



Data Paper

A spatially-explicit, participatively derived dataset for Nature-based Building Blocks integrating biophysical, social and ecological characteristics across EU coastal restoration pilots

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Abstract

Effective large-scale coastal restoration requires moving beyond successful yet isolated pilot projects towards integrated, landscape-scale implementation of Nature-based Solutions (NbS). Achieving this transition depends on systemic approaches that translate local knowledge into spatial planning and broader environmental objectives across connected ecosystems, while addressing entangled challenges driven by, for example, climate change, biodiversity loss and pollution. Within the EU H2020 REST-COAST project, we developed the Nature-based Building Blocks (NB³) Framework to support the participatory upscaling of NbS across European coastal restoration pilots. This data paper presents a spatially-explicit dataset generated through the participatory application of the framework at pilot sites. Using the Interactive Web Map tool that implements the Participatory Downscaling Approach of the framework, stakeholders mapped Coastal

Units representing context-specific spatial entities for restoration planning. Each Coastal Unit is coupled to a structured data sheet derived from the Input-Process-Output Model of the NB³ Framework, capturing locally relevant biophysical, ecological and socio-economic information. The resulting dataset provides a standardised, yet flexible representation of pilots' coastal restoration contexts, enabling comparative analysis, fostering cross-site learning and providing information for decision-making strategies in NbS upscaling. By making these data openly available, the dataset provides a benchmark for comparative reuse in future restoration strategies and promotes broader application of participatory, transdisciplinary approaches to upscaling coastal restoration.

Keywords

building blocks, coastal restoration, NbS, stakeholder-based, transdisciplinary dataset, upscaling

Background

Coastal areas host ecologically delicate systems that are rich in biodiversity and provide a broad range of ecosystem services (Snelgrove 1999, Barbier et al. 2011, Powell et al. 2019). Although coastal ecosystems cover only around five percent of the Earth's surface, they are home to nearly one third of the world's population and generate a disproportionately large share (around two thirds) of global ecosystem service value (Lau et al. 2019, Blythe et al. 2020, Rodrigues-Filho et al. 2023). Despite their environmental, social and economic importance, coastal systems are increasingly exposed to interacting pressures resulting from sea level rise, biodiversity loss, extreme weather events and pollution (Kulp and Strauss 2019, Smale et al. 2019, Pörtner et al. 2023, Ripple et al. 2024). These pressures are often entangled across spatial and temporal scales, adding to complex socio-ecological dynamics that challenge conventional, sectoral approaches (Lau et al. 2019, Griffiths et al. 2020, Defeo et al. 2021, IPCC 2023), as illustrated by coastal squeeze arising from the interactions amongst sea level rise, fixed infrastructure and upstream pollution.

In response, there is growing international emphasis on approaches that are integrated across space and adaptive across time in addressing complex challenges to protect these important ecosystems (EC 2022, IPCC 2022, Doelle and Puthucherril 2023, IEPP et al. 2024). Nature-based Solutions (NbS) have emerged as a promising strategy for climate adaptation and ecosystem restoration, supported by a growing body of empirical evidence and increasing policy uptake (Cohen-Shacham et al. 2019, Seddon 2022, Tiggeloven et al. 2022, van Loon-Steensma and Goldsworthy 2022). However, translating successful local efforts demonstrated by numerous NbS pilot projects into large-scale, long-term implementation remains challenging. Complex interactions amongst natural processes, ecological dynamics and land-use heterogeneity continue to hinder scaling of localised interventions to landscape-level restoration (Augenstein et al. 2020, Nelson et al. 2020, Bauwens et al. 2022, Cohn et al. 2022, Moraes et al. 2022).

The EU Horizon 2020 REST-COAST (<https://rest-coast.eu>) project brings together partners across science, policy and society to address this challenge by supporting the upscaling of NbS across European coastal restoration pilots (Sánchez-Arcilla et al. 2022, O'Leary et al. 2023, Horneman et al. 2026b). Within this context, the Nature-based Building Blocks (NB³) Framework was developed as a systemic and integrated approach to implement NbS-driven coastal restoration through spatially-explicit restoration units. The framework incorporated participatory processes in a progressive augmentation manner across pilots throughout its development and application, implemented through two fundamental methods: (i) Participatory Downscaling Approach, guiding stakeholders in delineating polygon-based Coastal Units within pilot sites and (ii) Input-Process-Output (IPO) Model, structuring the collaborative identification of locally relevant biophysical, socio-economic and ecological characteristics for each Coastal Unit. The framework and its methods are summarised in the NB³ Framework section. (Arslan and van Loon-Steensma 2025, Arslan et al. 2026).

This data paper focuses on the outputs generated through the practical application of the framework, presenting a harmonised dataset of Coastal Units developed across three pilot sites that represent diverse geomorphological and socio-ecological contexts (see Fig. 1). The dataset provides a structured basis for decision-making in forthcoming restoration upscaling within the REST-COAST pilots, supports collaborative learning across these pilots, and serves as a benchmark for comparative reuse in large-scale NbS implementation efforts grounded in participatory principles.

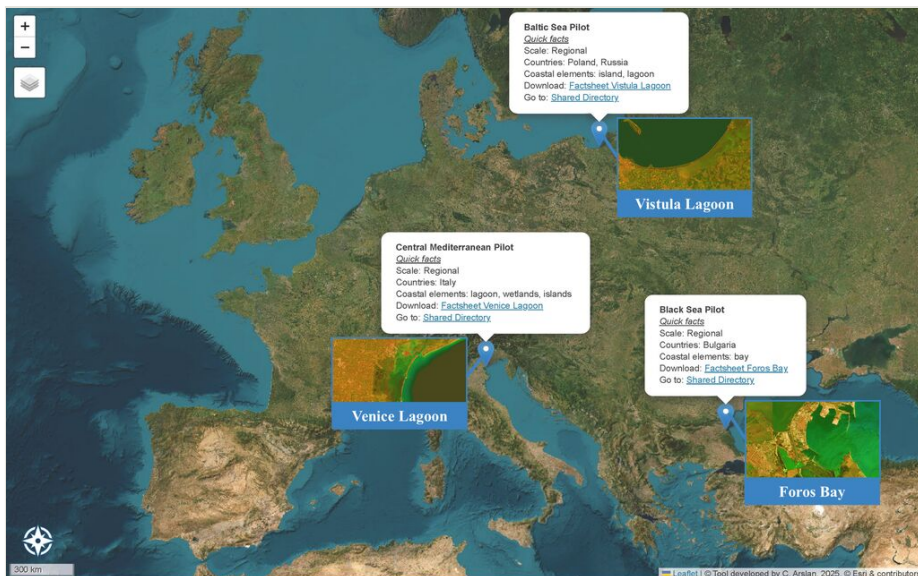


Figure 1.

Three coastal restoration pilot sites across diverse coastal contexts, visualised on the Interactive Web Map.

Data Collection

The dataset consists of a portfolio of Coastal Units, each representing a spatially-explicit restoration unit that integrates locally derived knowledge and expertise across two complementary dimensions guided by the NB³ Framework (see the NB³ Framework section). First, each Coastal Unit is defined by geographic boundaries and spatial identifiers, established through the Participatory Downscaling Approach. Second, each unit is associated with structured contextual information, established through the IPO model, capturing locally relevant biophysical, socio-economic and ecological characteristics.

