Ref. Ares(2024)3170694 - 30/04/2024

D6.5 Restoration Demo at Venice Lagoon

28/03/2024

WP6

Lead beneficiary: CORILA

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REST-COAST

Large Scale RESToration of COASTal Ecosystems through Rivers to Sea Connectivity

This project receives funding from the European Union's Horizon 2020 research and innovation programme, under Grant Agreement 101037097

Prepared under contract from the European Commission
Grant agreement No. 101037097
EU Horizon 2020 Coordination and Support Action

Project acronym:	**REST-COAST**
Project full title:	**Large Scale RESToration of COASTal Ecosystems through Rivers to Sea Connectivity**
Start of the project:	01.10.2021
Duration:	54 months
Project coordinator:	Prof. Agustín Sánchez-Arcilla, Universitat Politècnica De Catalunya (UPC)
Type:	Restoring biodiversity and ecosystem services
Call:	H2020-LC-GD-2020-3
Deliverable title	Restoration Demo - Venice lagoon pilot site
Deliverable n°	D6.5
Nature of the deliverable:	Report
Dissemination level:	Public
WP responsible:	WP6
Lead beneficiary:	CORILA
Citation:	Dabalà, C., F. Coccon, A. Rosina, P. Campostrini, F. Horneman, S. Torresan, A. Stocco, F. Pranovi, P. Comandini, A. Barausse, F. Scarton, D. Curiel, C. Miotti, A. Rismondo, M. Cianci, A. D. Ferrara, A. Mandarà, V. Volpe (2024). *Restoration Demo - Venice lagoon pilot site*. Deliverable D6.5. EU Horizon 2020 REST-COAST Project, Grant agreement No 101037097
Due date of deliverable:	Month n°30
Actual submission date:	Month n°30

Deliverable status:

Version	Status	Date	Author(s)
1.0	Final	27 March 2024	Dabalà Caterina (CORILA)

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Preface

REST-COAST is dedicated to demonstrating the potential of scaled-up coastal restoration as a sustainable, low-carbon solution for climate adaptation and disaster risk reduction in vulnerable low-lying coastal systems. By enhancing biodiversity and ecosystem services (ESS), the project aims at tackling key technical, social, financial, and governance challenges impeding restoration endeavours. Through the “Restoration Revolution” concept, REST-COAST aims at dismantling obstacles such as limited stakeholders’ engagement, economic uncertainties, and fragmented governance, thus facilitating extensive connectivity and the creation of climate-resilient habitats. REST-COAST seeks to showcase the benefits of coastal restoration by illustrating how active restoration measures contribute to supporting the increasing of biodiversity and delivering Ecosystem Services (ESS), referring to the valuable contributions that ecosystems make to human well-being (Potschin and Haines-Young, 2016).

Through a variety of dissemination and exploitation tools, WP6 “Dissemination/exploitation and social transformation tools” strives to ensure that all relevant socioeconomic sectors are provided with the necessary information to participate in and benefit from coastal restoration efforts.
This deliverable D6.5 describes the restoration interventions implemented in the Venice Lagoon pilot site. The main objective is to facilitate broad societal engagement in the envisioned Restoration Revolution. Through proactive communication efforts, each pilot site aims at producing and disseminating demonstrative materials, reports on ongoing restoration activities, and targeted promotional videos to diverse audiences, ensuring an effective communication of the importance and benefits of a widespread coastal restoration.

Summary

The REST-COAST pilot action to be implemented in the Venice lagoon consists in the restoration of already existing artificial saltmarshes located in the central/southern lagoon. These works aim at reversing the degradation processes occurring in the area and to improve some of the features that hindered the naturalization processes of these artificial structures. By mitigating saltmarsh border erosion and fostering conditions suitable to the subsequent colonization of vegetation and wildlife species, REST-COAST actions will enhance opportunities to expand priority habitat surfaces and bolster specific biodiversity.

