to define clear and shared criteria for the recognition of dune habitats (H1210, H2110, H2120, H2210, H2250*) and the marine habitat H1120* (*Posidonia oceanica*);
- to identify diagnostic, structural, and functional elements relevant for the correct classification of habitats;
- to propose a harmonised system of indicators for conservation status assessment, consistent with the framework defined under Article 17 of the Habitats Directive (range, area, structure and functions, future prospects);
- to ensure the integration of data collected within the project into future European reporting cycles;
- to provide a technical reference framework that can be replicated in other Natura 2000 sites within the Mediterranean region.

The Guidelines are addressed not only to technicians, Natura 2000 site managers, and environmental practitioners, but also to non-expert participants involved in project activities, including students, families, tourists, and other volunteers. Part of these stakeholders will form the Ecological Beach Communities, local groups actively engaged in the conservation and monitoring of coastal habitats.

In this context, the document is structured to make simplified monitoring methodologies understandable and applicable, where possible, based on citizen science approaches. These approaches enable the collection of useful data for conservation status assessment through standardised and scientifically validated protocols.

The integration of specialist monitoring and community participation represents a key feature of the LIFE terrAmare approach, contributing to increased environmental awareness and to the long-term sustainability of conservation actions.

The Guidelines therefore represent a multi-level technical reference tool, capable of combining scientific rigour, methodological harmonisation, and active citizen participation in the protection of Mediterranean coastal habitats.

1.2 Target habitats

These Guidelines apply to the following habitats of Community interest listed in Annex I of Directive 92/43/EEC:

- H1210 – Annual vegetation of drift lines
- H2110 – Embryonic shifting dunes
- H2120 – Shifting dunes with *Ammophila arenaria*
- H2210 – Fixed coastal dunes (Crucianellion maritimae)
- H2250 – Coastal dunes with Juniperus spp.*
- H1120 – *Posidonia oceanica* meadows*

Dune habitats (H1210, H2110, H2120, H2210 and H2250*) represent the main components of Mediterranean beach–dune systems and play a key role in sediment stabilisation, coastal protection against erosion, and biodiversity conservation.

The marine habitat H1120* (*Posidonia oceanica*) is a key element of Mediterranean coastal ecosystems, contributing to seabed stabilisation, banquette formation, and the overall resilience of beach–dune systems.

All habitats considered in this document are characterised by high vulnerability to anthropogenic pressures, including coastal urbanisation, intensive tourism, anchoring, mechanical beach cleaning, grazing, and the spread of invasive alien species.

The approach proposed in this document is designed to be applicable across different environmental and geographical contexts, allowing for adaptation based on site-specific conditions.

1.3 Regulatory framework

The Guidelines are framed within the main European policies concerning biodiversity conservation and coastal ecosystem management.

The Habitats Directive (92/43/EEC) represents the main legislative instrument of the European Union for the conservation of natural habitats and species of Community interest. The habitats addressed in this document are listed in Annex I of the Directive and, in the case of those marked with an asterisk (H2250* and H1120*), are considered priority habitats requiring special conservation attention.

The Directive provides for:

- the designation of Special Areas of Conservation (SACs);
- the adoption of appropriate conservation measures;
- the periodic monitoring of conservation status;
- the prevention of habitat deterioration.

In particular, Article 17 of the Habitats Directive requires Member States to report every six years on the conservation status of habitats and species of Community interest. This assessment is based on four main parameters:

- Range
- Area
- Structure and functions
- Future prospects

These Guidelines define indicators and monitoring protocols consistent with this framework, ensuring the integration of project data into future reporting cycles.

For the marine habitat H1120*, the document also considers the principles of the Marine Strategy Framework Directive (2008/56/EC) and the Water Framework Directive (2000/60/EC), particularly with regard to good environmental status and coastal water quality objectives.

1.4 Study areas

The Guidelines apply to Natura 2000 sites involved in the LIFE terrAmare project in Italy and Greece, characterised by the presence of the target habitats listed above.

The study areas include beach–dune systems and *Posidonia oceanica* meadows subject to different types of environmental pressures, including:

- coastal erosion
- habitat fragmentation
- seasonal tourism pressure
- anchoring and fishing activities
- spread of invasive alien species

The diversity of environmental contexts allows the application and testing of the proposed monitoring protocols under different ecological conditions, supporting their robustness and transferability within the Mediterranean region.

The selected Natura 2000 sites (Tab. 1) represent a wide range of Mediterranean coastal conditions, including dune and marine habitats subject to different levels and types of anthropogenic pressure. This variability supports the development and testing of transferable monitoring and conservation approaches within the LIFE terrAmare project.

Natura 2000 Site	Region / Country	Main Habitats	Main Pressures
IT51A0028 – Duna di Feniglia	Tuscany (Italy)	H1210, H2110, H2120, H2210	Tourist trampling, mechanical beach cleaning, habitat fragmentation
IT51A0026 – Laguna di Orbetello	Tuscany (Italy)	H1210, H2110, H2210	Urbanization, intensive tourism, invasive alien plant species (IAPS)
IT5160004 – Padule di Bolgheri	Tuscany (Italy)	H1210, H2110, H2120, H2210	Tourism pressure, hydromorphological alterations, IAPS
IT6040018 – Dune del Circeo	Lazio (Italy)	H2110, H2120, H2210, H2250*	Trampling, coastal urbanization, IAPS
IT9140005 – Torre Guaceto e Macchia S. Giovanni	Apulia (Italy)	H1210, H2110, H2120, H2210, H2250*	Trampling, grazing, IAPS
IT9330089 – Dune dell'Angitola	Calabria (Italy)	H2110, H2120, H2210	Habitat fragmentation, grazing, IAPS
IT9310051 – Dune di Camigliano	Calabria (Italy)	H1210, H2110, H2120	Trampling, mechanical cleaning, coastal erosion
IT9350160 – Spiaggia di Brancaleone	Calabria (Italy)	H1210, H2110, H2120	Tourism pressure, mechanical cleaning, erosion
IT9340092 – Fondali di Pizzo Calabro	Calabria (Italy)	H1120*	Anchoring, fishing activities, mechanical disturbance
IT9310048 – Fondali Crosia–Pietrapaola–Cariati	Calabria (Italy)	H1120*	Anchoring, fishing pressure, water turbidity
GR2230002 – Limnothalassa Korissïon (Kerkyra)	Corfu Island (Greece)	H2110, H2120, H2250*	Grazing, tourism pressure, fires, IAPS
GR4340013 – Nisoi Gavdos kai Gavdopoula	Crete / Gavdos (Greece)	H2110, H2120, H2250*	Overgrazing (goats), erosion, tourism pressure

Tab. 1 : The selected Natura 2000 sites cover diverse Mediterranean coastal conditions, enabling the testing of transferable monitoring and conservation approaches under varying anthropogenic pressures.

2. ECOLOGICAL AND GEOMORPHOLOGICAL FRAMEWORK

2.1 Dynamics of Mediterranean dune systems

Beach–dune systems are geomorphologically dynamic environments shaped by the interaction of marine, aeolian, and biological processes. The morphology and evolution of coastal dunes mainly depend on sediment availability, wave energy, the direction and intensity of prevailing winds, and the presence of stabilising psammophilous vegetation (Pye & Tsoar, 2009; Martínez et al., 2008).

In the Mediterranean context, coastal dunes develop primarily along low-lying sandy coasts characterised by shallow seabeds and significant sediment supply (Pranzini, 2017). The initial stage of dune formation is associated with the aeolian accumulation of sand trapped by pioneer vegetation, particularly species such as *Elymus farctus* and *Ammophila arenaria*, which play a key role in substrate stabilisation through their rhizomatous root systems (Maun, 2009).

Embryonic dunes (H2110) represent the initial stage of dune formation and are characterised by high sediment mobility and low vegetation cover. Shifting dunes with *Ammophila arenaria* (H2120), also known as “white dunes”, represent a more advanced stage and show a greater capacity for sand trapping and accumulation (Acosta et al., 2007; Biondi, 2007). Fixed dunes (H2210) and dunes with *Juniperus* spp. (H2250*) represent subsequent stages along the coastal dune gradient, characterised by higher geomorphological stability and increased structural complexity of vegetation.

The functionality of dune systems is closely linked to their morphological integrity. Alterations caused by urbanisation, tourism infrastructure, mechanical beach cleaning, and trampling lead to fragmentation and loss of natural zonation (Prisco et al., 2012; Malavasi et al., 2016). Fragmentation reduces system resilience and disrupts sediment dynamics, increasing vulnerability to coastal erosion (Feagin et al., 2005).

2.2 Sea–dune connectivity

Mediterranean dune systems are functionally connected to marine habitats, particularly *Posidonia oceanica* meadows (H1120*), which represent one of the key ecosystems of the Mediterranean basin (Boudouresque et al., 2012). *Posidonia oceanica* is an endemic Mediterranean seagrass forming highly structured meadows that provide essential ecosystem functions, including:

- stabilisation of the seabed;

- attenuation of wave energy;
- trapping and consolidation of sediments;
- high primary production;
- carbon sequestration and storage (“blue carbon”) (Duarte et al., 2013; Fourqurean et al., 2012).

Detached leaf biomass accumulates along the shoreline forming deposits known as banquettes, which play a crucial role in stabilising embryonic dunes and protecting the coast from erosion (Mateo et al., 2003; De Falco et al., 2008). Banquettes also enhance sediment and nutrient retention and create favourable microhabitats for the germination of psammophilous species.

The systematic removal of banquettes through mechanical beach cleaning disrupts this functional connectivity and reduces the resilience of the beach–dune system (Simeone & De Falco, 2013).

2.3 Anthropogenic pressures and vulnerability of Mediterranean coastal systems

Mediterranean coastal ecosystems are among the most vulnerable in Europe due to high population density and intense tourism pressure (EEA, 2019). The main pressures include:

- coastal urbanisation and infrastructure development;
- mechanical beach cleaning;
- unregulated anchoring;
- fragmentation and artificialisation of the coastline;
- spread of invasive alien plant species (IAPS).

Invasive alien species represent one of the main threats to dune and marine biodiversity (Vilà et al., 2011). In dune environments, species such as *Carpobrotus* spp. and *Acacia saligna* alter vegetation structure and composition, modifying soil chemistry and sediment dynamics (Celesti-Grapow et al., 2009). In marine environments, invasive algae such as *Caulerpa taxifolia* and *Caulerpa cylindracea* can compete with *Posidonia oceanica*, negatively affecting meadow structure (Ceccherelli & Cinelli, 1999).

According to recent Article 17 reports, many Mediterranean dune habitats are in an “unfavourable–inadequate” or “unfavourable–bad” conservation status, highlighting the need to strengthen monitoring and management systems (EEA, 2020; Prisco et al., 2020). In Italy, dune habitats are particularly threatened by coastal erosion, urbanisation, and transport infrastructure (Biondi et al., 2014).

The main pressures affecting these environments are linked to beach tourism activities, including coastal roads, tourist facilities and residential development, mechanical beach cleaning and levelling, trampling, waste accumulation, and vehicle transit on dunes. Additional pressures include invasive species, erosion processes, and other alterations of natural dynamics, such as drainage, coastal defence structures, and sediment extraction.

PART I – RECOGNITION AND CLASSIFICATION OF DUNE HABITATS

3. CRITERIA FOR THE RECOGNITION OF DUNE HABITATS

3.1 Diagnostic species

Diagnostic species are taxa whose presence, frequency and structural arrangement are characteristic of a specific habitat and allow its identification and conservation status assessment under the Habitats Directive 92/43/EEC (European Commission, 1992, 2013). Within the LIFE TERRAMARE project, they represent the main biological reference for assessing target coastal dune habitats.

H1210 – Annual vegetation of drift lines

Habitat H1210 includes nitrophilous therophytic communities developing along storm drift lines on sandy substrates enriched with organic matter. Typical diagnostic species include Cakile maritima, Salsola kali, Polygonum maritimum and Atriplex prostrata. The presence of well-structured and dynamic communities indicates the natural cyclicity of organic material deposition and removal processes, while their absence may be linked to intensive mechanical beach cleaning or altered sediment dynamics (European Commission, 2013). These deposits often include Posidonia oceanica banquettes (accumulations of stranded leaves and rhizomes), which are an integral component of the beach–dune system functioning (Boudouresque et al., 2025). The presence of intact banquettes together with typical H1210 therophytic communities represents a positive indicator of ecosystem functionality and management consistent with natural processes.