Data collection followed a stepwise process that reflects the progressive elaboration of these two dimensions for each Coastal Unit. An initial phase of bilateral pilot workshops (see Bilateral pilot workshops section) preliminarily demarcated Coastal Units and provisionally characterised them with locally relevant information, followed by a phase of extended pilot applications (see Extending pilot applications section), in which Coastal Units were spatially refined and contextually enriched into the finalised data records presented in Data Records section. Both phases implement the framework's two core methods (see the NB³ Framework section) through iterative, participatory engagement with stakeholders at each pilot site. A tailored geospatial tool, the Interactive Web Map, was developed to support this process, enabling collaborative spatial delineation and centralised data management associated with each Coastal Unit (Arslan 2025). Fig. 2 presents a schematic overview of this workflow.

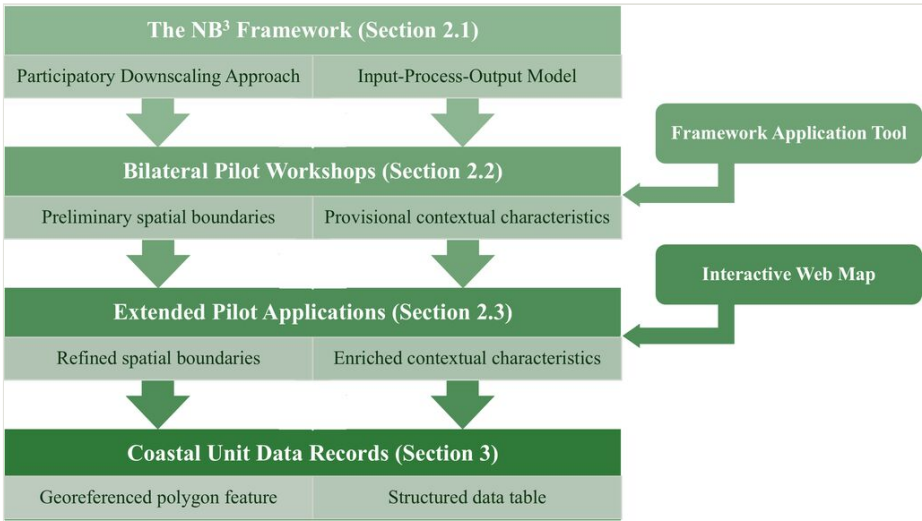


Figure 2. Schematic overview of data collection workflow through the NB³ Framework's two core methods, applied across bilateral pilot workshops and extended pilot applications in producing the Coastal Unit data records.

The NB³ Framework

The NB³ Framework conceptualises seascapes as assemblies of small, homogeneous, spatially-explicit restoration units. The framework treats each unit as a modular *building block* that can be diagnosed, restored and eventually re-assembled into landscape-scale adaptation strategies. Through this building-block logic, the framework addresses a persistent upscaling challenge: individual NbS pilots tend to remain fragmented, isolated success stories that are difficult to compare or connect within or across sites. The framework resolves this by giving each restoration unit the same underlying structure, so that units become commensurable across sites, regardless of their diverse local contexts. Fig. 3 presents a graphical overview of the framework.



Figure 3.
The graphical overview of the NB³ Framework (adapted from Arslan et al. (2026a)).

This concept is implemented through two complementary methods:

The Participatory Downscaling Approach guides stakeholders in collaboratively identifying the physical boundaries of a restoration unit within a larger seascape. This approach draws on two conceptually orthogonal axes: *Coastal Categories*, which position a unit along the land-to-sea continuum associated with characteristic morphological and ecological conditions (ranging from *Subtidal* and *Intertidal* zones through *Barrier*, *Hinterland* and *Upstream* zones) and *Coastal Delineations*, which further subdivide a coastline into distinct stretches, based on natural and social characteristics. Together, these two axes guide stakeholders in demarcating restoration units that are modular, thus self-contained and coherent, yet able to link together into a larger system.

The Input-Process-Output (IPO) Model organises each restoration unit's characterisation into three functionally linked compartments. The *input* compartment captures the unit's degraded state through key biophysical and socio-economic parameters, including sediment load, current-wave characteristics, governance structure and funding availability. These parameters together explain why and how the unit has degraded, while indicating where restoration potential lies. The *process* compartment identifies the specific NbS-driven restoration action selected to address that degraded state, for example, seagrass restoration, dune revegetation, managed realignment. The *output* compartment projects the unit's anticipated restored state through ecosystem services and biodiversity indicators, providing information for each unit's potential alignment within a larger seascape mosaic in accordance with specific adaptation goals.

A *Coastal Unit* is the operational unit emerging from the application of these two methods together: a spatially demarcated area (via the Participatory Downscaling Approach) that is systematically contextualised by the IPO model. Every *Coastal Unit* in this dataset was generated through stakeholders by first identifying the spatial extent of the unit and then populating its input, process and output compartments through iterative workshops and extended applications (see Bilateral pilot workshops and Extending pilot applications sections). This standardised structure enables the production of contextual data records where all three pilots, despite representing ecologically very different systems, report against the same IPO template, making cross-pilot comparison possible.

Complementary literature describes the full theoretical development of the NB³ concept, including its four-stage conceptual definition process and participatory refinement across nine REST-COAST pilots (Arslan and van Loon-Steensma 2025) and the framework's participatory application across six pilot sites, including the workshop methodology and the development of the Framework Application Tool (Arslan et al. 2026a). This data paper focuses specifically on the resulting Coastal Unit data records from three pilot sites.

Bilateral pilot workshops: preliminary delineation and provisional characterisation

Initial data collection was conducted through a series of bilateral pilot workshops with stakeholders at each pilot site. These stakeholders were primarily REST-COAST project

partners, including natural scientists, environmental modellers, ecologists and local managers. Stakeholder representation at each pilot followed the framework's inherent participation requirement spanning natural and social science domains. In some cases, workshops also included stakeholders beyond the project consortium, which was not strictly required, but further enriched the participation. Workshops were facilitated using a dedicated Framework Application Tool designed to ensure consistent and systemic application of the framework across pilots.

The workshops followed a structured three-step process, directly implementing the framework's two methods introduced in the NB³ Framework section. First, participants were introduced to the NB³ Framework. Second, guided by the Participatory Downscaling Approach, participants identified the preliminary spatial boundaries of a Coastal Unit within their pilot site and guided by the IPO model, participants identified the provisional contextual characteristics of that unit. Third, participants verified and refined the workshop outputs.

Stakeholder expertise and local knowledge at each site were mobilised around the NB³ Framework through a collaborative process: first demarcating a spatially coherent Coastal Unit along the Coastal Categories and Coastal Delineations axes and then characterising this unit's biophysical and socio-economic parameters relevant to its degraded state and how these parameters provided information for the potential NbS-driven restoration effort and its prospected environmental benefits, indicated by enhanced ecosystem services and biodiversity. These preliminary outputs from the workshops were consolidated into a central database managed by the framework developers. Complementary publications describe the detailed methodological design of the workshops (Arslan and van Loon-Steensma 2025) and the participatory application process of the framework (Arslan et al. 2026).