The first phase of the Nature-Based Solutions (NBS) restoration intervention consists of the solid waste removal and the reparation of the degraded edges of the saltmarshes, to facilitate the subsequent naturalization process. This involves measures to promote water permeability and the creation of small water channels, alongside with the reshaping of the most elevated areas suitable for non-native vegetation species. Subsequently, the second phase entails nourishing saltmarshes with sediments sourced from canal dredging activities, ensuring their continued vitality and resilience. Therefore, as mentioned above, with these activities, the suitable conditions for a subsequent naturalization process (colonization from vegetation and use of the habitats from different wildlife species) of the morphological structures are created.

Within the REST-COAST project, the restoration of saltmarshes is studied to enhance the understanding of how these NBS can help to enhance ecosystem services (ESS) such as water quality purification, reduction of erosion and flood risk, climate mitigation through carbon sequestration and food provisioning, as well as biodiversity.
After the selection of a comprehensive set of indicators (e.g. marsh elevation, erosion rates, sedimentation, sediment compaction, loss on ignition, soil granulometry, vegetation cover and diversity, bird species presence, water quality, and seagrass cover and abundance), the monitoring activities started in 2023 and the first benefits in terms of ESS are expected as the naturalisation of the saltmarshes will occur.
Importantly, through the analysis of previous restoration activities, which in the Venice Lagoon are going on since the ‘90 years of last century, and the application of high-resolution spatial models on a lagoon scale, it will be possible to assess the effects of the saltmarshes restoration with a focus on the ESS provided by this unique lagoon habitat, and to identify the up- and out scaling restoration strategy.

List of abbreviations

ESS	Ecosystem Services
REST-COAST	RESToration of COASTal Ecosystems through Rivers-to-Sea Connectivity Project
WP	Work Package
BDV	Biodiversity
DB	Database
CORE-PLAT	COastal REstoration PLATform
PROVV	Provveditorato Interregionale per le Opere Pubbliche per il Veneto, Trentino Alto Adige e Friuli Venezia Giulia

1 Introduction to the Pilot Site

1.1 The Venice lagoon

1.1.1 Morphology and hydrodynamic

The Venice Lagoon (Italy), situated in the Northwest Adriatic Sea, is the largest lagoon in the Mediterranean, covering an area of approximately 550 km^2 (Janowski et al., 2020; Lionello et al., 2021). Its area is represented by 8% of land above sea level, including the city of Venice, littorals, reclaimed areas, weir fishing traps, islands, and embankments, while 92% of the surface forms the "water system," including channels (11.9%), shallows, mudflats, and saltmarshes (80.1%). It is connected to the Northern Adriatic Sea through three inlets called, from North to South, Lido, Malamocco, and Chioggia.
Originating during the Holocene transgression, the lagoon has evolved through constant interactions between natural processes (i.e. the natural tendency to silt up) and the artificial ones implemented by man, since the XV Century, to counteract these trends for maintaining the typical peculiarities of a land-sea transitional waters environment (Ivajnšič et al., 2018).
Its average depth is 1.2 meters, but the depth of the lagoon ranges between 10 and 20 m in the main canals, except for the Malamocco inlet, which is the deepest site of the Northern Adriatic Sea (ca. 50 m) (Tagliapietra et al., 2018). Morphological barriers, including the Malamocco-Marghera canal in the South and the saltmarshes of Burano and Torcello in the North, divide the lagoon into three hydrological basins (Sfriso et al., 2020).

Water renewal in the Venice Lagoon is vital for its metabolism, affecting salinity, oxidation, nutrient levels, and pollutant distribution (Ravera, 2000). Tides play a significant role in shaping the lagoon's morphology and driving water exchange, dissolved oxygen levels, salinity, nutrient distribution, and sediment movement (Tagliapietra et al., 2018). With mixed, predominantly semidiurnal and microtidal regime, the lagoon experiences an average tidal range of 61 cm and an intertidal range of 121 cm (Tagliapietra et al., 2018). The tidal sea-water exchange through the three inlets is approximately 1.46×10^9 m^3 at each tidal cycle (12 hr) (Gacic et al., 2005), which accounts for more than half of the entire water loading, although the water renewal in the inner, more protected, areas may take approximately 10-20 days (Cucco & Umgiesser, 2006). Meteorological surges often coincide with astronomical tides, resulting in significantly high tides during periods of low atmospheric pressure (Finotello et al., 2023).
The lagoon receives freshwater discharge from 11 major tributaries, along with several minor rivers and human-regulated channels primarily used for agriculture (Solidoro et al., 2010). The mean annual freshwater input from 24 tributaries is ca. 35.5 m^3 s^{-1} (Zuliani et al., 2005), carrying substantial nutrient loads, mainly due to intensive agriculture in the Veneto region (Solidoro et al., 2010). However, efforts to mitigate nutrient inputs have been made, leading to a reduction in nutrient loading and the eutrophication of the lagoon (Tagliapietra et al., 2018).