H2110 – Embryonic shifting dunes

Embryonic dunes represent the initial stage of dune formation. Diagnostic species are pioneer plants highly tolerant to salinity, substrate instability and aridity. Key species include *Elytrigia juncea* (syn. *Thinopyrum junceum*), *Calystegia soldanella*, and residual elements of H1210 communities. Their discontinuous but active distribution indicates functioning sediment dynamics and natural sand supply (Ciccarelli et al., 2021).

H2120 – Shifting dunes with Ammophila arenaria

Habitat H2120 is characterized by the dominance of *Ammophila arenaria*, an ecosystem engineer species capable of trapping and stabilizing wind-blown sand, promoting vertical dune growth. Frequent accompanying species include *Eryngium maritimum*, *Echinophora spinosa* and *Medicago marina*. The cover, vitality and regeneration capacity of *A. arenaria* are direct indicators of the geomorphological functionality of the habitat. Significant reductions may reflect erosion, trampling or system fragmentation (Acosta et al., 2017).

H2210 – Fixed coastal dunes (Crucianellion maritimae)

Fixed dunes are characterized by greater substrate stability and the development of chamaephytic and suffruticose communities. Diagnostic species include *Crucianella maritima*, *Helichrysum italicum* subsp. *microphyllum*, *Fumana procumbens* and *Teucrium polium*. The presence of these species in a pattern consistent with natural zonation indicates ecological maturity and reduced substrate mobility (European Commission, 2013).

*H2250 – Coastal dunes with Juniperus spp.**

The priority habitat H2250* is characterized by shrub formations dominated by *Juniperus communis* subsp. *communis* and/or *Juniperus oxycedrus* subsp. *macrocarpa*. These species represent key structural elements and indicate advanced stability and ecological continuity. Their fragmentation or lack of natural regeneration signals degradation or anthropogenic pressure (European Commission, 2013; EEA, 2019).

Operational role in monitoring

Within the TERRAMARE project framework, the assessment of presence, cover and regeneration of diagnostic species across the five target habitats represents a primary criterion for evaluating representativity, structure and functions, in line with Article 17 reporting guidelines (European Commission, 2017). These species also provide observable indicators suitable for participatory monitoring contexts, provided they are included within a standardized methodological protocol.

3.2 Vegetation structure and zonation

The assessment of the conservation status of coastal dune habitats requires the integration of diagnostic species (Section 3.1) with structural and functional indicators, in accordance with the definition of “favourable conservation status” under the Habitats Directive 92/43/EEC (European Commission, 1992) and with the reporting guidelines under Article 17 (European Commission, 2017). The methodological approach adopted is based on technical manuals on Mediterranean and Adriatic dune habitats, as well as on recent scientific literature concerning dune system dynamics and resilience (Acosta et al., 2017; Ciccarelli et al., 2021).

Structural indicators describe the physical and vegetation organization of the habitat, while functional indicators represent the ecological processes that ensure its dynamics, resilience and regeneration capacity.

Structural indicators

The main structural indicators include:

- Vegetation zonation along the sea–inland gradient, with a recognizable sequence of habitat belts (2110 – embryonic dunes; 2120 – shifting dunes; 2210/2230 – fixed dunes; 2240 – backdune systems) (Fig. 3.2.1). The continuity of this zonation represents a key indicator of ecological integrity (European Commission, 2013).

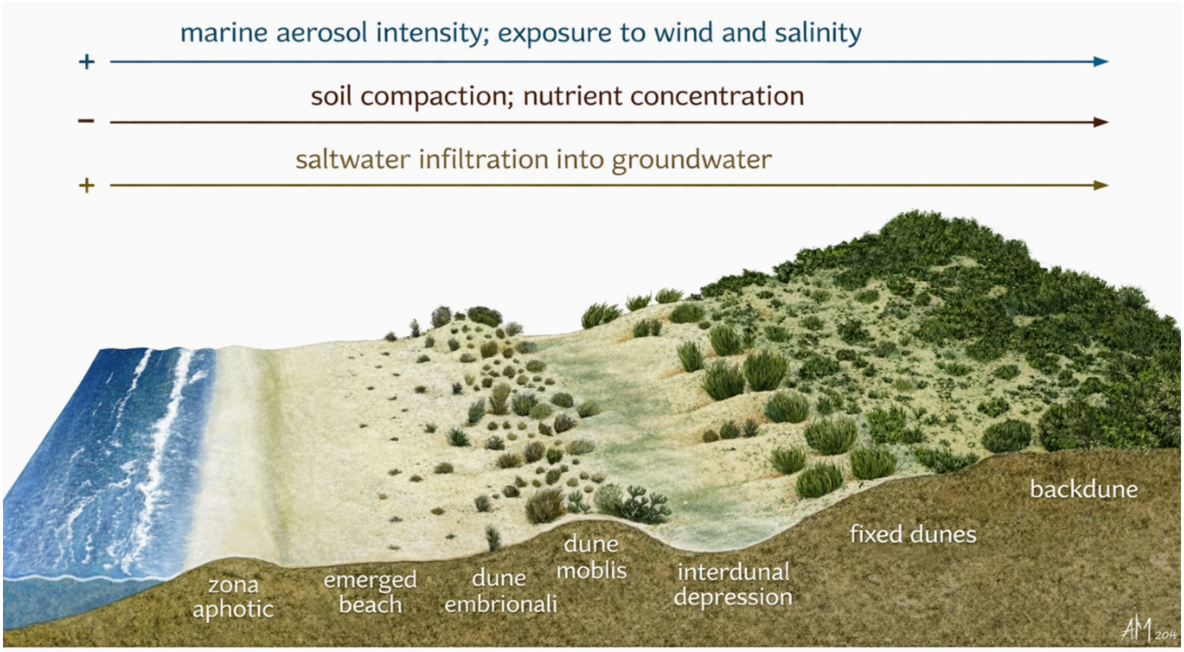


Fig. 3.2.1: Zonation of a coastal dune system from the beach to the backdune, showing the transition from embryonic to fixed dunes and associated environmental gradients.

- Percentage cover of psammophilous vegetation, consistent with the successional stage of the habitat. Anomalous reductions in vegetation cover or fragmented distribution patterns indicate erosion processes or anthropogenic pressure (Ciccarelli et al., 2021).

- Presence and abundance of invasive alien species, such as *Carpobrotus* spp., *Oenothera* spp. and *Agave americana*, recognized as drivers of structural and functional alteration in Mediterranean dune systems (Acosta et al., 2017; Pyšek et al., 2020).

- Morphological continuity of the dune ridge, with the absence of artificial interruptions (e.g. pathways, infrastructures, vehicle tracks) that may disrupt the system structure and natural aeolian processes.

Spatial fragmentation and the loss of connectivity among different stages of the dune succession represent clear signs of structural degradation and reduced ecosystem resilience (Acosta et al., 2017).

Functional indicators

Functional indicators refer to the dynamic processes supporting the habitat:

- Active sediment dynamics, evidenced by sand accumulation, formation of embryonic dunes and recolonization by pioneer species. Alterations in sediment fluxes compromise habitat functionality (Ciccarelli et al., 2021).
- Natural regeneration capacity, assessed through the presence of seedlings and juvenile individuals of characteristic species.
- Absence of soil compaction and widespread trampling, which reduce permeability and germination capacity of sandy substrates (European Environment Agency [EEA], 2019).
- Ecological connectivity with adjacent environments, essential to ensure genetic and functional exchanges and to counteract fragmentation effects (European Commission, 2017).

A dune system in good conservation status is characterized by a balance between mobility and stability: sand must be able to circulate through natural aeolian processes, while psammophilous vegetation progressively traps and stabilizes it.

Applicability to monitoring

The indicators described can be assessed through transects perpendicular to the shoreline, permanent plots, floristic–structural survey forms and georeferenced photographic documentation, in accordance with national technical protocols for coastal habitat monitoring and with European reporting guidelines (European Commission, 2017).

For participatory monitoring within the Community of Ecological Beaches, easily observable indicators can be selected (e.g. presence of key species, continuity of the dune ridge, signs of disturbance, invasive species), while maintaining a methodological framework consistent with technical-scientific criteria.

The integration of structural and functional indicators (see Sections 4.1 and 4.2) allows for a robust and replicable assessment of conservation status, supporting management and restoration actions in line with the objectives of the LIFE TERRAMARE project.

3.3 Geomorphological criteria

Geomorphological criteria represent a central element in the assessment of the conservation status of dune habitats (H1210, H2110, H2120, H2210, H2250), as they describe the physical structure of the beach–dune system, its sedimentary dynamics, and its capacity to respond to natural and anthropogenic stresses. Coastal dune systems result from the interaction between aeolian transport, sediment availability, vegetation cover, and marine forcing; their morphology reflects the balance between accumulation and erosion processes (Hesp, 2002; Sloss et al., 2012) (Fig. 3.3.1).

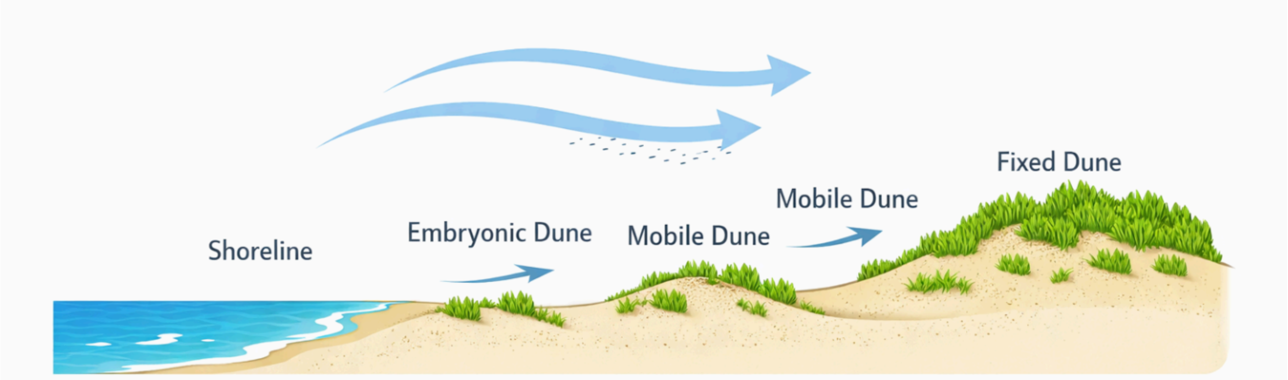


Fig. 3.3.1: Simplified schematic of dune formation from shoreline to fixed dunes, driven by wind transport and progressive vegetation stabilization.

A first criterion concerns the morphological continuity of the system and the presence of the natural sequence that, from the drift line (H1210), leads to embryonic dunes (H2110), mobile dunes (H2120), and fixed dunes (H2210, H2250). This sequence represents the expression of active sedimentary processes and is indicative of a functioning system (Martínez et al., 2008).