Extending pilot applications: spatial refinement and contextual enrichment

In a subsequent phase, a focused task force was established at each pilot site to refine and extend the preliminary outputs generated during the workshops. This phase addressed both dimensions of a Coastal Unit introduced in the NB³ Framework section: i) the spatial component, realised as a georeferenced polygon defining the unit's extent and boundaries, was refined from raw workshop boundaries to operationally precise delineation; and ii) the contextual component, realised as a structured data table incorporating the unit's IPO-derived parameters, was extended from descriptive attributes to quantitative and qualitative metrics, harmonised across pilots. The structure, format, content and curation of these resulting data records are explained in detail in Structure of data records section.

To support this process, the Interactive Web Map was developed as a static web application (HTML and JavaScript) using the Leaflet library and Open Street Map as base layers for interactive mapping. The application is published via GitHub Pages, freely and

directly accessible at <https://c-arslan-wur.github.io/interactive-web-map/>, with full documentation provided in the GitHub repository (Arslan 2025).

The Interactive Web Map integrates each Coastal Unit along two dimensions, serving both as a collaborative interface for pilot interactions during this refinement phase and as the centralised, most up-to-date repository for the dataset presented in Data Records section.

Data Records

The dataset presented in this paper comprises Coastal Units developed across three pilot sites: the Venice Lagoon, the Foros Bay and the Vistula Lagoon. For each pilot, a spatially-explicit Coastal Unit was identified through the participatory application of the NB³ Framework. These Coastal Units consist of two interlinked components, as described in Extending pilot applications section: a geospatial feature and an associated contextual data table. As a link between the data collection described in Data Collection section and the pilot-specific data records presented in the sections for the Venice Lagoon pilot, the Foros Bay pilot and the Vistula Lagoon pilot, Structure of data records section provides a detailed description of these data records, covering both their spatial and contextual dimensions.

Structure of data records

The geospatial feature of each Coastal Unit is represented as a georeferenced polygon, defined by an ordered sequence of [latitude, longitude] coordinate pairs in decimal degrees within the WGS 84 geodetic coordinate reference system (EPSG:4326). Each polygon is associated with a set of identifiers, including a unique unit code, unit area and the NbS-driven restoration action under consideration. In the Interactive Web Map environment, these polygons further support iterative refinement of the data collection process through core user interaction functions, including editing spatial boundaries and identifiers and removing units. Each polygon has a persistent link to its corresponding contextual data table, available in the GitHub repository (Arslan 2025).

The contextual component of a Coastal Unit is provided as a structured spreadsheet that captures locally relevant information describing the restoration context. This table summarises geographical characteristics of the unit, identifies key environmental pressures motivating restoration and designates the NbS-driven restoration process together with locally appropriate implementation methods. It further records the biophysical, socio-economic and ecological characteristics identified by local stakeholders as most relevant, through participatory application of the framework's IPO Model. Fig. 4 presents a template data table illustrating the fields populated through stakeholder input.

Within the *input* compartment of the IPO model, the table records the stakeholder input, for each biophysical and socio-economic parameter, its descriptive name, measurement

unit (using SI standards where applicable), impact and its supporting basis (documented through any combination of a model description, empirical data or literature reference, each accompanied by a link to the corresponding source). Impact is recorded as a directional relationship between the parameter and the selected NbS-driven restoration process.

Application of the NB3 Framework @										Select pilot site		
Data Owners		List of all stakeholders involved in the framework application and data collection										
Coastal Unit	Coastal Categories	Select Coastal Category				Drivers	Pressure				Impact	
	Coastal Delineations	e.g. user-defined code, central coordinates...					list the environmental and anthropogenic pressures on the Coastal Unit, and rate the NB3 process' expected impact on each pressure				☆☆☆☆	
	Spatial Location	insert link to the shared map with spatially distributed Coastal Units										
NB3 FW		NbS-driven restoration process within the Coastal Unit										
Parameters		Name	Unit	Impact*	Model	Link	Data	Link	Literature	Link		
KBP	key biophysical parameter 1	-			briefly describe model	insert link	briefly describe data	insert link	briefly describe literature	insert link		
	...	-										
		right click to insert row above										
KSP	key socio-economic parameter 1	-			briefly describe model	insert link	briefly describe data	insert link	briefly describe literature	insert link		
	...	-										
		Stakeholders' engagement**	Nomi...									
		right click to insert row above										
* Legend for the impact drop-down list												
[KBP/KSP] suppresses the success of [NB3] [KBP/KSP] boosts the success of [NB3] [KBP/KSP] is suppressed after the implementation of [NB3] [KBP/KSP] is boosted after the implementation of [NB3]												
KBP: Key Biophysical Parameter KSP: Key Socio-economic Parameter NB3: NbS-driven restoration process within the Coastal Unit												
**Four nominal categories across decision-making and knowledge-exchange axes, reflecting prevailing mode of engagement between managing authorities and local stakeholders associated with the Coastal Unit and its restoration. Categories are inspired by Reed et al. (2018)'s the wheel of participation.												
Top-down Informing: Decisions are made by project or managing authority, only informing local stakeholders.												
Top-down Co-deciding: Decisions are led by project or managing authority, including local stakeholder inputs.												
Bottom-up Informing: Decisions are made by local stakeholders, reporting upward to project or managing authority.												
Bottom-up Co-deciding: Decisions are jointly made by local stakeholders and project or managing authority.												
NB3 FW Outputs					HABITATS			SPECIES				
	ESS	Reduction Flood Risk ☆☆☆☆☆				BDV	briefly describe the expected benefits from the NB3 process on the habitats of the Coastal Unit			briefly describe the expected benefits from the NB3 process on the species of the Coastal Unit		
		Reduction Coastal Erosion ☆☆☆☆☆										
		Climate Change Regulation ☆☆☆☆☆										
Water Purification ☆☆☆☆☆												
		Food Production ☆☆☆☆☆										

Figure 4.

Template of the data table used to capture stakeholder input for each Coastal Unit, aligned with the NB³ Framework's (NB3 FW) IPO model. Table records the unit's spatial identity (Coastal Category, Coastal Delineation, link to spatial location), NbS-driven restoration process, unit's input parameters (KBP and KSP: key biophysical and socio-economic parameters, each with supporting attributes) and its projected outputs (ESS and BDV: ecosystem services scores and biodiversity narratives for habitats and species). Placeholder text and table notes illustrate the guidance provided to stakeholders during data entry.

Within the *output* compartment of the IPO model, the table records ecosystem services and biodiversity indicators as stakeholder-assessed ecological benefits associated with the selected NbS-driven restoration process in a Coastal Unit. These benefits together represent a preliminary ecological assessment of a spatial unit's restoration.

For ecosystem services, the REST-COAST project defined five overarching services, applied consistently across all pilot sites: *Reduction of Flood Risk*, *Reduction of Coastal Erosion*, *Climate Change Regulation*, *Water Purification* and *Food Production* (Sánchez-Arcilla et al. 2022). Stakeholders provided an expert-based semi-quantitative score each service using a five-point scale, reflecting a habitat's capacity to deliver that service rather than a direct, site-specific indicator. These capacity scores were derived for standardised EUNIS habitat types through a modified Delphi process, combining literature review with expert questionnaires and consensus-building among REST-COAST scientific partners (Baptist et al. 2024). At each pilot, these generic habitat-based scores were then locally adapted by stakeholders to reflect the specific restoration context and the expected

improvements in habitat condition resulting from the NbS-driven restoration process within each Coastal Unit.