The hydrodynamics and morphodynamics of the Venice Lagoon are significantly influenced by major wind systems, with Bora (NE) and Scirocco (SE) as the main drivers (Carniello et al., 2009; Finotello et al., 2023; Janowski et al., 2020). These wind regimes superimpose a strong circulation on top of the tidal pumping action inside the lagoon, important for mixing and transport. They also create wind waves locally that are then responsible for the resuspension of sediments in the shallow parts of the lagoon and can enhance erosion phenomena on salt marsh edges (Umgiesser et al.,2004). Bora winds produce water-level setups in the southern lagoon and promote sediment resuspension from tidal mudflats, particularly during fall and winter (Carniello et al., 2009). In contrast, Sirocco winds cause water-level setups in the northern Adriatic Sea and often result in the flooding of settlements in the lagoon (Finotello et al., 2023). Sediment suspension on tidal flats is primarily induced by shear stresses from wind waves, with the Bora wind being the dominant meteorological condition affecting sediment dynamics (Carniello et al., 2009).

1.1.2 Main challenges

Despite the potential resilience capacity (understood as the system's ability to return to its original state after a disturbance), the Venice Lagoon is at risk of substantial loss of characteristic habitats, inevitably resulting in biodiversity loss and the depletion of ecosystem services. Indeed, the Venice Lagoon faces a myriad of challenges stemming from natural dynamics and human impacts. Despite longstanding efforts by Venetians, pollution, erosion, and biodiversity loss persist, exacerbated by the threats of global sea level rise and subsidence, jeopardizing both environmental and cultural assets (Solidoro et al., 2010; Carbognin and Tosi, 2002; Carbognin et al., 2009; Stocco & Pranovi, 2023). Human activities, including dredging, artificial channel construction and industrial development, notably Port Marghera, have further disrupted the lagoon's equilibrium, resulting in widespread environmental degradation. Consequences include diminished environmental quality, loss of self-purification capacity, reduced species diversity, heightened risk of shoreline damage, and navigational challenges. Currently, the lagoon sediment budget indicates a general tendency of sediment loss through the inlets of an overall value of $3.8x10^5 m^3$/yr (Defendi et al., 2010)./yr (Defendi et al., 2010).

In particular, the extent of saltmarshes has diminished by over 76% in the past two centuries, declining from 180 km2 to 43 km^2 in the present day (Carniello et al., 2009). The disappearance of saltmarshes is influenced by a multitude of physical and biological processes that dictate their evolution in both vertical and horizontal dimensions (Tommasini et al., 2019).