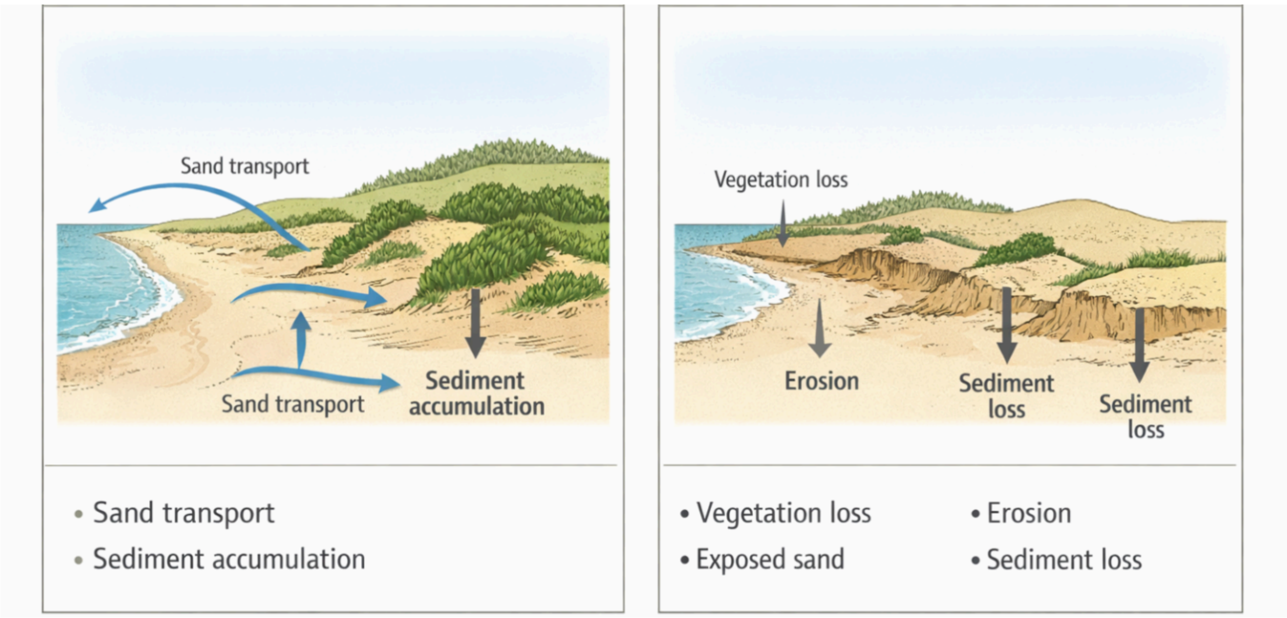


Fig. 3.3.2. Comparison between an intact (left panel) and a degraded (right panel) coastal dune system, highlighting sediment dynamics, vegetation role, and erosion processes.

Figure 3.3.2 highlights how intact systems exhibit morphological and functional continuity, with active sediment transport and accumulation processes and well-developed vegetation cover, whereas degraded systems show disruption of the dune sequence, vegetation loss, and the predominance of erosive processes.

The morphology of the dune ridge (height, width, slope) provides direct indications of the system's capacity to accumulate sediment and protect the coastline. Well-developed dunes, with regular and continuous profiles, indicate stable conditions and proper functioning, whereas low, flattened, or discontinuous dunes are generally associated with erosion or anthropogenic disturbance (Durán & Moore, 2013) (Fig. 3.3.3).

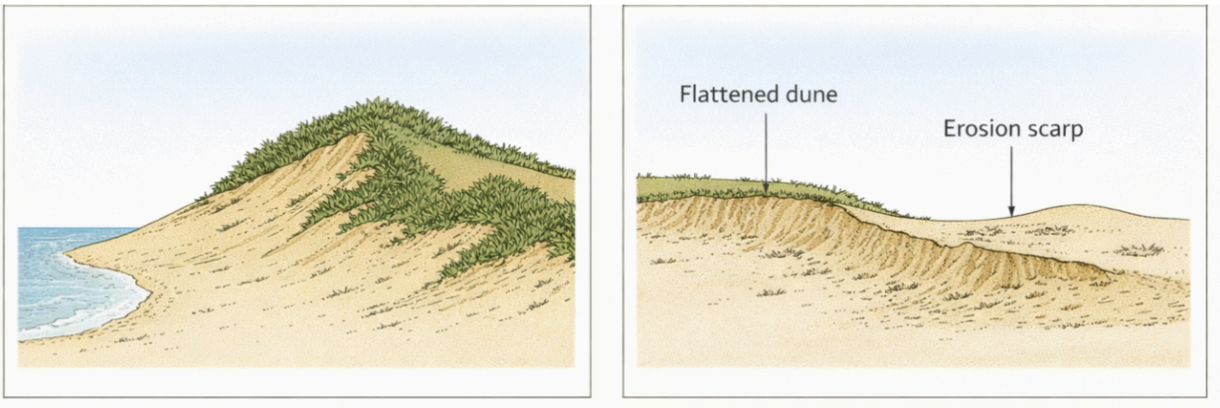


Fig. 3.3.3. Comparison between a well-developed dune profile (left) and a degraded one (right).

Well-developed dunes exhibit greater height, continuity, and vegetation cover, contributing to system stability and coastal protection. In degraded systems, flattened or eroded profiles, vegetation loss, and a reduced capacity for sediment accumulation are observed.

The sediment budget represents a key element in geomorphological assessment. Under favorable conditions, accumulation processes occur, with the formation of embryonic dunes and sand deposition, whereas under sediment deficit conditions, erosive processes prevail, such as scarps, retreat of the dune toe, and vegetation loss (Hesp, 2002; Martínez et al., 2008).

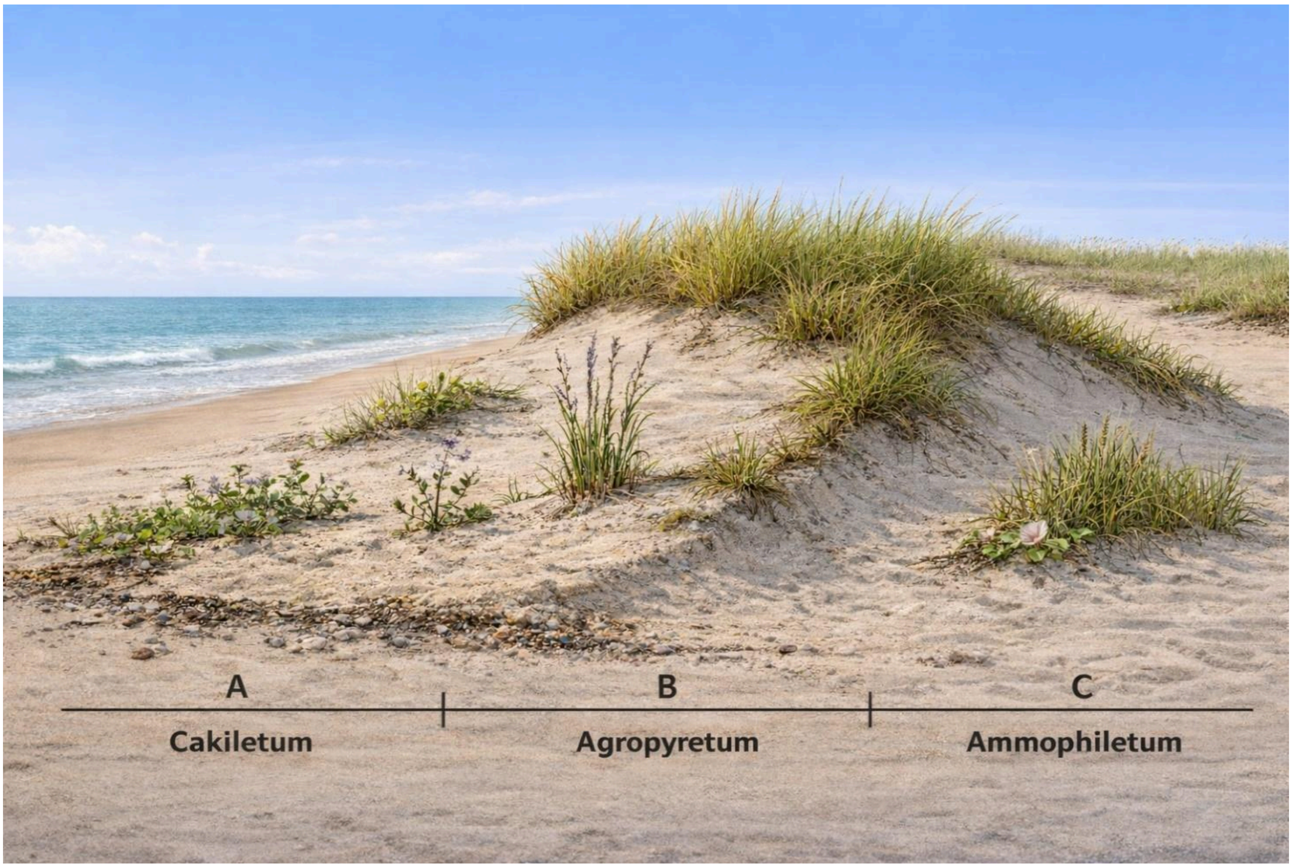


Fig. 3.3.4. Embryonic dune with zonation.

A dune system in good condition is characterized by active dynamics, where sand is transported by wind and trapped by pioneer vegetation. The presence of embryonic dunes and sand accumulations indicates an evolving system (Fig. 3.3.4). In contrast, in heavily degraded systems a reduction or absence of sediment dynamics is evident (Fig. 3.3.5), often linked to:

- mechanical beach cleaning;
- trampling;
- system fragmentation.

Fig. 3.3.5. Example of a degraded dune system characterized by trampling and reduced vegetation cover (in particular here motocross tire tracks), leading to weakened sediment dynamics and dune flattening (picture taken in Angitola dune system, Calabria).

The presence of infrastructure, unregulated access points, tracks, and mechanical leveling disrupts the continuity of the dune system and alters sediment flows, reducing system resilience (Martínez et al., 2008). In the analyzed contexts, fragmentation is often associated with:

- direct access to the beach
- tourist infrastructure
- mechanical beach management

Geomorphological criteria can be assessed through observations along transects, georeferenced photographic documentation, and, where available, topographic surveys. Even within a citizen science framework, useful information can be collected by focusing on easily recognizable elements such as:

- presence of the dune sequence
- evidence of erosion
- system interruptions

Geomorphological analysis should directly guide management actions. In systems characterized by erosion and morphological simplification, interventions should aim not only to protect existing dunes, but also to restore sediment dynamics and natural zonation, promoting vegetation recolonization and reducing anthropogenic pressures.

3.4 Spatial delimitation and mapping methodologies

The spatial delimitation and cartographic representation of dune habitats (H1210, H2110, H2120, H2210, H2250*) constitute an essential step in the assessment of conservation status, as they allow the quantification of the extent, configuration, and degree of fragmentation of the beach–dune system. The methodologies adopted must ensure consistency with the geomorphological and vegetation criteria previously described, guaranteeing reproducibility, temporal comparability, and integration with geographic information systems.

Delimitation is based on the integration of field surveys, photo-interpretation, and GIS analysis, following a multi-scale approach widely recognized in the scientific literature for coastal environments (Martínez et al., 2008; Levin et al., 2007). First, habitat boundaries are defined through direct field surveys along transects perpendicular to the coastline, useful for identifying the cross-shore zonation from the drift line (H1210) to the inland dunes (H2210, H2250). Boundaries are identified based on morphological changes (break in slope, dune toe and crest) and floristic-vegetation features (variation in the composition and cover of diagnostic species).

The photo-interpretation of high-resolution orthophotos and satellite imagery allows refinement and validation of field-based delimitation, as well as diachronic analysis of the spatial evolution of habitats. The use of remote sensing data is particularly effective in detecting morphological changes, dune toe retreat, and variations in vegetation cover, contributing to the assessment of coastal dynamics (Levin et al., 2007). Where digital terrain models (DTMs) are available, altimetric information can be integrated to distinguish embryonic dunes, foredunes, and stabilized dunes based on objective morphometric parameters. In this context, LiDAR (Light Detection and Ranging) data can provide high-resolution digital terrain models, useful for identifying morphological elements such as dune toe and crest and for distinguishing different dune units (embryonic, mobile, and stabilized dunes). These data are particularly valuable where habitat boundaries are unclear or in degraded systems. However, delimitation can also be effectively carried out through field surveys and photo-interpretation alone, while LiDAR represents a supporting tool when available.

Delimitation must also consider the intrinsic dynamism of coastal habitats, avoiding static interpretations of boundaries. The margins between beach and dune, as well as between mobile and fixed dunes, may vary seasonally or following extreme events; therefore, mapping should be accompanied by metadata specifying survey date, mapping scale, and spatial accuracy. Periodic repetition of surveys allows monitoring of surface changes and shifts in habitat boundaries, providing quantitative indicators of evolutionary trends and resilience (Hesp, 2002).

BOX 1 – How to recognize and delimit dune habitats in the field

Dune habitat recognition and delimitation are based on the integrated analysis of dune morphology and vegetation distribution, which together define the spatial succession of habitats along the sea–dune gradient.