Biodiversity outcomes were documented separately for *habitats* and *species*. These outcomes were recorded as consensus-based qualitative narratives from stakeholders describing expected improvements, informed by local knowledge, past restoration experience and available monitoring data. Together with the ecosystem service scores, they provide a structured representation of stakeholders' baseline assessment of a Coastal Unit's ecological status.

The Venice Lagoon pilot

Study area and the Coastal Unit

The Venice Lagoon is the largest lagoon in the Mediterranean, located along the northern Adriatic coast in Italy, covering approximately 550 km² (Lionello et al. 2021). The Lagoon's complex mosaic of channels, shallow waters, mudflats, saltmarshes and human settlements has been shaped by centuries of human intervention, with more recent efforts increasingly focused on conserving its ecological functioning and cultural heritage (Bonometto 2008, Stocco and Pranovi 2023).

As a result of long-term ecosystem research and management, substantial environmental data are available for the Lagoon, including monitoring records, literature-based studies and modelling outputs. Salt marsh restoration has been one of the important interventions in the Lagoon since the introduction of the first Special Law for Venice (Law No. 171/1973), aiming to recover morphological degradation and enhance ecological processes through measures, such as salt marsh edge protection, sediment retention and habitat provision (Munaretto and Huitema 2012).

Under the Water Framework Directive, the Venice Lagoon is subdivided into eleven natural and three heavily modified waterbodies based on salinity gradients and levels of confinement (Cacciatore et al. 2019). These waterbodies serve as managerial units for environmental assessment and restoration planning (Tagliapietra and Ghirardini 2006). Within the REST-COAST project's scope, the pilot site restoration interventions are located in the Millecampi Teneri waterbody (PC2).

In this context, nine salt marshes within the Millecampi Teneri waterbody, covering approximately 138 ha, constituted the Coastal Unit for application of the NB³ Framework, shown as the darker green shaded areas in Fig. 5. *Artificial Salt Marsh Reconstruction* was identified as the NbS-driven restoration process for this unit, to which the unique identifier *PC2_SM4326* was assigned in light of this study (spatial extent available as *SpatialData_CoastalUnit_PC2_SM4326.geojson* (Arslan et al. 2026b)).

The Coastal Unit is subject to multiple environmental pressures with varying intensities, including lateral edge erosion, sea level rise, dredging and biodiversity loss. Drawing on existing practices and local knowledge, stakeholders outlined a phased implementation

concept comprising stages of site cleaning, containment, refilling and naturalisation (pressures, associated expert-based qualitative impact and implementation details in *Table1_CoastalUnit_PC2_SM4326.xlsx* (Arslan et al. 2026b)).

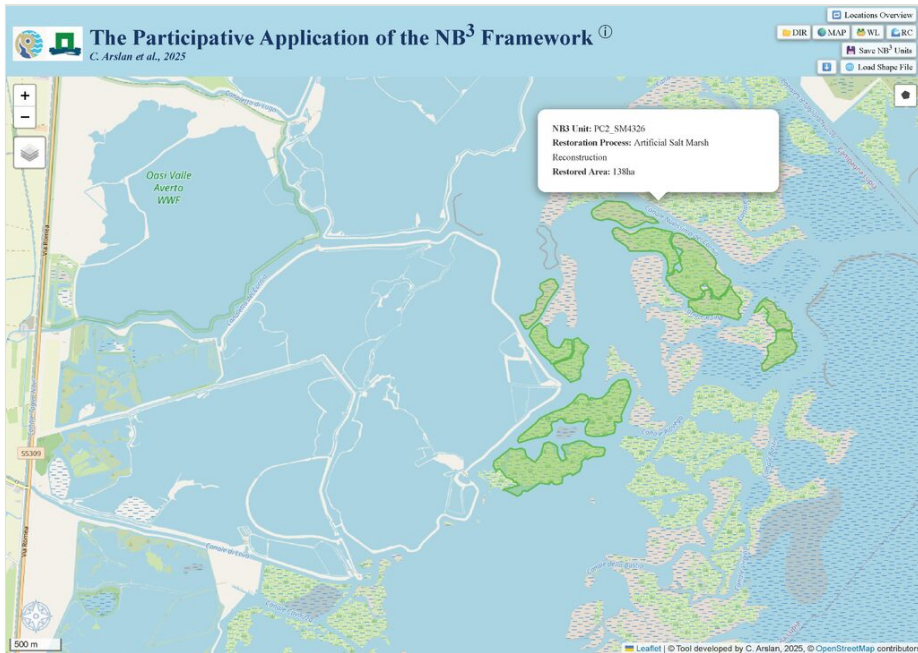


Figure 5.

The identified Coastal Unit, *PC2-SM4326*, within the Venice Lagoon pilot site, shown as the darker green shaded areas.

Key biophysical parameters

For the Coastal Unit under investigation, stakeholders identified a set of biophysical parameters reflecting important environmental pressures, site-specific processes and available long term observational and model-based data from the Venice Lagoon. These parameters characterise interactions between the Coastal Unit and the NbS-driven restoration process and provide an indication of NbS effectiveness regarding local ecological functions and ecosystem services (Horneman et al. 2026a, Horneman et al. 2026b). The parameters are briefly described below in relation to the Coastal Unit and the NB³ Framework perspective, while detailed parameter values, units, data sources and locally relevant metadata are documented in *Table1_CoastalUnit_PC2_SM4326.xlsx* (Arslan et al. 2026b).

Future sea level rise: Projected increase in mean sea level relative to a reference period. This scenario-based parameter provides information for potential salt marsh submergence and drowning under climate change (Zanchettin et al. 2021).

Sea level rise rate: Rate derived from observational records. This parameter provides information for the adaptive capacity of salt marshes to relative sea level change through sediment accretion processes (Neijns et al. 2021).

Sediment input: Rate derived from sediment transportation measurements. This parameter indicates sediment availability in maintaining salt marshes. When combined with modelling approaches, it supports the assessment of saltmarsh persistence and restoration outcomes (Fagherazzi et al. 2020).

Sediment granulometry: Grain size distribution derived from measurements, characterising the sediment quality to support recreation of natural salt marsh processes during restoration (Bonometto 2008).

Salt marsh morphology: Physical shape and structure of the salt marsh. This spatially explicit parameter provides a proxy for marsh's health, long-term stability and ecological functioning (Bonometto 2003, D'Alpaos 2010). In combination with other parameters, it provides information for restoration design considerations.

Salt marsh vegetation: Ground cover and abundance derived from in situ observations and/or remote sensing. This parameter provides a proxy for healthy salt marshes through its role in sediment stabilisation, wave attenuation and erosion reduction (Marani et al. 2004, Baptist et al. 2019, Willemsen et al. 2022).

Current-wave characteristics: Hydrodynamic conditions driven by wind direction and speed. This measurement-based parameter influences salt marsh stability and restoration feasibility (Umgiesser et al. 2004).