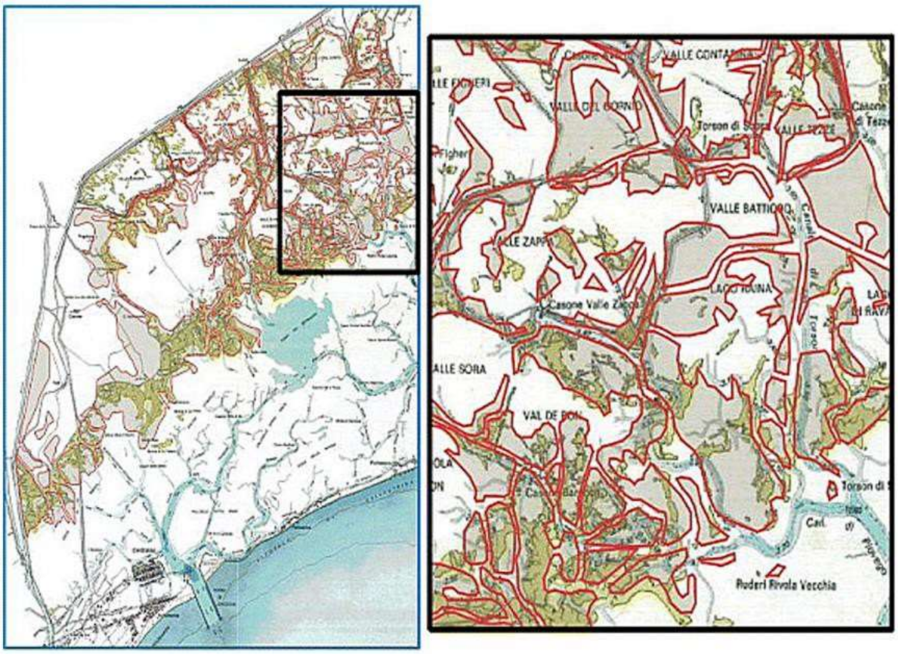

Figure 1: Loss of saltmarsh areas. Red lines bound the regions occupied by saltmarshes in 1901, the green regions inside the red lines represent the actual saltmarshes areas surviving in 1972 (Tambroni & Seminara, 2006).

In response to these trends, the "Venice Special Law" (Legge 16 aprile 1973, n. 171) enacted in the 1970s reflects the evolving priorities in managing and conserving the lagoon, emphasizing the need for protection and restoration of this unique ecosystem. Addressing these challenges requires comprehensive strategies. Therefore, since the 1990s, a variety of mitigation and adaptation interventions have been implemented. Restoration works conducted under these plans range from excavation of channels to the reconstruction of tidal flats and saltmarshes, to the re-naturalisation of lagoon areas and seagrass transplantations (Tagliapietra et al., 2018).

Central to these endeavours is the Provveditorato Interregionale per il Veneto, Trentino Alto Adige, Friuli Venezia Giulia (PROVV, Venice Water Authority), operating as a decentralized office of the Italian Ministry for Infrastructure and Transport. Endowed with direct responsibility for safeguarding, security, and hydraulic protection of the Venice Lagoon, the PROVV assumes a pivotal role in the restoration and preservation of its habitats. Through a multifaceted approach, encompassing defence mechanisms against high waters, such as the MOSE System[1], and environmental NBS initiatives, like dredging of lagoon channels and saltmarsh reconstruction, the PROVV actively upholds the ecological resilience and vitality of the Venice Lagoon ecosystem.

Recent endeavours have witnessed a concerted focus on innovative methodologies, including low-impact soil bioengineering techniques for saltmarsh restoration and the transplantation of seagrasses, reflecting an unwavering commitment to the enduring sustainability of this singular environment. The General Plan of Interventions addresses a comprehensive range of state-mandated activities aimed at the physical and environmental protection of Venice and its lagoon.

It is important to highlight that in the Venice Lagoon, the sediment input allowing for the maintenance of saltmarshes alongside sea level rise occurs during high water events. Saltmarshes are morphological structures typical of tidal environments, such as lagoons and estuaries, characterized by elevation levels ranging between mean sea level and the highest tidal levels. For this reason, they are periodically submerged by tides, but not submerged most of the time. The rise in mean sea level can compromise their survival if they are unable to grow vertically.

While the use of the MOSE system mostly solves the issue of high waters, it may have an impact on the morphological evolution of the lagoon in general, and on the saltmarshes in particular. By blocking tides with a predicted level exceeding 110 cm, the MOSE system will significantly reduce sediment input from the inlets and consequently it will impact negatively on the growth rates of saltmarshes, with worrying consequences for the conservation of the lagoon ecosystem (Tognin et al., 2021). The contribution of high-water events to saltmarsh accretion, and the modification resulting from the use of MOSE, has been quantified: the closure of mobile barriers at the current safety thresholds of 110 cm will lead to a reduction between 25 and 30% in annual sedimentation on saltmarshes (Tognin et al., 2021). This reduction, combined with other phenomena triggered by weather and marine conditions, promote erosion in lagoon environments and therefore strongly affects the survival of saltmarshes in the lagoon, unless conservation interventions are implemented, through the artificial reconstruction/restoration of saltmarshes and tidal flats.