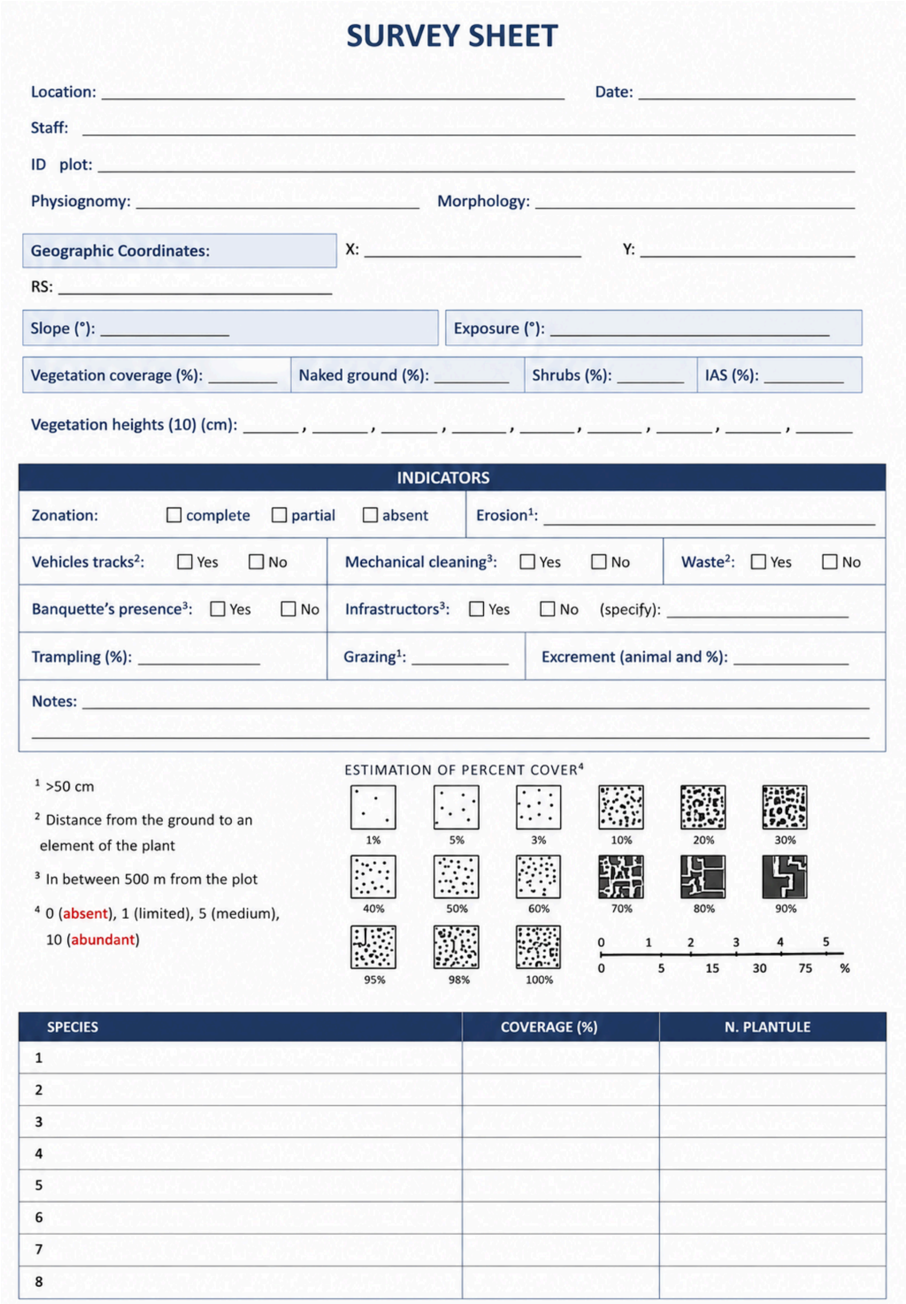
Prior to field activities, a preliminary ecological framework of the study area should be defined using available literature and existing data, in order to identify the expected distribution and organisation of dune habitats. In the field, study sites are subdivided into homogeneous sub-areas characterised by relative uniformity in geomorphology and vegetation. A preliminary assessment can be supported by mobile GIS tools (e.g. QField linked to QGIS), allowing georeferenced data collection and integration into a GIS environment (Fig. 3.4.1 on the left). Within each sub-area, the number of surveys is defined according to its extent and heterogeneity.

Fig. 3.4.1 Preliminary delimitation of dune habitats using GIS tools (left) and field measurements within a standard plot at the Brancaleone site (Calabria) (right).

Surveys are carried out using standard 2 × 2 m plots (Fig. 3.4.1 on the right), where environmental, structural and pressure-related parameters are recorded using a standardised survey sheet (Table 2, Fig. 3.4.2).

Parameter	**Description**	**Values / Method**
Locality	Name of the site	Text
Surveyors	Names of operators	Text
Date	Survey date	Date
Coordinates	Geographic location	GPS
Slope	Inclination of the plot	Measured with level / app
Aspect	Exposure	Compass
Total vegetation cover	% vegetation cover	%
Bare soil	% uncovered surface	%
Shrubs and invasive species	% cover	%
Vegetation height	10 random measurements	cm
Zonation	Habitat zonation presence	Absent / Partial / Complete
Vehicle tracks	Disturbance indicator	0 = absent; 1 = low; 5 = moderate; 10 = abundant
Mechanical cleaning	Disturbance indicator	0 = absent; 1 = low; 5 = moderate; 10 = abundant
Litter	Disturbance indicator	0 = absent; 1 = low; 5 = moderate; 10 = abundant
Banquettes (Posidonia oceanica)	Presence of beach-cast material	0 = absent; 1 = low; 5 = moderate; 10 = abundant
Infrastructure	Human presence	0 = absent; 1 = low; 5 = moderate; 10 = abundant
Trampling	Human pressure	%
Grazing pressure	Herbivory indicator	0 = absent; 1 = low; 5 = moderate; 10 = abundant
Droppings/excrement	Faunal evidence	Quantity + presumed origin
Species inside plot	Floristic list with cover	% cover per species
Species outside plot	Additional species	Presence only

Table 2 : Parameters recorded in the field survey sheet



SURVEY SHEET

Location: ______________________ Date: ______________
Staff: ______________________
ID plot: ______________________
Physiognomy: ______________ Morphology: ______________
Geographic Coordinates: X: ______________ Y: ______________
RS: ______________
Slope (°): ________ Exposure (°): ______________
Vegetation coverage (%): ______ Naked ground (%): ______ Shrubs (%): ______ IAS (%): ______
Vegetation heights (10) (cm): ____ , ____ , ____ , ____ , ____ , ____ , ____ , ____ , ____

INDICATORS

Zonation: ☐ complete ☐ partial ☐ absent
Erosion[1]: ______________
Vehicles tracks[2]: ☐ Yes ☐ No
Mechanical cleaning[3]: ☐ Yes ☐ No
Waste[2]: ☐ Yes ☐ No
Banquette's presence[3]: ☐ Yes ☐ No
Infrastructors[3]: ☐ Yes ☐ No (specify): ______________
Trampling (%): ________
Grazing[1]: ________
Excrement (animal and %): ________
Notes: ______________________

[1] >50 cm

[2] Distance from the ground to an element of the plant

[3] In between 500 m from the plot

[4] 0 (absent), 1 (limited), 5 (medium), 10 (abundant)

ESTIMATION OF PERCENT COVER[4]

SPECIES	COVERAGE (%)	N. PLANTULE
1		
2		
3		
4		
5		
6		
7		
8		

Fig. 3.4.2 Survey sheet

The floristic survey includes the identification of species within the plot with percentage cover estimation, and additional species observed outside the plot without cover quantification. At the end of the field survey, each sub-area is reassessed and assigned to one or more habitat types based on vegetation composition, structure and spatial context, together with the identification of dominant species and overall vegetation cover.

This method provides a standardised and replicable framework for dune habitat recognition and mapping and has already been tested and applied in Mediterranean dune systems, including the coastal dune systems of Calabria.

4. ASSESSMENT OF CONSERVATION STATUS – DUNE HABITATS

4.1 Structural indicators

Structural indicators describe the physical and vegetation organization of dune habitats and represent the first level in the assessment of conservation status. They allow verification of whether the habitat structure is consistent with its evolutionary stage and whether the system maintains a configuration compatible with proper ecological functioning.

To be effective within the LIFE terrAmare project, these indicators must not only be scientifically robust, but also easily observable and applicable in the field, including by non-specialist operators and, in simplified form, by volunteers involved in citizen science activities.

Typical vegetation cover

The cover of psammophilous vegetation represents one of the most immediate indicators of habitat structure. It reflects the system's capacity to stabilize sediment and to support plant communities consistent with dune zonation.

Under natural conditions, vegetation cover increases progressively from the shoreline inland:

- very low in embryonic dunes
- intermediate in mobile dunes
- high in fixed dunes

How to assess it

It can be estimated visually or by using sampling quadrats along transects. Even a qualitative estimate (low, medium, high cover) is sufficient for an initial assessment.

How to interpret it

- cover consistent with the evolutionary stage → favorable condition
- reduced or discontinuous cover → possible erosion or disturbance
- absence of vegetation → degraded condition

Citizen Science

Volunteers can visually estimate vegetation presence and report areas with bare sand or very sparse vegetation.

Fig. 4.1.3 Comparison between a well-vegetated dune (top) and a dune with sparse or absent vegetation (bottom) (both pictures from the Brancaleone site, Calabria).

Presence and abundance of diagnostic species

Diagnostic species represent a key element for habitat identification and for assessing its structural quality. The presence and vitality of species such as *Ammophila arenaria* or Juniperus spp. indicate conditions of stability and ecological continuity.

How to assess it

Through simple floristic lists or observations along transects. A complete survey is not required: it is sufficient to verify the presence of key species.

How to interpret it

- species present and vital → coherent structure
- rare or declining species → possible degradation
- absence of key species → loss of habitat identity

Citizen science

Volunteers can recognize some easily identifiable species (e.g., Ammophila) using simplified guides or apps.

Fig. 4.1.2 Examples of diagnostic species

Continuity of dune zonation

The continuity of the beach–dune sequence represents a synthetic indicator of system structure. The presence of the different zones in succession indicates an intact and functioning system.

How to assess it

Observation along a transect perpendicular to the coastline, verifying the presence of the different units (embryonic, mobile, fixed).

How to interpret it

- complete sequence → favorable condition
- partial sequence → intermediate condition
- absent sequence → degraded condition

In the project contexts, particularly along the Ionian coast of Calabria, zonation is often incomplete or strongly simplified.

Citizen science

Volunteers can document the presence or absence of the different zones through photographs.

Geomorphological integrity of the system

The integrity of the dune system depends on the continuity of the dune ridge and the absence of artificial interruptions. Gaps, tracks, leveling, and infrastructure represent elements of structural alteration.

How to assess it

Direct observation and mapping of interruptions along the dune system.

How to interpret it

- continuous system → good condition
- presence of gaps → intermediate condition
- fragmented system → degraded condition

Citizen science

Volunteers can report:

- paths
- beach access points
- disturbed areas.

Fig. 4.1.3 Examples of degraded and fragmented dunes: on the left, a dune at the Brancaleone site affected by a coastal wall built for the railway; on the right, a dune at the Circeo site showing erosion and fragmentation.

Presence of invasive alien species (IAS)

Invasive alien species directly affect habitat structure by altering the composition and distribution of vegetation.

How to assess it

Visual observation and georeferenced reporting.

How to interpret it

absence or limited presence → preserved structure

widespread presence → significant alteration

Citizen science

This is one of the most suitable indicators for public participation:

- reporting via apps
- georeferenced photos.

Fig. 4.1.4 Invasive species observed at the Calabria site: *Carpobrotus acinaciformis* (left), *Carpobrotus edulis* (centre), and *Agave americana* (right).

4.2 Functional indicators

Functional indicators describe the ecological and dynamic processes that allow dune habitats to maintain their structure and adaptive capacity over time. Unlike structural indicators, which describe “what the habitat looks like”, functional indicators help to understand “how the system works” and whether it is capable of regenerating and responding to pressures. In beach–dune systems, functionality is closely linked to sediment dynamics, vegetation renewal capacity, and the connection between marine and terrestrial environments. A system may appear structurally present but be functionally compromised.

Sediment accumulation dynamics

Sediment dynamics represent the key process for dune formation and maintenance. The presence of sand accumulation and new embryonic dunes indicates an active system, where aeolian transport and sediment deposition are still functioning.