Erosion rate: Rate of salt marsh retreat derived from monitoring data. This parameter provides information for both restoration design choices and the evaluation of restoration performance in salt marshes.

Carbon sequestration: Rate of soil organic carbon accumulation derived from monitoring data. This parameter reflects restoration outcomes through indicators, such as primary production, surface accretion and organic carbon stocks (Puppin et al. 2024).

WFD indices related to the benthic community structure: Quality index per benthic community derived from monitoring data. This parameter provides a measure of ecological status relevant to both restoration planning and assessment in salt marshes.

Key socio-economic parameters

For the Coastal Unit under investigation, stakeholders identified a set of socio-economic parameters reflecting governance dynamics, policy contexts, economic activities and social structures influencing the restoration setting. These parameters characterise interactions between the Coastal Unit and the NbS-driven restoration process from societal, economic and governance perspectives and provide contextual information relevant to NbS design and implementation. The parameters are briefly described below

in relation to the Coastal Unit and the NB³ Framework perspective, while detailed parameter values, units, data sources and locally relevant metadata are documented in *Table1_CoastalUnit_PC2_SM4326.xlsx* (Arslan et al. 2026b).

National funding: Annual budget regulated by national legislation, describing financial resources allocated to safeguard the Lagoon ecosystem and its inhabitants.

EU funding: Project-based budget allocation, describing financial support to the Lagoon for research and practical restoration activities aligned with the EU policy priorities and missions.

WFD regulation: Regulatory requirements and associated monitoring obligation, capturing governance drivers influencing restoration planning through the assessment of ecological status and water quality.

Water traffic: Vessel size, speed and loading derived from monitoring and statistics. This parameter quantifies pressures from vessel-induced waves and their erosive impacts on salt marsh edges (Indirli et al. 2014).

Cultural and natural heritage: National and international designation programmes, providing information for constraints and opportunities shaping the design and scope of restoration activities within the Lagoon.

Nutrient loading: Nitrogen and phosphorous concentrations in the water column, serving as a proxy for regional agricultural and industrial activities affecting water quality in the Lagoon.

Proximity to industrial areas: Distance from the salt marsh perimeter to nearest industrial zones, indicating potential exposure to pollution that may influence restoration outcomes.

Fishing interests: Annual catch data and fishing effort, providing contextual information on socio-economic dependencies and potential interactions with salt marsh restoration.

Stakeholders' engagement: Four nominal categories reflecting stakeholder engagement inspired by the wheel of participation (Reed et al. 2018). This parameter describes the level of participation and support of institutional, scientific and local stakeholders in planning and implementing restoration measures within the Lagoon.

Stakeholder-assessed ecological benefits

Stakeholders' expert-based scoring of anticipated ecosystem service benefits from artificial salt marsh reconstruction within the *PC2_SM4326* Coastal Unit identified coastal protection — indicated by *Reduction of Flood Risk* and *Reduction of Coastal Erosion* — as the highest priority. *Climate Change Regulation* and *Water Purification* received moderate and equal scores, while *Food Production* was rated more conservatively. This scoring pattern reflected the critical role of salt marshes in the Lagoon's coastal

adaptation to increasing hydrodynamic and climate change-driven pressures, while simultaneously delivering multiple co-benefits.

In parallel, stakeholder narratives emphasised the role of salt marsh restoration in enhancing biodiversity, with expected benefits for benthic communities, salt marsh and submerged vegetation, fish and bird species, while acknowledging the gradual nature of re-naturalisation processes. These ecological improvements were linked to anticipated progress towards achieving targeted ecological status under the Water Framework Directive.

Table1_CoastalUnit_PC2_SM4326.xlsx (Arslan et al. 2026b) provides a comprehensive overview of ecosystem service scores and biodiversity narratives, representing the stakeholders' baseline assessment of the current ecological status and projected restoration trajectory of *PC2_SM4326* Coastal Unit.

The Foros Bay pilot

Study area and the Coastal Unit

The Foros Bay, part of the microtidal Black Sea, is located in the innermost section of the Burgas Bay along the Bulgarian coast. The Bay is structurally and functionally connected to a network of wetlands, including the *Burgas Lake*, the *Mandra Lake* and the *Poda Protected Area*, together forming a part of the Burgas Wetlands Complex (Bulgarian Society for the Protection of Birds (Birdlife International) 2002). This wetland system is ecologically significant due to its role along the Via Pontica migratory bird route and its importance for regional biodiversity. It is designated as a NATURA 2000 site for habitat and bird protection (Ministry of Environment and Waters 2012).

Within the REST-COAST project's scope, the pilot site was established inside a coastal area in the close vicinity of the *Poda Protected Area*, where restoration activities aim to extend beyond the physical boundaries, reflecting the broader ecological connectivity of the system. Seagrass restoration is a key intervention focus in the Foros Bay, aiming at reversing degradation, improving water quality and recovering ecological processes through the conservation of existing meadows within the NATURA 2000 site and their expansion across the Bay.

Within this context, a seagrass meadow dominated by *Zostera noltii*, covering an area of 39 ha, was identified as the Coastal Unit next to the *Poda Protected Area* for application of the NB³ Framework. This unit, shown as the darker green shaded area in Fig. 6, was assigned the unique identifier *CS_1*, Fig. 6 and *Seagrass Conservation* was specified as the NbS-driven restoration process (spatial extent available as *SpatialData_CoastalUnit_CS_1.geojson* (Arslan et al. 2026b)).

The Coastal Unit is subject to multiple environmental pressures of varying intensities, including anthropogenic and upstream impacts, such as port activities, intensive agriculture, degraded wetlands. Drawing on existing practices and local knowledge,

stakeholders developed a phased implementation concept comprising three stages: enhancing water exchange, reducing suspended sediment concentrations and managing upstream nutrient loads (pressures, associated expert-based qualitative impact and implementation details in *Table2_CoastalUnit_CS_1.xlsx* (Arslan et al. 2026b)).



Figure 6.

The identified Coastal Unit, CS_1, within the Foros Bay pilot site, shown as the darker green shaded area.

Key biophysical parameters

For the Coastal Unit under investigation, stakeholders identified a set of biophysical parameters reflecting important environmental pressures, site-specific ecological processes and available data from field surveys and modeling activities in the Foros Bay. These parameters characterise the interactions between the Coastal Unit and the NbS-driven restoration process, providing information for restoration requirements and design considerations.

The parameters are briefly described below in relation to the Coastal Unit and the NB³ Framework perspective, while detailed parameter values, units, data sources and locally relevant metadata are documented in *Table2_CoastalUnit_CS_1.xlsx* (Arslan et al. 2026b). Data collected through *in situ* measurements during the REST-COAST project are not publicly available. These data are stored in proprietary archives at IO-BAS and can be accessed subject to institutional approval.

Wave energy: Realised wave exposure derived from long-term wave forcing. In the inner bay, low values indicate sheltered conditions that promote seabed stability and persistence of seagrass meadows.

Wind fetch: Wave generation potential, based on coastline orientation and prevailing wind direction. This contextual parameter influences favourable conditions for seagrass meadows (Fonseca and Bell 1998).