[1] MOSE system aims to defense the settlements in the Venice Lagoon from flooding by separating the sea and the lagoon during the most intense marine weather phenomena that cause a rise in sea level, temporarily and for the necessary duration.

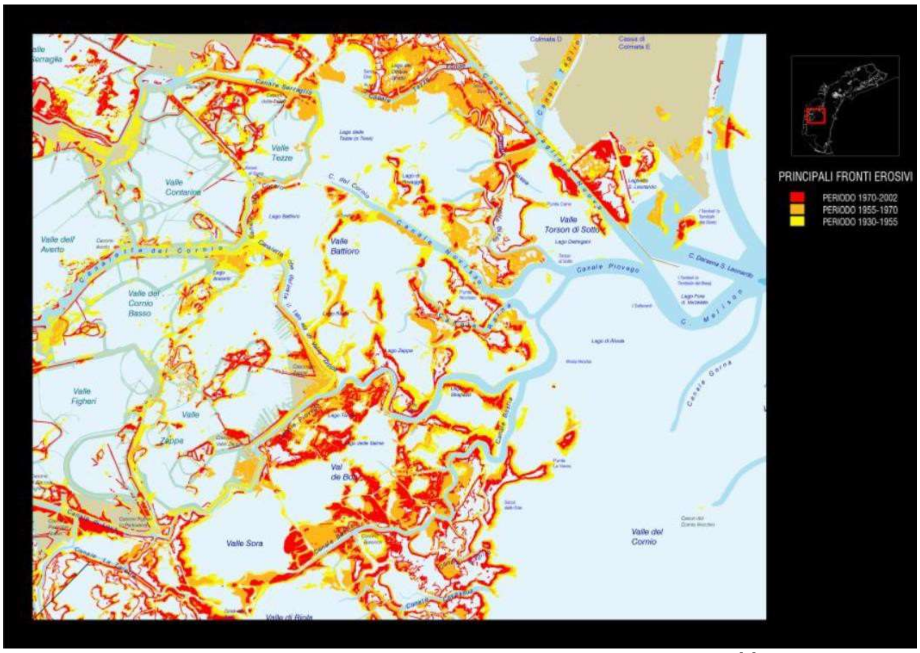

Figure 2: The main erosive fronts in the REST-COAST pilot site (source https://www.mosevenezia.eu/).

Saltmarshes also serve as 'blue carbon' sinks, a result of their primary production combined with rapid surface accretion. While organic carbon stocks and accumulation rates vary significantly among different marshes due to factors such as organic and inorganic inputs and preservation conditions, recent estimates indicate that the saltmarshes can sequester carbon equivalent to that absorbed by 130.000 trees. However, flood regulation measures may reduce the annual CO_2 sequestration potential of marshes by up to 33% (Puppin et al., 2023).

1.1.3 The Venice Lagoon ecosystem

The lagoon of Venice is designated as a Special Protection Area (SPA) covering the entire lagoon, with four Sites of Community Importance (SCI) strategically positioned around the inlets (Figure 3). Recognized as a World Heritage site since 1987, the Venice Lagoon stands as a testament to the importance of preserving its unique ecological and cultural significance.