How to assess it

- observation of sand accumulation at the base of vegetation
- presence of embryonic dunes or small sandy ridges
- photographic comparison over time (seasonal)

How to interpret it

- active accumulation → functioning system
- absence of accumulation → possible disruption of processes
- evidence of sediment loss → system under erosion

Citizen science

Volunteers can:

- take repeated photographs of the same areas over time
- report the presence/absence of sand accumulation.

Fig. 4.2.1 Active sand accumulation (embryonic dunes), absence of sand accumulation / eroded surface.

Vegetation renewal capacity

Natural regeneration capacity represents a key indicator of system resilience. The presence of seedlings and young individuals of typical species indicates that the habitat is able to regenerate spontaneously.

How to assess it

- observation of young plants
- presence of new individuals of diagnostic species
- distribution of seedlings along the dune gradient

How to interpret it

- widespread presence of seedlings → good resilience

- sporadic presence → reduced resilience
- absence → system under stress

Citizen science

Volunteers can:

- report the presence of new seedlings
- document areas lacking regeneration.

Fig. 4.2.2 Photo of psammophilous plant seedlings (*Pancratium maritimum*) in Brancaleone's site.

Dune system stability (absence of active erosion)

The functional stability of the system is expressed in the ability of the dune to maintain its profile without being subject to active erosion.

How to assess it

- presence of dune scarps
- exposed roots
- retreat of the dune toe

How to interpret it

- absence of erosive signs → stable condition

- localized erosion → intermediate condition
- widespread erosion → compromised system

Citizen science

Volunteers can:

- photograph scarps and exposed roots
- report changes in dune profiles over time.

Fig. 4.2.3 Examples of erosive slopes: Circeo dune (left) and Brancaleone dune (right).

Sea–dune connectivity

The connection between the marine environment and the dune system is a key element for overall functioning. The presence of Posidonia oceanica banquettes and their preservation promote sediment retention and the formation of embryonic dunes.

How to assess it

- presence of Posidonia deposits

- continuity between the beach and the dune system

- absence of mechanical removal

How to interpret it

- presence of banquettes → functioning system

- systematic removal → disruption of processes

- absence of connection → altered system

The removal of banquettes, still widespread in many tourist contexts, compromises sediment dynamics and system functionality.

Citizen science

Volunteers can:

- report the presence/absence of banquettes

- document mechanical beach cleaning activities.

Fig. 4.2.4 Posidonia's banquette and beach cleaned artificially.

4.3 Pressure indicators

Pressure indicators describe external factors, both natural and especially anthropogenic, that cause the degradation of dune habitats and compromise their structure and functionality. Unlike structural and functional indicators, which assess the condition of the habitat, pressure indicators help identify the causes of degradation and therefore represent an essential tool for guiding management actions. In the Mediterranean context, and particularly in the LIFE terrAmare project sites, pressures are mainly linked to tourism activities and beach management practices that are often not consistent with natural processes.

Trampling and human disturbance

Trampling is one of the most widespread pressures in dune environments, especially in areas with high tourist use. It leads to direct destruction of vegetation, soil compaction, and disruption of regeneration processes.

How to assess it

- presence of informal paths (multiple tracks)
- areas of bare sand
- damaged or absent vegetation along pathways

How to interpret it

- limited presence of tracks → low pressure
- evident but localized paths → moderate pressure
- widespread network of paths and bare sand → high pressure

Citizen science

Volunteers can:

- map pathways
- photograph trampled areas
- report zones with vegetation loss.

Fig. 4.3.1 informal paths, area with bare sand for trampling

Mechanical beach cleaning

Mechanical beach cleaning represents one of the main causes of alteration in beach–dune systems. It involves the removal of organic material (banquettes) and the destruction of early stages of vegetation colonization.

How to assess it

- leveled and uniform sandy surface
- absence of organic material
- tracks of mechanical vehicles

How to interpret it

- absence of interventions → favorable condition
- occasional interventions → moderate pressure
- systematic cleaning → high pressure

This practice is particularly impactful as it disrupts sediment dynamics and sea–dune connectivity.

Citizen science

Volunteers can:

- document vehicle tracks
- report “artificially cleaned” beaches.

Fig. 4.3.2 mechanically graded beach.

Coastal urbanization and infrastructure

The presence of tourist infrastructure and unregulated access points leads to fragmentation of the dune system, disruption of sediment flows, and habitat loss.

How to assess it

- distance and density of structures (beach facilities, roads)
- presence of direct access points to the beach
- rigid structures (walls, barriers)

How to interpret it

- absence or large distance → low pressure
- limited presence → moderate pressure
- high level of infrastructure → high pressure

Citizen science

Volunteers can:

- report infrastructure
- document access points and system interruptions.

Fig. 4.3.3 infrastructure and coastal human development.

Grazing and biological disturbance

Grazing and other forms of biological disturbance can alter the composition and structure of dune vegetation, especially in less urbanized areas.

How to assess it

- presence of animal tracks

- droppings

- damage to vegetation

How to interpret it

- absence → no pressure

- limited presence → moderate pressure

- widespread disturbance → significant pressure

Citizen science

Volunteers can:

- report tracks and signs of grazing

- document damaged areas.

Fig. 4.3.4 Signs of grazing on *Ephedra distachya:* the brown and yellow parts are visibly eaten and are the old ones, the green ones are new and still not eaten.

4.4 Indicators related to invasive alien species (IAS)

WP4 of LIFE terrAmare includes an Early Warning and Rapid Response System integrated with Automatic Risk Assessment (ARA) tools and participatory mapping, in line with LIFE medCLIFFS methodologies.

Proposed indicators

1. Presence and distribution

   Number of georeferenced records (e.g., iNaturalist)

   Extent of colonized area (ha or % of habitat surface)

   Assessment: volunteer reporting + WP4 technical validation

2. Abundance and ecological impact

   IAS percentage cover (%)

   Evidence of replacement of typical species (e.g., Ammophila, Juniperus)

   Scale: <10% (low), 10–30% (moderate), >30% (high)

3. Dynamics and expansion risk

   Annual trend (expansion/stability/regression)

   Proximity to dispersal corridors (paths, gardens, nurseries)

   Supported by ARA tools and risk maps

Control/eradication actions follow LIFE medCLIFFS best practices (e.g., Carpobrotus, Acacia, Ailanthus). The integration of participatory monitoring and technical validation enables early warning, prioritization of interventions, and adaptive management at the Mediterranean scale.

4.5 Alignment with Article 17 reporting

The proposed indicators are organized according to the four parameters of the Habitats Directive:

- Range

Assessment of habitat contraction or fragmentation.

- Area occupied

Surface estimated through mapping and GPS surveys.

- Structure and functions

Based on structural and functional indicators (vegetation cover, typical species, sediment dynamics).

- Future prospects

Combined assessment of pressures (4.3) and presence of IAS (4.4).

The final classification may follow the scheme:

FAVOURABLE (FV) – INADEQUATE (U1) – BAD (U2)

The system is compatible with national reporting and can be integrated into LIFE terrAmare monitoring cycles, including validated citizen science contributions.

PART II – RECOGNITION AND CLASSIFICATION OF *POSIDONIA OCEANICA* (H1120*)

5. ECOLOGICAL FRAMEWORK OF *POSIDONIA OCEANICA* MEADOWS

Posidonia oceanica (L.) Delile is a marine seagrass endemic to the Mediterranean Sea, belonging to the family Posidoniaceae (order Alismatales). Unlike macroalgae, it is a higher plant with true vascular tissues, roots, rhizomes, leaves, flowers, and fruits (Fig. 5.1.1). From a habitat classification perspective, *P. oceanica* meadows correspond to habitat 1120* "Posidonia beds (Posidonion oceanicae)" under Directive 92/43/EEC and are considered a priority habitat. In the EUNIS classification, they correspond to unit A5.535 (European Environment Agency, 2019).

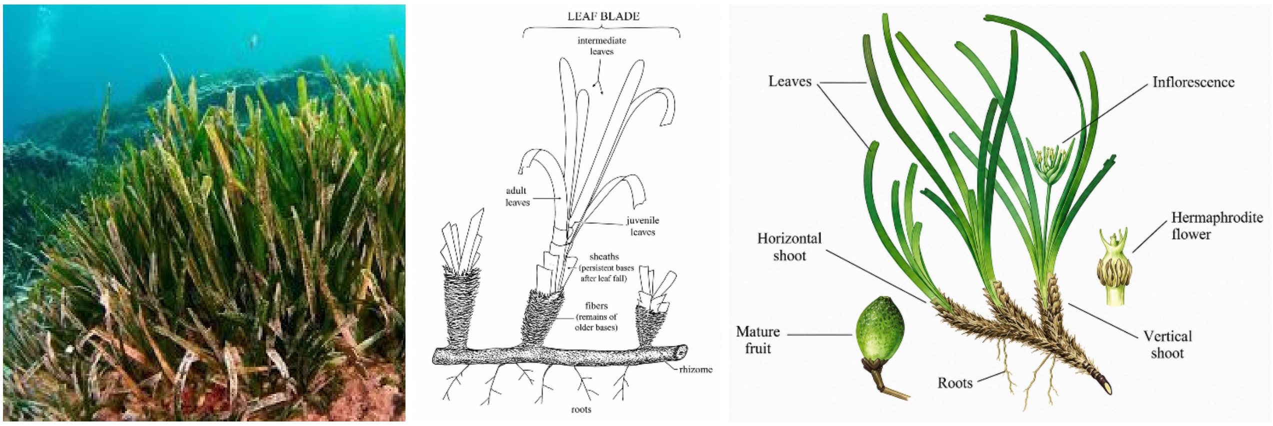


Fig. 5.1.1 *Posidonia oceanica* and the main structural components of the plant.

Field identification is based on distinctive morphological characteristics. The plant is organized into leaf bundles (shoots) inserted on plagiotropic and orthotropic rhizomes. Each shoot generally bears 4–8 ribbon-like leaves, up to 1 m long and about 1 cm wide, with a rounded or truncated apex and clearly visible parallel veins. The leaves have a persistent basal sheath which, together with lignified leaf remains, contributes to the formation of the "matte", a compact structure of rhizomes and sediment that can reach several meters in thickness (Boudouresque et al., 2012). The presence of the matte is a key diagnostic feature distinguishing *P. oceanica* meadow from those of other seagrasses.

Compared to species such as *Cymodocea nodosa* or *Zostera marina*, *P. oceanica* is distinguished by the greater robustness of its shoots, wider leaves, the formation of the matte, and its distribution mainly on well-lit sandy or detrital substrates, generally from a few meters down to over 30–40 m depth, depending on water transparency (Pergent et al., 2014).

Recognition can also be based on stranded deposits (banquettes), mainly composed of dead leaves, fibers, and rhizome fragments accumulated along the shoreline. These organic accumulations represent a functional component of the coastal ecosystem and can contribute to the characterization of habitat 1210 – Annual vegetation of drift lines, by facilitating the establishment of psammophilous species and playing a significant role in sediment dynamics and erosion protection. The stranded leaves are fibrous, brown-green in color, with clearly visible parallel veins; egagropili (sea balls), spherical structures formed by interwoven fibers, are often present (Fig. 5.1.2). Banquettes play an important ecological role in erosion protection and coastal sediment balance, and their correct identification is essential for management consistent with conservation objectives (Boudouresque et al., 2016).

Fig. 5.1.2 Posidonia oceanica banquette (left) and aegagropiles (right).

For ecological classification and conservation status assessment, standardized structural and functional indicators are used. Key parameters include shoot density (expressed as shoots/m²), percentage cover, thickness and continuity of the matte, depth of the lower limit of the meadow, and phenological characteristics (Pergent-Martini et al., 2005). Variation in the lower bathymetric limit is considered a sensitive indicator of environmental conditions and water quality. National and international protocols provide harmonized methodologies for monitoring, ensuring spatial and temporal comparability of data, including the Marine Strategy Framework Directive guidelines (2008/56/EC), and UNEP/MAP–MEDPOL protocols for the Mediterranean.