Wave parameters: Wave height, wave period and wave direction derived from *in situ* measurements. These parameters describe site-specific hydrodynamic forcing, controlling mechanical stress, sediment suspension and light attenuation dynamics.

Current velocity: Flow rates derived from *in situ* measurements. This parameter indicates hydrodynamic thresholds that may disturb or damage seagrass restoration (Koch 2001).

Bottom orbital velocity: Near-bed orbital wave-induced motion. This parameter is related to wave exposure that may limit seagrass establishment (Infantes et al. 2009, Erftemeijer et al. 2023).

Bottom substrate – Soft: Categorical substrate types indicating suitability for seagrass colonisation and succession (Erftemeijer et al. 2023).

Water temperature: Sea surface temperature derived from *in situ* measurements. This serves as a key ecological factor influencing seagrass growth, productivity and distribution (Jiang et al. 2022).

Salinity: Practical Salinity Units (PSU) derived from *in situ* measurements. This serves in defining seasonal tolerance ranges for persistence of *Zostera noltii* (Sousa et al. 2017).

Water transparency: Secchi Depth profiles derived from *in situ* measurements. This parameter is a proxy for underwater light availability, providing information for limits of seagrass colonisation (Dennison 1987, Koch 2001).

Nutrient input: Nitrogen and phosphorous concentrations in the water column. This parameter indicates eutrophication potential and toxicity thresholds affecting *Zostera noltii* persistence (Brun et al. 2002, Cabaço et al. 2008).

Biodiversity variables: Indicators of ecological status for sea grass meadows derived from monitoring in the Bay. They are proxies for healthy seagrass meadows when combined with relevant parameters:

Species biomass: Aboveground wet seagrass biomass;

Species abundance: Seagrass shoot density per unit area;

Species count: Diversity of soft-bottom macrozoobenthos species.

Blue carbon: Organic carbon storage rate derived from sediment samples. This indicates carbon sequestration potential of seagrass meadows through above- and belowground biomass and sediment accumulation (Howard et al. 2014).

Future sea level rise: Projected relative sea level increase. This scenario-based parameter provides information for susceptibility to inundation, landward retreat or habitat transformation under climate change, particularly in the microtidal Black Sea context (Poulos 2020).

Key socio-economic parameters

For the Coastal Unit under investigation, stakeholders identified a set of socio-economic parameters reflecting governance dynamics, policy contexts, economic activities and social structures influencing the restoration setting. These parameters characterise interactions between the Coastal Unit and the NbS-driven restoration process from societal, economic and governance perspectives and provide contextual information relevant to NbS design and implementation. The parameters are briefly described below in relation to the Coastal Unit and the NB³ Framework perspective, while detailed parameter values, units, data sources and locally relevant metadata are documented in *Table2_CoastalUnit_CS_1.xlsx* (Arslan et al. 2026b).

National funding: Public budget regulated by national legislation, describing financial resources allocated to safeguarding and research on the Foros Bay ecosystem.

EU funding: Project-based budget allocation, describing financial support for research and practice aligned with the EU policy priorities and missions in a larger Foros Bay area.

NATURA 2000: Regulatory and legislative requirements, directives and management plans, framing the extent and context of interventions in and around the protected area (Ministry of Environment and Waters 2012).

Near-shore fishing: Gear impact per unit area, indicating type and scale of disturbance and damage from fishing gear on seagrass meadows (Vieira et al. 2020).

Grey coastal infrastructure: Potential area available for future coastal infrastructure investments, describing impacts on succession and persistence of seagrass meadows.

National and EU policies: Applicable legislative instruments supporting ecosystem protection and restoration in the Bay, with provisions favoring the succession and persistence of seagrass meadows.

Stakeholders' engagement: Level of participation and support of institutional, scientific and local stakeholders in planning and implementing restoration measures within the Bay. Four nominal categories reflecting stakeholder engagement inspired by the wheel of participation (Reed et al. 2018).

Stakeholder-assessed ecological benefits

Stakeholders' expert-based scoring of anticipated ecosystem service benefits from seagrass conservation within the CS_1 Coastal Unit indicated highest potential gains in *Water Purification* followed by *Climate Change Regulation*. These scores reflect the role of seagrass meadows in mitigating upstream and port-related anthropogenic drivers, while contributing to nature-positive targets across the wider NATURA 2000 Protected Zone.

In parallel, stakeholder narratives emphasised the significance of conserving these rare and endangered meadows along the Bulgarian coast. The restoration was described as critical for resilience of both habitat integrity and species diversity, particularly under continued anthropogenic and environmental stresses.

Table2_CoastalUnit_CS_1.xlsx (Arslan et al. 2026b) provides a comprehensive overview of ecosystem service scores and biodiversity narratives, representing the stakeholders' baseline assessment of the current ecological status and projected restoration trajectory of CS_1 Coastal Unit.

The Vistula Lagoon pilot

Study area and the Coastal Unit

The Vistula Lagoon — the second largest lagoon in the Baltic Sea — is a transboundary coastal system shared by Poland and Russia, extending approximately 91 km in length and 6.8–13 km in width, with a mean depth of about 2.7 m. The entire Polish sector is designated as a NATURA 2000 site for bird (PLB280010) and habitat (PLH280007) protection (Różyński et al. 2015). Following the transition to a market economy in the 1990s, the Lagoon region experienced prolonged socio-economic decline, particularly along its southern banks, highlighting the need for integrated management across physical, ecological and socio-economic dimensions (Bielecka and Różyński 2014).

In response, the Polish Government adopted a strategic development plan to establish an independent navigation passage connecting the port of Elbląg to the Baltic Sea. Financed through direct state investment, this plan transformed into a large project, involving excavation through the coastal barrier and dredging of a new navigation channel within the Lagoon. Marine sands from the barrier were safely deposited along the outer beaches (facing the Baltic Sea) avoiding adverse ecological impacts.

Within the REST-COAST project's scope, the pilot site was established in relation to these dredging activities, where restoration efforts explore the sustainable use of dredged sediments. Prior extensive studies on contamination of these sediments confirmed compliance with EU and Polish environmental norms (Różyński and Bielecka 2022). Combining economic revitalisation strategies with ecosystem restoration measures, the pilot provides a context for ecological connectivity and integrated coastal upscaling approaches.

The rapid decline of grasslands has resulted in habitat loss and decreasing populations of endangered bird species. Thus, interventions aimed at restoring biodiversity in the Lagoon area are of key concern, aligned with NATURA 2000 obligations. As a result, the strategic development plan incorporated the construction of an artificial island designed as managed grassland, linking sediment reuse to biodiversity protection by functioning as a bird sanctuary (Różyński and Szmytkiewicz 2023). This artificial island, covering approximately 180 ha, was identified as the Coastal Unit within the Vistula Lagoon for application of the NB³ Framework. This unit, shown as the darker green shaded area in Fig. 7, was assigned the unique identifier *WE* and *Artificial Bird Island Construction* was specified as the NbS-driven restoration process (spatial extent available as *SpatialData_CoastalUnit_WE.geojson* (Arslan et al. 2026b)).