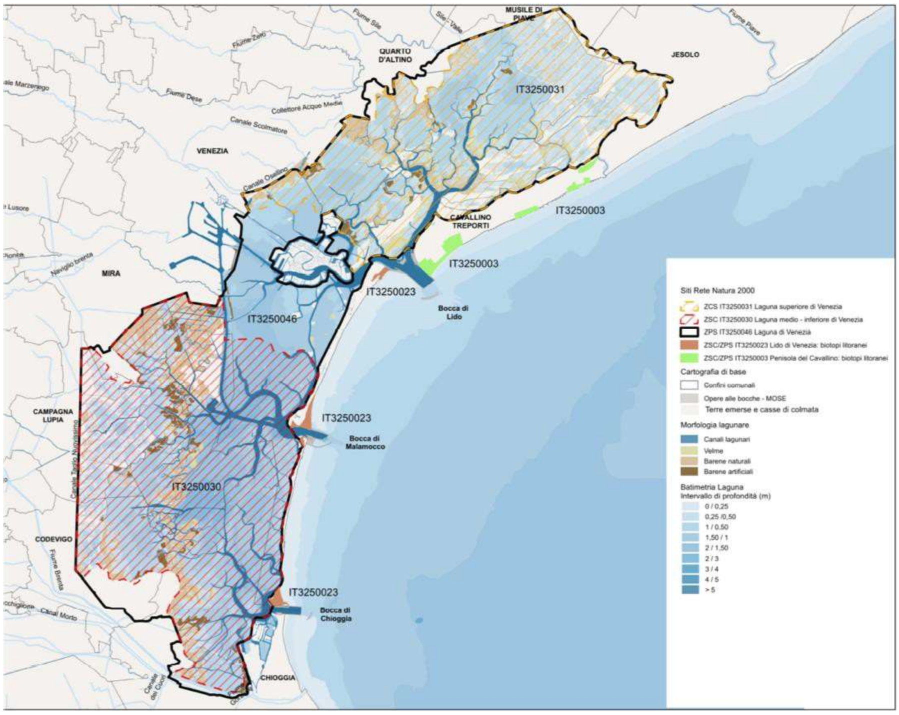

Figure 3: N2000 Sites in the Venice Lagoon.

The actual morphology of the Venice Lagoon encompasses different habitats, whose distribution depends on the hydrodynamic regime (Sfriso et al., 2020; Tagliapietra et al., 2018). This dynamic interaction creates a complex mosaic of coastal environments, including saltmarshes, seagrasses, wetlands, mudflats, islands, and ponds (Carniello et al., 2009; Ravera, 2000; Rova et al., 2022; Solidoro et al., 2010). These habitats give the lagoon a varied ecological environment (Sfriso et al., 2020), characterized by intense dynamics and a great spatio-temporal diversity in ecotone environments. In the typical environments of the Venice Lagoon, both emerged and submerged, diversity and functionality are the result of marine and continental inputs, as well as present and historical human interference (Ivajnšič et al., 2018).

In the Venice Lagoon, where ecological restoration efforts have been ongoing for decades, it’s crucial to distinguish between natural habitats with their inherent geomorphological origins and those that have been reconstructed or artificially created to imitate natural habitats (Tagliapietra et al., 2018); in particular, Venice Lagoon covers 6.000 ha of seagrass, about 6.800 ha of natural saltmarshes and mudflats and 1.600 ha of artificial morphological structures (i.e., artificial saltmarshes and mudflats).
Next image shows EUNIS habitats in the Venice Lagoon pilot site (from REST-COAST Deliverable 4.1).