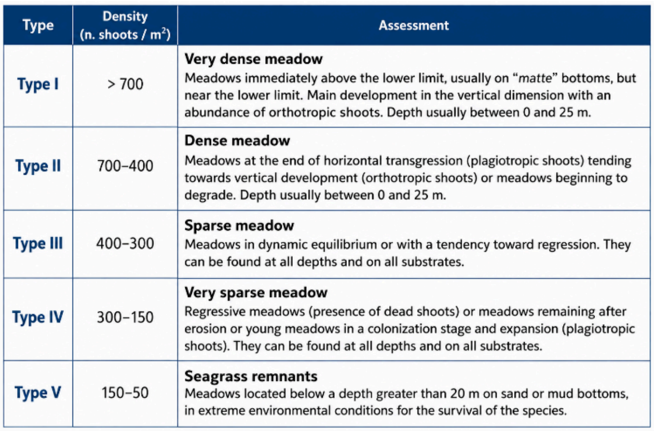
6. CRITERIA FOR THE RECOGNITION OF HABITAT H1120*

6.1 Meadow typology and structure

Posidonia oceanica meadows exhibit a complex three-dimensional structure, determined by the organization of rhizomes, the density of leaf shoots, and the formation of the matte. Meadow typology varies depending on environmental conditions (depth, hydrodynamics, substrate type, water transparency) and conservation status (Pergent et al., 1995; Pergent-Martini et al., 2005).

From a structural perspective, the meadow consists of plagiotropic rhizomes (horizontal growth), responsible for lateral expansion, and orthotropic rhizomes (vertical growth), which compensate for sedimentation processes and contribute to matte formation. The matte is a permanent biogenic structure composed of intertwined living and dead rhizomes, roots, and trapped sediment, which can reach several meters in thickness and represents a key element for seabed stability and carbon accumulation processes (Boudouresque et al., 2012).

Based on coverage continuity, meadows can be classified as continuous meadows, characterized by high cover and homogeneous shoot density, and discontinuous or patchy meadows, where vegetation is fragmented and alternates with bare substrate. The spatial configuration includes an upper limit and a lower limit, the latter being particularly sensitive to variations in water quality and light availability, thus representing an effective indicator of ecological status (Pergent-Martini et al., 2005; UNEP/MAP, 2014).The main structural descriptors used to characterize meadow typology include: shoot density (shoots/m^2), percentage cover, leaf biomass, matte thickness and compactness, as well as the depth and morphology of the lower limit (progressive, sharp, regressive or erosive) (Fig. 5.1.3). Shoot density naturally varies along the bathymetric gradient, but abnormal reductions may be associated with anthropogenic pressures or environmental alterations (Pergent et al., 1995; Pergent-Martini et al., 2005).



Type	Density (n. shoots / m^2)	Assessment
Type I	> 700	**Very dense meadow** Meadows immediately above the lower limit, usually on "*matte*" bottoms, but near the lower limit. Main development in the vertical dimension with an abundance of orthotropic shoots. Depth usually between 0 and 25 m.
Type II	700–400	**Dense meadow** Meadows at the end of horizontal transgression (plagiotropic shoots) tending towards vertical development (orthotropic shoots) or meadows beginning to degrade. Depth usually between 0 and 25 m.
Type III	400–300	**Sparse meadow** Meadows in dynamic equilibrium or with a tendency toward regression. They can be found at all depths and on all substrates.
Type IV	300–150	**Very sparse meadow** Regressive meadows (presence of dead shoots) or meadows remaining after erosion or young meadows in a colonization stage and expansion (plagiotropic shoots). They can be found at all depths and on all substrates.
Type V	150–50	**Seagrass remnants** Meadows located below a depth greater than 20 m on sand or mud bottoms, in extreme environmental conditions for the survival of the species.

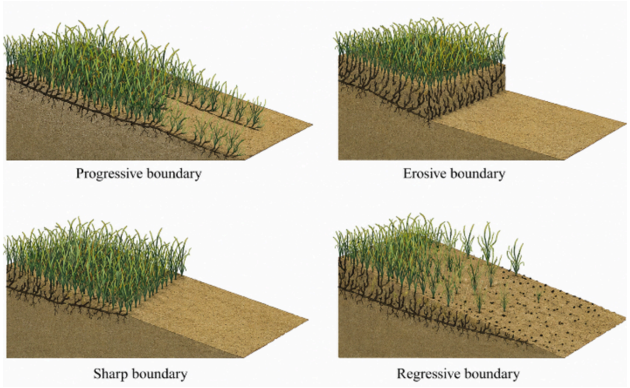


Fig. 5.1.3 Classification of *Posidonia oceanica* meadows according to Giraud (1977) (left) and main types of lower limit (progressive, sharp, erosive and regressive; after Pergent et al., 1995) (right).

The description of meadow typology and structure is therefore a fundamental step for the classification of habitat 1120* and for the assessment of conservation status according to monitoring protocols shared at national and Mediterranean levels (Pergent-Martini et al., 2005; UNEP/MAP, 2014).

6.2 Morphological and bathymetric characteristics

The analysis of morphological characteristics along the bathymetric gradient is a fundamental tool for interpreting the ecological functionality of *Posidonia oceanica* meadows and their conservation status. Morphometric variations observed with increasing depth mainly reflect light availability and hydrodynamic conditions, representing key parameters in monitoring protocols (Short & Duarte, 2001; Gobert et al., 2009).

Along the depth gradient, a general decrease in shoot density and percentage cover is observed, accompanied by a reduction in leaf biomass and average leaf length in deeper sectors, where light intensity approaches the minimum threshold for photosynthetic compensation. These patterns fall within the natural variability of the species; however, significant deviations from local reference values may indicate environmental stress conditions, such as increased turbidity, eutrophication, or mechanical disturbance (Gobert et al., 2009).

The upper limit of the meadow is generally influenced by physical factors such as wave action, currents, and coastal sediment dynamics. In highly dynamic environments, it may appear fragmented or retreating, while under more stable conditions it can be continuous and well-structured. Its position provides insights into interactions between the meadow and coastal processes.

Importance is given to the lower limit, which is strictly controlled by light penetration in the water column. The maximum depth of distribution is a sensitive indicator of environmental conditions and is frequently used as a descriptor in ecological monitoring programs (Gobert et al., 2009; Ruiz et al., 2009). The morphology of the lower limit can be classified as:

- progressive, when shoot density gradually decreases downward;
- sharp, when coverage abruptly ends;
- erosive or regressive, when exposed matte scarps or clear signs of retreat are observed.

The documentation of lower limit typology, together with depth measurements obtained through standardized techniques (underwater surveys, georeferencing, bathymetric profiles), allows the evaluation of meadow evolution over time. In monitoring contexts, accurate recording of depth, cover, and margin continuity is essential to ensure temporal comparability of data and consistency with internationally shared methodological standards (Short & Duarte, 2001; Ruiz et al., 2009).

6.3 Delimitation and mapping methodologies

The cartographic delimitation of *Posidonia oceanica* meadows is based on an integrated approach that considers not only vegetation cover (canopy continuity), but also the type of substrate on which the meadow develops and its conservation status. The meadow boundary is therefore defined through the identification of coverage (continuous or discontinuous) associated with different colonized substrates (sand, matte, and rock), as well as the distinction between intact meadow, degraded meadow, and areas of dead matte, which represent conditions of regression or structural alteration (Pergent-Martini et al., 2005; Montefalcone et al., 2010). The correct classification of these units is essential for interpreting meadow dynamics and ensuring temporal comparability of data.

Remote sensing techniques (high-resolution satellite imagery, orthophotos, and drone surveys) enable mapping of meadows in shallow and clear waters, allowing a synoptic analysis of canopy distribution (Fig. 6.1.1).

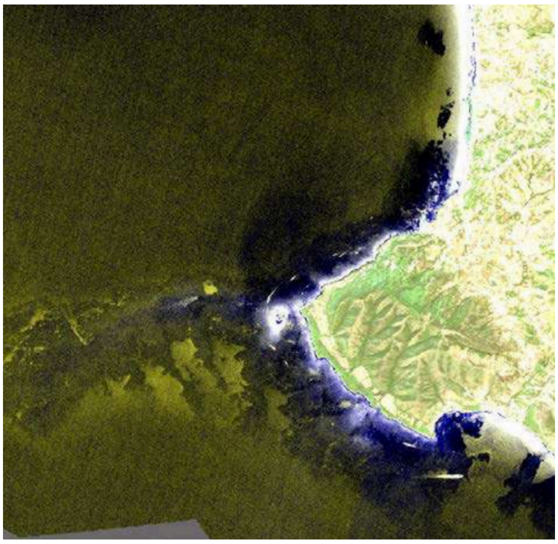


Fig. 6.1.1 High-resolution Sentinel-2 satellite image showing the upper limit of a *Posidonia oceanica* meadow in the Castellabate coastal area (source: LIFE SeaForest, Action A1.1 deliverable).

However, distinguishing between substrates and conservation states requires integration with acoustic tools. Side-scan sonar (Fig. 6.1.2) and multibeam systems allow seabed morphology to be characterized and enable differentiation between meadow, exposed matte, and bare substrate based on distinct acoustic signatures (Montefalcone et al., 2010).

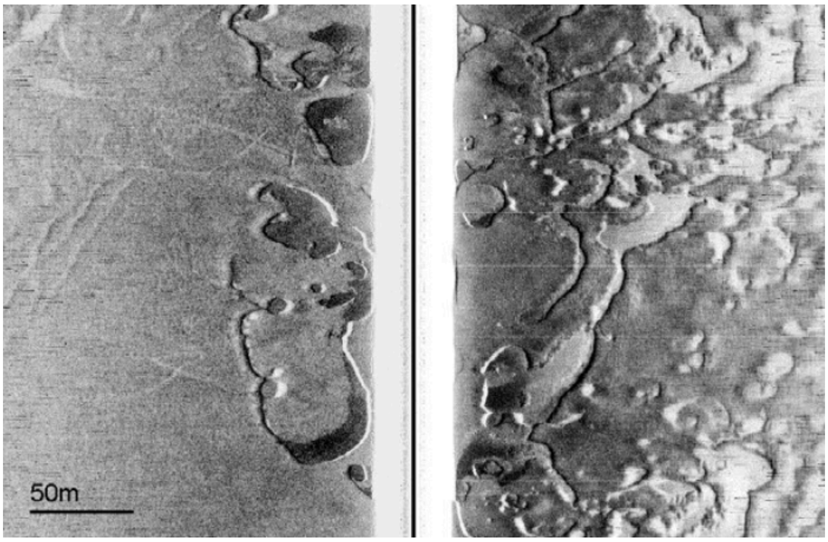


Fig. 6.1.2 Dead and degraded *Posidonia oceanica* matte, detected using side-scan sonar (SSS): relatively compact in the left panel and highly affected by erosion in the right panel (Savini, 2011).

In recent years, the use of autonomous vehicles (AUV – Autonomous Underwater Vehicles; USV – Unmanned Surface Vehicles) equipped with acoustic and optical sensors has improved the efficiency and resolution of benthic mapping (Fig. 6.1.3). These platforms enable high-precision surveys, reducing operational time and increasing spatial coverage, with particularly effective results in the fine-scale delimitation of meadow boundaries and the identification of degraded areas (Piazzolla et al., 2024).

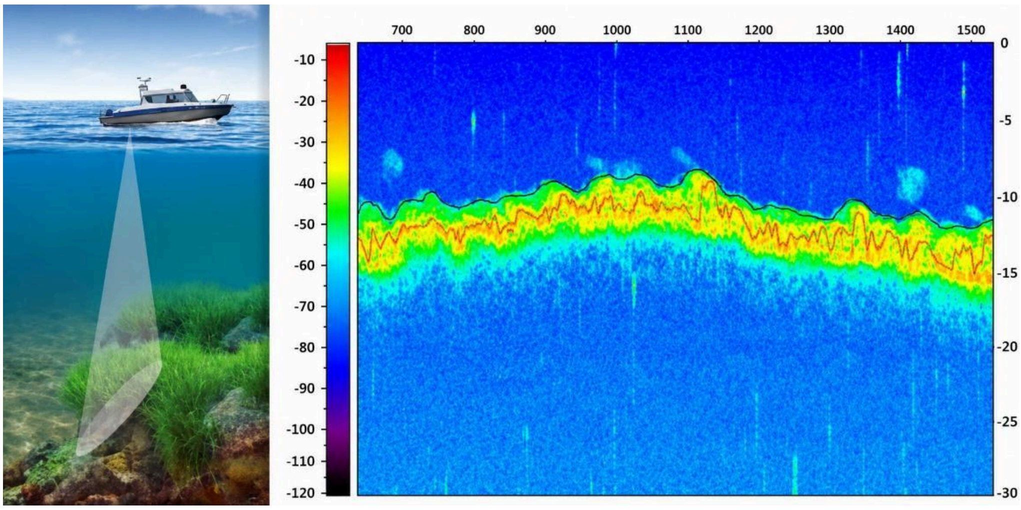


Fig. 6.1.3 Above-ground biomass estimation using a Biosonics acoustic sensor deployed on an autonomous underwater vehicle (AUV).