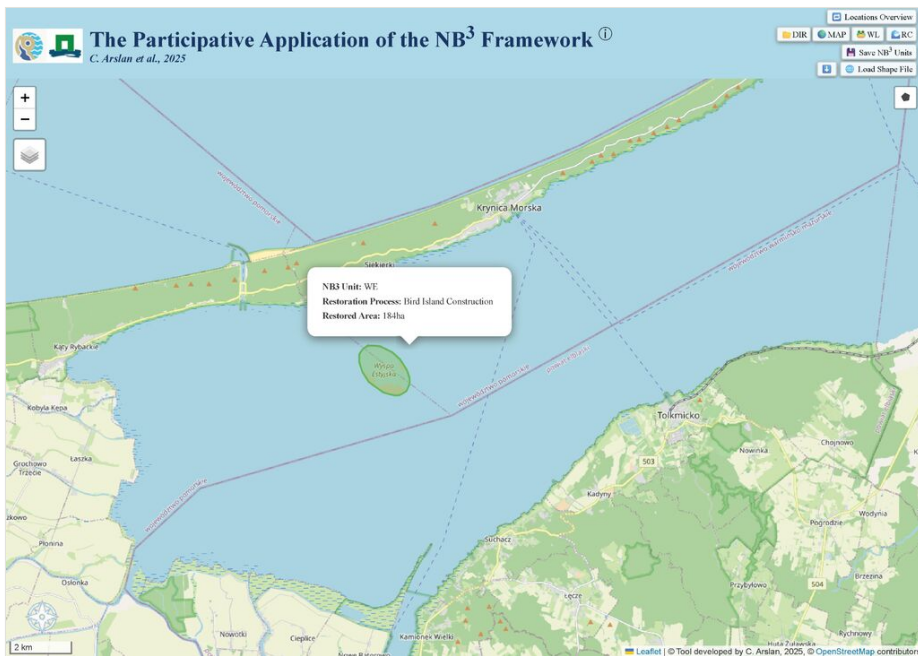


Figure 7.

The identified Coastal Unit, *WE*, within the Vistula Lagoon pilot site, shown as the darker green shaded area.

The Coastal Unit is subject to multiple environmental pressures of varying intensities, including habitat loss, long-term maintenance requirements and weak lagoon bed conditions. Drawing on local knowledge and previous implementation experience, stakeholders outlined a phased implementation concept comprising encirclement with Larsen sheet piles, gradual deposition of dredged sediments, managed revegetation and facilitation of natural succession (pressures, associated expert-based qualitative impact and implementation details in *Table3_CoastalUnit_WE.xlsx* (Arslan et al. 2026b)).

Key biophysical parameters

For the Coastal Unit under investigation, stakeholders identified a set of biophysical parameters reflecting historical degradation, prevailing environmental stresses, site-specific hydrological conditions and recent studies in the Vistula Lagoon. These parameters characterise interactions between the Coastal Unit and the NbS-driven restoration process, reflecting restoration design, implementation phasing and long-term effectiveness. The parameters are briefly described below in relation to the Coastal Unit and the NB³ Framework perspective, while detailed parameter values, units, data sources and locally relevant metadata are documented in *Table3_CoastalUnit_WE.xlsx* (Arslan et al. 2026b).

Wind forcing: Wind speed and wind direction reconstructed from historical air pressure maps. This parameter constitutes the primary atmospheric forcing input for wave modelling in the south-western part of the Lagoon.

Wave parameters: Wave energy and wave-induced currents derived from hydrodynamic modelling. These simulated parameters provide energy and current fields across the Lagoon, characterising site-specific hydrodynamic forcings relevant for determining wave action.

Wind-driven storm surge: Extreme wind conditions derived from long-term meteorological records. In combination with simulated wave parameters, this parameter is evaluated in determining wave action.

Wave action: Indicator of wind-driven variations in water level derived from wave parameters and storm surge. This parameter supports the assessment of wave exposure relevant for positioning, phased implementation and long-term maintenance of the Coastal Unit.

Bottom substrate - soft: Categorical substrate types in the Lagoon bed, influencing foundational stability relevant to construction and contamination-related safety for sediment deposition.

Carbon sequestration: Rate of carbon exchange per unit area derived from theoretical assessments, indicating the potential of the restoration in climate change mitigation.

Biodiversity: Indicators of ecological status for bird, fish and macrozoobenthos species aligned with NATURA 2000 designation. These indicators serve to evaluate restoration progress and ecological performance for the Coastal Unit:

Birds: Inventory of bird species and specimen counts derived from site inspections and monitoring campaigns;

Fish: Expert-based assessment of anticipated and observed restoration impacts on fish species;

Macrozoobenthos: Expert-based assessment of anticipated and observed restoration impacts on benthic fauna communities.

Key socio-economic parameters

For the Coastal Unit under investigation, stakeholders identified a set of socio-economic parameters reflecting governance dynamics, legal constraints and financial incentives influencing the restoration setting. These parameters characterise interactions between the Coastal Unit and the NbS-driven restoration process from management, economic and societal perspectives, outlining the institutional landscape relevant for NbS design, implementation and long-term maintenance. The parameters are briefly described below in relation to the Coastal Unit and the NB³ Building Blocks perspective, while detailed parameter values, units, data sources and locally relevant metadata are documented in *Table3_CoastalUnit_WE.xlsx* (Arslan et al. 2026b).

National funding: Total public budget allocated through direct state investment for implementation and maintenance of the artificial bird island.

EU funding: Project-based budget allocation, describing financial support for research and implementation activities associated with the Lagoon ecosystem, aligned with EU policy priorities and missions.

NATURA 2000: Regulatory and legislative requirements, directives and management plans, framing permissible interventions within the designated protected area.

Legal framework: Jurisdictional and legislative context at national and regional levels that may enable, regulate or constrain restoration activities associated with the artificial bird island.

Local economy: Qualitative diagnosis of regional economic conditions, indicating the relevance of the artificial bird island within the broader lagoon system.

Regional cooperation: Scholarly assessment of collaboration amongst regional governing bodies, reflecting effective governance potential relevant to site management.

Transboundary cooperation: Descriptive evaluation of cross-border collaboration arena, influencing lagoon-scale coordination capacity for integrated environmental management.

National and EU policies: Applicable legislative instruments supporting protection and restoration of the Lagoon's ecosystem and biodiversity, with provisions favouring the construction of an artificial bird island.

Transformative change: Expert-based evaluation of long-term impacts of construction and persistence of the artificial bird island on local communities.

Stakeholders' engagement: Four nominal categories reflecting stakeholder engagement inspired by the wheel of participation (Reed et al. 2018). This parameter describes the

level of participation and support of institutional, scientific and local stakeholders in planning and implementing restoration measures within the Lagoon.

Stakeholder-assessed ecological benefits

Stakeholders conducted an expert-based scoring of anticipated ecosystem service benefits associated with the artificial bird island construction within the *WE* Coastal Unit. The evaluation indicated the highest expected gain in *Food Production*, followed by a modest expected gain in *Water Purification*, while the remaining ecosystem services were rated as negligible. Notably, this provisioning service was evaluated specifically in relation to ecological food supply for bird species inhabiting the island, rather than for direct human use. These scores reflected the biodiversity-centred orientation of the restoration effort, prioritising habitat creation and species support over diversifying ecosystem services.