The validation phase (ground-truthing) is essential to correctly link remote data to actual seabed conditions. It is carried out through surveys conducted by trained divers or by using ROVs (Remotely Operated Vehicles) (Fig. 6.1.4), which allow precise verification of upper and lower limits, confirmation of substrate type, and classification of meadow condition. Georeferenced surveys and control points are fundamental elements for data integration within a GIS environment.

Fig. 6.1.4 Monitoring of the upper and lower limits of *Posidonia oceanica* meadows using a remotely operated vehicle (ROV).

The final cartographic output must include standardized thematic classes (e.g., meadow on matte and sand, meadow on rock, dead matte, bare substrate) and incorporate metadata regarding scale, spatial resolution, positional accuracy, and methodology used. Consistency in classification thresholds and interpretative criteria is necessary to ensure comparability between successive surveys and to support medium- and long-term evolutionary analyses.

7. ASSESSMENT OF CONSERVATION STATUS – H1120*

7.1 Structural and physiographic indicators

The assessment of the conservation status of the priority habitat H1120* is based on structural indicators capable of describing the integrity, extent, and spatial organization of the meadow, in accordance with Directive 92/43/EEC. Structural indicators represent the primary component for defining a favourable conservation status, as they reflect the long-term stability of the habitat and its ability to maintain ecological structure and functions (Boudouresque et al., 2012).

Among the primary structural indicators, shoot density is the most widely used and standardized parameter. It is measured using sampling quadrats along georeferenced transects, following established protocols (e.g., counting shoots per unit area), allowing comparison with bathymetric reference classes (Pergent et al., 1995) (Fig. 7.1.1). Percentage cover and meadow continuity (continuous, mosaic, fragmented) represent additional key descriptors, detectable through underwater surveys, photo-interpretation, or digital photogrammetry techniques.

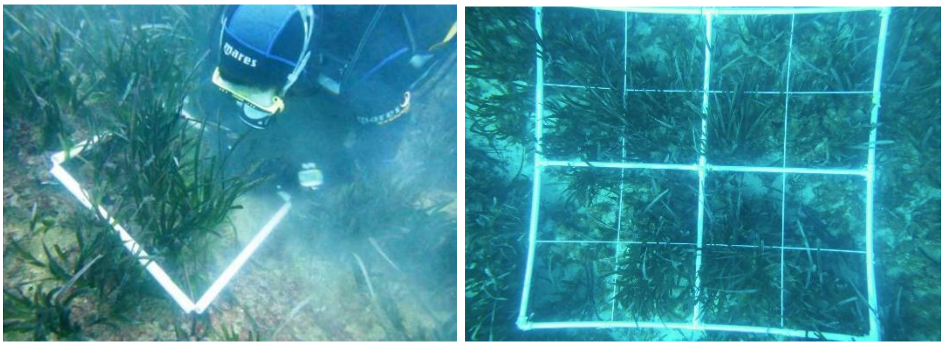


Fig. 7.1.1 On the left, a quadrat for estimating shoot density in *Posidonia oceanica* meadows; on the right, a quadrat for assessing percentage cover of the meadow on the substrate.

Another fundamental structural indicator is the depth of the lower limit of the meadow, considered a proxy for the balance between growth and regression and sensitive to changes in water transparency (Boudouresque et al., 2012). The structure of the matte (thickness, compactness, exposure) also provides information on sediment stability and habitat resilience.

Among indicators of physical integrity, particular relevance is given to the presence of matte erosion, spatial fragmentation, margin regression, and the occurrence of mechanical pressures (anchoring, fishing marks, coastal structures). Thematic mapping and comparison of time series are essential tools for documenting evolutionary dynamics and regressive trends (Montefalcone et al., 2007). These indicators can be integrated with citizen science approaches, maintaining a distinction between highly specialized measurements and simplified observations. Participatory activities may include: georeferenced photographic documentation of meadow boundaries; reporting of fragmented patches or regression areas; standardized surveys of surface cover in shallow waters using visual grids; monitoring of stranded shoots (indicative of mechanical detachment). Digital tools (reporting apps, shared protocols, simplified sheets validated by experts) enable the integration of data collected by volunteers with official monitoring networks, improving spatial coverage without compromising scientific quality (Thiel et al., 2014).

7.2 Functional indicators

For the purposes of the Habitats Directive, a favourable conservation status depends not only on the extent and density of the meadow, but on the maintenance of its specific structures and ecological functions, ensuring long-term persistence and resilience. Functional indicators are therefore essential to assess habitat integrity in accordance with the Article 17 framework (structure and functions, future prospects).

A primary indicator is the stability of the lower bathymetric limit, which reflects the balance between light availability, water transparency, and anthropogenic pressures. Its regression is widely recognised as an early signal of functional degradation. A second key aspect concerns the balance between production and loss processes. Meadows in favourable condition exhibit stable or expanding margins, whereas fragmentation and regression indicate alterations in recruitment and rhizome growth dynamics, with implications for resilience and recovery capacity.

Functional assessment is further strengthened by plant-based indicators. Phenological parameters (e.g. leaf production, elongation and senescence) describe seasonal dynamics and provide information on the physiological status of the meadow in response to environmental variability. Lepidochronological parameters, derived from rhizome scale analysis, allow the reconstruction of long-term growth trends (e.g. annual production, rhizome elongation, age structure), integrating environmental conditions over time and supporting the detection of cumulative impacts (Fig. 7.2.2).

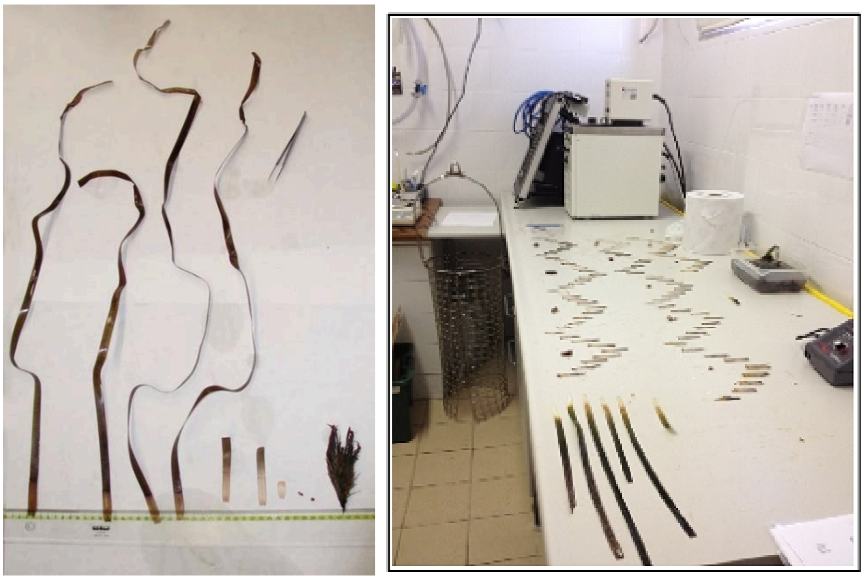


Fig. 7.2.2 phenological (left) and lepidochronological (right) analyses used to assess above-ground and below-ground growth dynamics of *Posidonia oceanica*.

The role of the meadow in coastal regulation is also relevant, through wave attenuation and sediment stabilisation. The continuity between the submerged meadow and Posidonia banquettes represents an indicator of sea–dune system connectivity; their removal disrupts sediment and organic matter fluxes.

Additional functional indicators include the capacity to sustain complex trophic networks (habitat and nursery function) and the role in carbon sequestration (blue carbon), where the conservation of an intact matte reflects long-term biogeochemical stability.

From an operational perspective, functional indicators are grouped as follows:

Expert-based indicators:

- Lower limit stability;
- Margin dynamics (expansion/regression);
- Phenological parameters;
- Lepidochronological parameters;
- Matte integrity and continuity;
- Water and sediment quality.

Citizen science indicators:

- Presence and continuity of banquettes;
- Visual evidence of fragmentation or damage;
- Occurrence of pressures (anchoring, turbidity, litter);
- Qualitative observations of associated fauna.

7.3 Calculation of the PREI index

The PREI (Posidonia oceanica Rapid Easy Index) is a tool developed to assess the ecological status of Mediterranean coastal waters through the analysis of *Posidonia oceanica* meadows, in accordance with the Water Framework Directive 2000/60/EC. The method is based on the assumption that the structure and vitality of the meadow reflect, in an integrated way, environmental conditions and anthropogenic pressures, making this seagrass an effective bioindicator (Gobert et al., 2009).

The PREI is constructed from a set of descriptive parameters measured in the field along a bathymetric gradient, generally at the lower limit of the meadow, an area particularly sensitive to changes in water quality. The main parameters considered include shoot density, depth of the lower limit, meadow cover, and matte condition. These variables are compared with site-specific reference conditions in order to calculate the deviation from a "high" ecological status.

The index is calculated by standardizing individual parameters and integrating them into a synthetic value expressed as an Ecological Quality Ratio (EQR), ranging from 0 to 1. Values close to 1 indicate conditions similar to the reference, corresponding to high or good ecological status, whereas lower values indicate moderate, poor, or bad status, according to classes defined at the regulatory level. This integrated approach reduces variability associated with individual indicators and provides a robust and comparable overall assessment across different areas.

From a methodological perspective, the PREI requires standardized underwater surveys, the use of sampling techniques along permanent transects, and the collection of quantitative data according to shared protocols. The correct application of the index requires specialized expertise, particularly for determining the lower limit and analyzing shoot density, which must be carried out by trained operators.

However, some complementary activities can be integrated into participatory monitoring schemes. Citizen science initiatives can contribute by reporting evidence of regression, fragmentation, or local impacts (anchoring, turbidity, litter), providing useful information to guide expert surveys and promptly identify potential deterioration. In this way, although not directly involved in the calculation of the index, public participation strengthens the environmental monitoring system.

7.4 Assessment of impacts from anchoring and small-scale fishing

Anchoring and small-scale fishing activities represent some of the main local pressures on *Posidonia oceanica* meadows, affecting both the physical structure and ecological functioning of habitat H1120*. The assessment of these impacts is relevant for determining conservation status under the Habitats Directive and ecological status under the Water Framework Directive, as it contributes to the interpretation of regression or fragmentation processes.

Anchoring with traditional systems (anchors and chains) can cause direct impacts, such as uprooting of leaf shoots, breakage of rhizomes, and fragmentation of the matte, leading to the formation of furrows or vegetation-free “gaps” (Fig. 7.3.1) The movement of the chain on the seabed, especially in the presence of currents or wave action, amplifies the damage through circular abrasion, hindering natural recolonization processes (Boudouresque et al., 2012). Over time, the repetition of such disturbances can reduce meadow continuity and compromise sediment stability.

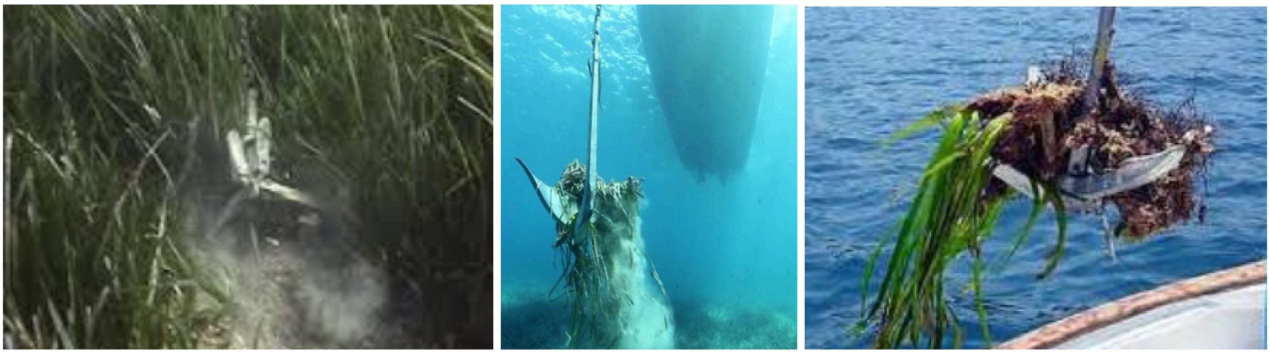


Fig. 7.3.1 From left to right, different phases of anchoring on a *Posidonia oceanica* meadow.

Small-scale artisanal fishing can also generate significant pressures, particularly through the use of set nets, longlines, and other gear that, when deployed or retrieved directly over the meadow, may cause mechanical damage, rhizome tearing, and biomass entanglement. In some cases, accidental gear loss (“ghost fishing”) leads to long-lasting impacts, altering the associated biological community (Fig. 7.3.2). Although these activities generally have a lower impact than more intensive fishing practices, their cumulative intensity in confined coastal areas can contribute to functional degradation of the habitat.

Fig. 7.3.2 Impact of small-scale fishing activities.

From an assessment perspective, the presence of linear scars, vegetation-free patches, margin fragmentation, and abnormal sediment accumulation represent observable indicators of pressure from anchoring or fishing. Quantification of damage requires specialized underwater surveys and comparison with reference conditions, but preliminary identification of critical areas can be supported by citizen science activities.

Volunteers from the Ecological Beach Communities, together with recreational boaters and local fishers, can actively contribute to pressure detection by reporting anchoring on seagrass, the presence of non-ecological mooring systems, abandoned fishing gear, or visual evidence of damage. For this purpose, the Blue Discovery App, developed within the LIFE SeaForest project (LIFE19 NAT/IT/000816; see SeaForest Manual), can be used. It allows the georeferenced collection of observations, photographs, and reports directly in the field. The use of the App ensures a minimum level of standardization of collected information (location, type of impact, photographic evidence), improving its usability for technical and scientific purposes.

Once validated by expert operators, these reports can contribute to identifying areas subject to higher pressure, supporting prevention measures, anchoring regulation, and adaptive management. In this way, active citizen participation does not replace specialist monitoring but complements it, strengthening the environmental surveillance system and promoting greater awareness of the importance of conserving *Posidonia oceanica* meadows.

7.5 Consistency with Article 17 reporting

Reporting under Article 17 of Directive 92/43/EEC requires a periodic and harmonized assessment of the conservation status of habitats, based on four parameters: Range, Area, Structure and Functions, and Future prospects. The Terramare Guidelines, through the methodological framework described in the previous chapters, ensure that data collected at the local scale are consistent with and traceable to these parameters, thus supporting alignment with the national reporting systems.

Regarding Range, the project contributes by collecting updated and georeferenced evidence on the distribution of habitat H1120*, helping to confirm the persistence of the meadow in monitored sites and to identify potential local contractions. While not replacing assessments at the biogeographical scale, standardized observations improve the quality of spatial information and its comparability over time.

In relation to Area, the delimitation and cartographic updating activities described in this deliverable allow verification of the stability or variation in the extent of the meadow within intervention sites. These data, integrated with institutional datasets, contribute to defining the “habitat area” parameter required by Article 17 reporting.

The Structure and Functions parameter, which is central to conservation status assessment, directly corresponds to the structural and functional indicators defined above and, where applicable, to metrics recognized at national and European levels, such as the PREI index for ecological status classification (Gobert et al., 2009). The systematic collection of data on meadow continuity, margin stability, presence of local pressures, and functional integrity allows objective documentation of the maintenance—or deterioration—of the ecological conditions required for a favourable status.

Finally, the Future prospects parameter is based on the analysis of ongoing pressures and threats, as well as on the evaluation of the effectiveness of management measures. In this context, monitoring the impacts of anchoring, small-scale fishing, and other coastal pressures represents a key element for estimating the risk of habitat regression in the medium term and for guiding adaptive management actions.

Data and information useful for Article 17 reporting can also be collected by volunteers, recreational boaters, and local fishers through already developed apps that are simple and accessible to non-experts, allowing georeferenced observations and photographic documentation. These may include reports of anchoring on seagrass, the presence of scars or “gaps”, margin fragmentation, localized regression, abandoned fishing gear, litter, or episodes of abnormal turbidity, as well as information on the presence and continuity of banquettes as indicators of sea–coast functional connectivity.

Once validated by expert operators, these observations provide operational support, particularly for the Structure and Functions and Future prospects parameters of Article 17 reporting, contributing to the documentation of ongoing pressures, local trends, and potential risks of deterioration. While not replacing the specialist surveys required for official assessments, such data serve as an “early warning” tool, guiding targeted monitoring campaigns and facilitating the timely identification of areas requiring further technical investigation or management measures.

8. HARMONIZED MEDITERRANEAN FRAMEWORK FOR MONITORING AND CLASSIFICATION

The harmonized Mediterranean framework for monitoring and classification developed within the LIFE terrAmare project stems from the need to ensure comparability, methodological consistency, and integration into future reporting cycles under Article 17 of the Habitats Directive (92/43/EEC), while respecting the national specificities of Mediterranean coastal contexts.

The methodologies used to assess conservation status across different Mediterranean countries may differ in terms of indicators applied, threshold values, monitoring frequency, and the level of detail of structural and functional parameters. These differences represent a relevant basis for defining a Minimum Common Monitoring Framework (MCMF) at the Mediterranean biogeographical scale.

The adopted approach does not aim to impose a single system, but to propose a flexible and adaptable harmonized matrix, based on:

- a minimum set of core indicators;
- complementary indicators that can be integrated depending on site-specific conditions;
- qualitative alignment of conservation status classes (FV, U1, U2);
- compatibility with the parameters Range, Area, Structure and Functions, and Future Prospects required under Article 17.

The matrix is conceived as a dynamic and adaptive technical tool, to be progressively refined based on monitoring results from the project sites, integrating newly acquired knowledge, site-specific ecological and territorial features, and the evolution of European legislation.

The harmonization approach is based on:

- review of available methodological references;
- identification of recurring and comparable indicators;
- qualitative alignment of assessment criteria;
- definition of comparable minimum monitoring requirements.

The system is designed to support transferability to other Mediterranean Natura 2000 sites and future projects, while maintaining consistency with European reporting standards.

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8.1 Harmonized indicator matrix

The table 3 below provides a comparative organisation of core and complementary indicators for dune habitats, structured according to the parameters defined under Article 17 of the Habitats Directive. The framework is based on available methodological references and scientific literature, and is intended to support the alignment and comparability of conservation status assessments across Mediterranean contexts.

Habitat	**Range (Art.17)**	**Area (Art.17)**	**Structural Indicators (CORE)**	**Functional Indicators (CORE)**	**Pressures (CORE)**	**IAS Indicators (CORE)**	**Complementary Indicators**
H1210	Extent and continuity of drift lines	Occupied area of drift line habitat	Cover and composition of typical annual species	Natural depositional dynamics and organic matter accumulation	Mechanical beach cleaning and litter removal	Presence and cover of annual invasive alien species	Microtopographic parameters; organic matter content; drift line width
H2110	Continuity and spatial distribution of embryonic dunes	Area of embryonic dune systems	Presence, cover and diversity of pioneer species	Sediment stability and accretion processes	Trampling and recreational pressure	Presence of pioneer invasive alien species	Sediment granulometry; beach–dune interface dynamics
H2120	Distribution of Ammophila-dominated dune systems	Area of mobile (white) dunes	Cover, density and vitality of Ammophila arenaria	Sand trapping and dune-building capacity	Coastal erosion and trampling	Invasive species affecting dune mobility	Culm density; dune morphology parameters
H2210	Continuity and spatial distribution of fixed dunes	Area of perennial vegetation cover	Structure, composition and stratification of plant communities	Structural maturity and ecological stability	Coastal urbanisation and habitat fragmentation	Woody invasive alien species	Fragmentation metrics; patch connectivity

Habitat	**Range (Art.17)**	**Area (Art.17)**	**Structural Indicators (CORE)**	**Functional Indicators (CORE)**	**Pressures (CORE)**	**IAS Indicators (CORE)**	**Complementary Indicators**
H2250*	Distribution of Juniperus formations	Area of shrub-dominated habitats	Condition and structure of Juniperus spp. individuals	Natural regeneration capacity	Grazing and disturbance pressure	Shrub invasive alien species	Phytosociological composition; regeneration rate

Table 3 : Harmonized CORE and complementary indicators proposed for the conservation status assessment of Mediterranean dune habitats, aligned with the Article 17 reporting framework.

The table 4 below provides a comparative organisation of structural, functional, pressure and IAS-related indicators for *Posidonia oceanica* meadows (H1120*), structured according to the parameters defined under Article 17 of the Habitats Directive. The framework is based on available methodological references and scientific literature, and is intended to support the alignment and comparability of conservation status assessments across Mediterranean contexts.

Parameter	**Range (Art.17)**	**Area (Art.17)**	**Structural Indicators (CORE)**	**Functional Indicators (CORE)**	**Pressures (CORE)**	**IAPS (CORE)**	**Complementary Indicators**
Meadow extent	Distribution range	Occupied area	Continuity / fragmentation	Area trend	Anchoring	Invasive macroalgae	High-resolution mapping
Structure			Shoot density (class)	Leaf and rhizome production	Artisanal fishing	*Caulerpa* spp.	Biomass

Parameter	**Range (Art.17)**	**Area (Art.17)**	**Structural Indicators (CORE)**	**Functional Indicators (CORE)**	**Pressures (CORE)**	**IAPS (CORE)**	**Complementary Indicators**
Ecological function			Matte integrity	PREI or equivalent index	Turbidity	Other IAS	Sedimentological indicators
Future prospects			Overall conservation status	Functional trend	Cumulative pressures	IAS trend	Climate parameters

Table 4 : Harmonized CORE and complementary indicators proposed for the conservation status assessment of *Posidonia oceanica* meadows, consistent with the Article 17 reporting framework.

8.2 Data quality control

The data quality control system (Quality Assurance / Quality Control – QA/QC) adopted in the LIFE terrAmare project aims to ensure that the information collected for dune habitats (H1210, H2110, H2120, H2210, H2250*) and for habitat H1120* (*Posidonia oceanica*) is reliable, consistent, and suitable for conservation status assessment and reporting purposes under Article 17 of the Habitats Directive.

Quality control is based on key principles: accuracy in the application of standardised protocols, internal consistency among structural, functional, and pressure indicators, comparability of results across different monitoring contexts, and traceability of data sources and revisions.

The process is structured in three main phases. First, data collection is carried out using standardised protocols and field forms developed within the project framework. Second, datasets are checked for completeness and internal consistency, including the identification of anomalies or outliers. Finally, the data are validated by expert personnel, who verify methodological correctness and consistency with the qualitative thresholds FV/U1/U2, ensuring alignment with the assessment criteria defined under Article 17.

Data derived from citizen science activities are used as supporting information, particularly for the identification of pressures and invasive alien species and are incorporated into the system only after technical validation.

The outcome of the QA/QC process is a validated dataset, suitable for supporting conservation status assessments and facilitating integration into future European reporting cycles.

8.3 Integration with the LIFE terrAmare monitoring system

The monitoring framework defined in this document is integrated into the monitoring system developed within the LIFE terrAmare project, ensuring consistency between field activities, technical analysis, and the reporting of results at different spatial scales.

This integration is based on the use of standardised protocols and a minimum common set of indicators (CORE), applied across pilot sites with the possibility of context-specific adaptations. The collected data are organised within a structured information system designed to ensure consistency in data formats, traceability of sources, and compatibility with European reporting requirements.

The LIFE terrAmare monitoring system integrates different types of information:

● technical-specialist data derived from field surveys and structural and functional analyses of habitats;

● assessments of pressures and invasive alien species;

● supporting information from citizen science activities, appropriately validated.

For habitat H1120*, integration also includes the use of functional metrics consistent with the PREI index, ensuring continuity with assessment systems already adopted at national and EU levels. For dune habitats, the application of structural and functional indicators enables an integrated interpretation of the beach–dune system, facilitating comparability across different territorial contexts.

The LIFE terrAmare monitoring system is conceived as an operational and replicable tool, capable of supporting not only project activities but also the future management of the Natura 2000 sites involved. In this perspective, the integration of the monitoring framework, data quality control procedures, and project monitoring activities represents a key element for ensuring continuity beyond the project duration and for contributing to future reporting cycles under Article 17 of the Habitats Directive.

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