Complementing these scores, stakeholder narratives described the creation of new resting (e.g. mudflats) and breeding (e.g. grasslands) habitats for diverse bird species. These include endangered and target species in the EU Birds Directive and Polish Red Book. The narratives also highlighted the anticipated function of adjacent shallow waters as spawning grounds for the Lagoon's essential fish species.

Together, these scores and narratives position the artificial bird island as an ecological compensation addressing environmental pressures driven by navigation channel activities in the Lagoon.

Table3_CoastalUnit_WE.xlsx (Arslan et al. 2026b) provides detailed ecosystem service scores and biodiversity narratives, representing the stakeholders' baseline assessment of the current ecological status and projected restoration trajectory of the *WE* Coastal Unit.

Data Consistency and Framework-based Quality Assurance

The consistency and credibility of the dataset is grounded in the design and structured application of the NB³ Framework implemented through its two core methods (the NB³ Framework section), where spatial consistency was achieved through the Participatory Downscaling Approach and thematic consistency through the IPO model. Together, these approaches provided process-based credibility through a systemic translation of spatially-explicit pilot sites into comparable data records across pilots.

Data consistency was further strengthened through phased and iterative stakeholder engagement at each pilot, from the initial pilot workshops to the extended pilot applications (see Bilateral pilot workshops and Extending pilot applications sections). This iterative refinement, enabling spatial and contextual to be cross-checked, enriched and annotated, constitutes a form of framework-based quality assurance, enhancing transparency, accountability and internal coherence of the dataset.

The framework's inherent design requires, at minimum, stakeholder composition spanning natural and social sciences for its effective application. The REST-COAST project consortium supported meeting this requirement while further helping overcome a critical limitation of participatory studies — sustained participation — throughout the framework's application process. This structure also contributed to data consistency: alongside stakeholders' own knowledge and expertise, data generated across other REST-COAST work packages were integrated into the framework's application where relevant, providing an additional route for data integration that enhanced the quality of the data records. Across the three pilots, participation drew on technical and natural science expertise (e.g. coastal engineers, hydro-morphodynamic modellers, environmental consultants, marine and coastal ecologists, biologists, environmental researchers) and governance and policy actors (e.g. spatial planners, environmental managers, coastal authorities, NGOs). Pilot-specific contributions were additionally documented, while preserving participant anonymity, in the *Data Owners* field of the corresponding Coastal Unit's data table.

Beyond these participatory processes, the standardised attributes structuring each parameter (e.g. units, relevance to restoration processes, source types, metadata) act as an additional validation layer, transforming individual parameters into multidimensional data entries that constrain interpretation and increase granularity. As a result, the dataset's restoration units are both descriptive, enabling cross-pilot exchange and operational, remaining grounded in site-specific data, together, support commensurability and reuse in future NbS upscaling efforts.

Data Usage

The dataset comprises a portfolio of Coastal Units across the restoration pilots, each representing a spatially-explicit restoration unit integrating biophysical, socio-economic and ecological information. These units embed context-specific restoration processes supported by locally grounded evidence derived from scientific knowledge, policy frameworks and stakeholder input, while explicitly documenting data availability, knowledge gaps, disciplinary biases and contextual assumptions. The dataset is intended for decision-makers and practitioners engaged in coastal restoration and NbS upscaling within the pilot sites, including local and regional authorities, coastal managers, technical implementors and research organisations. In this way, the Coastal Units support the assessment of opportunities, constraints and trade-offs in restoration planning by translating complex local contexts into operational restoration units, thus functioning as a structural blueprint for NbS upscaling.

Co-developed with partners across the REST-COAST pilot sites around a shared objective of restoration upscaling, the dataset also functions as a benchmark for cross-pilot comparison. Coastal Units derived from the systemic application of the NB³ Framework provide a common reference against which restoration approaches, process priorities and expected outcomes can be compared and iteratively refined across pilots.

This establishes a structured basis for capacity building, mutual learning and the iterative refinement of best practices, supporting adaptive strategies for NbS upscaling.

Besides its immediate use value, the dataset represents an extensible foundation that supports ongoing participatory exploration of NbS upscaling. It constitutes an inventory of Coastal Units designed to be expanded within existing pilots and through the inclusion of remaining REST-COAST sites. In addition, the NB³ Framework provides a transferable set of methods and tools that enable data generation beyond the scope of the project, as demonstrated through ongoing applications (e.g. EU H2020 WaterLANDS project). This creates the potential to grow the dataset into a broader portfolio of Coastal Units, supporting comparative analysis and upscaling strategies across diverse contexts.

The upscaling potential of the NB³ Framework rests specifically on the modularity of its Coastal Units. Each unit, scaled down from a larger landscape perspective through the Participative Downscaling Approach, shares the same IPO model structure across its biophysical, socio-economic and ecological dimensions, rendering these units commensurable regardless of their local ecological context. This methodological consistency allows individual units to be positioned alongside one another within a larger landscape or across geographies not as isolated interventions, but as *building blocks* that can be combined in harmony through physical fluxes, institutional cohesion or ecological continuity, aligning with the connectivity of seascapes. The present dataset, with one Coastal Unit per pilot, reflects an initial step in this modular logic. As further units are identified, both within existing pilots and across new geographies, the resulting portfolio of commensurable Coastal Units is what ultimately support scaling restoration strategies from individual pilots to a connected, landscape-wide mosaic.

Limitations

The dataset presented in this paper is not normative of NbS implementations in the pilot sites, but rather functions as a structured blueprint for restoration upscaling — explicitly documenting site-specific characteristics, processes, targets and gaps relevant to effective large-scale coastal restoration. It is designed to provide information for restoration planning in advance by rendering data, knowledge, assumptions and biases spatially explicit and integrated across biophysical, socio-economic and ecological dimensions. As such, it supports evidence-informed decision-making, while recognising uncertainty.

As participation-driven output, the dataset reflects the composition and expertise of the stakeholders involved in the framework's application. Despite the participatory design aimed at ensuring internal consistency, stakeholder involvement was largely dominated by REST-COAST project partners. This resulted in observable disciplinary imbalances, where biophysical parameters were generally more detailed and elaborated, while socio-economic parameters persistently lacked comparable resolution and rigour (Arslan and van Loon-Steensma 2025). Related to this is the reliance on the high-quality, spatially-explicit data for identifying and characterising Coastal Units. Data availability varied

across pilot sites and disciplines, depending on historical research intensity and geographic context, as exemplified by the contrast between data-rich sites with long-term monitoring, such as the Venice Lagoon and under-studied sites with recently intensifying research, such as the Vistula Lagoon.

Additional limitations arise from contextual uncertainties inherent to restoration upscaling. These include persistent conflicts, diverging stakeholder interests, institutional and governance variability, resource constraints and physical limitations, which may amplify when moving from individual Coastal Units to landscape-scale restoration. These factors underscore the context-sensitive nature of the dataset and highlight the need for adaptive and iterative engagement with Coastal Units when grounding the dataset in restoration planning and NbS upscaling.

Data Resources

The data underpinning the analysis reported in this paper are deposited in the Zenodo Repository at <https://doi.org/10.5281/zenodo.19452085>.

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The authors have declared that no competing interests exist.

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