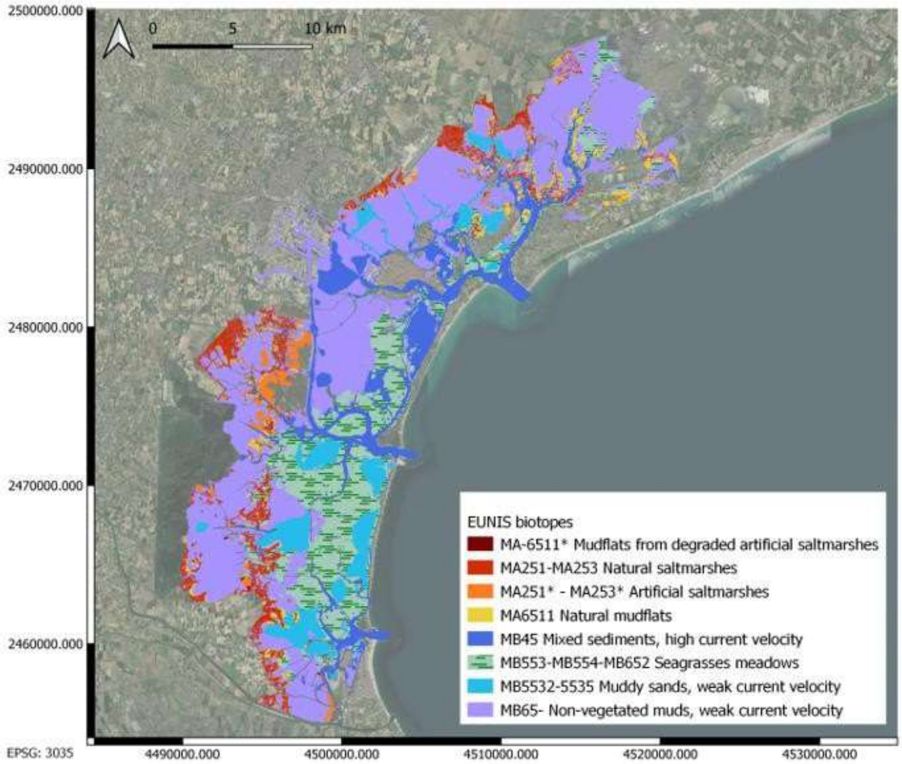

Figure 4: EUNIS habitats in Venice Lagoon.

Limonium narbonense, *Salicornia europaea, Salicornia veneta, Salicornia procumbens subsp. procumbens*, *Arthrocaulon macrostachyum*, *Sarcocornia fruticosa*, *Halimione portulacoides*, *Puccinellia festuciformis*, and *Spartina maritima* are the main saltmarsh species which dominate the extensive intertidal plains of the Venice Lagoon. These communities hold significant conservation importance due to their large spatial coverage, high productivity, and significance for vegetation and breeding bird populations. However, research has indicated a declining trend in these valuable and protected habitats, with their extent decreasing from approximately 12.000 hectares at the turn of the century to around 4.000 hectares today, attributed to amelioration, erosion, and natural or human-induced processes causing significant morphological changes in the lagoon (Carniello, Defina, & D'Alpaos, 2009; Day et al., 1998), independent of considerations regarding climate change and sea level rise.

Marine seagrasses play an important role in the ecology of coastal areas, for example sustaining biodiversity and providing habitat for numerous species, baffling wave energy, enhancing sedimentation and stabilize sediments (Fonseca & Kenworthy, 1987; Sfriso et al. 2004; 2005). For this reason, their presence is an important factor that contributes to reduce saltmarshes erosion. The latest Venice lagoon seagrasses distribution map (2017) (OO.PP.-KOSTRUTTIVA-SELC, 2018) showed a total meadows coverage of 6,796 ha, corresponding to 21.9% of the lagoon seabottoms. The vegetation patches highlighted a high degree of differentiation, for species composition, extension and distribution in the three lagoon basins (north, central, and south). The analysis of the results showed that over 70.1% of the seagrasses meadows are in the southern basin, 19.3% in the central one and 10.6% in northern one, with coverages distributed among 5 seagrass species: *C. nodosa*, *Z. marina*, *Z. noltei*, *Ruppia maritima* and *Ruppia cirrhosa*.

The lagoon of Venice is an area of outstanding importance for the birds, especially for waterbirds. Indeed, it represents the largest Important Birds Area (IBA) in Italy, boosting a diverse array of species of Community interest that require preservation. More than 300 species have been observed so far, while between

400.000 and 500.000 birds regularly spend the winter among about 20 fish farms, the open basin and along the littoral strip (Basso & Bon, 2016-2020).
Similarly, a huge number of species nest among the many lagoon habitats, from the sandy beaches to saltmarshes, both natural and man-made, islands, and fish farms. Very few recent data were published for birds who cross the lagoon during spring and autumn migration, apart from the results coming from ringing activities made in some fish farms and dealing mostly with Passerines (Sattin, 2019). Estimates of the number of birds overstaying at the lagoon of Venice during their migration journeys have never been attempted, but most likely these must be in the order of several hundreds of thousands.
Among the nesting birds, the waterbird community in particular is known fairly well; the open basin hosts each year between 3.000-3.500 pairs of several species, including some of conservation importance, due to their inclusion in the Annex I of the EU 147/09 Bird Directive, in the Italian Red List with the status of "threatened" (Rondinini et al., 2022), or because they have a scattered or restricted distribution throughout Italy (Scarton, 2017). In the 10.000 ha of fish farms, several species are nesting as well, but in this case only unpublished data are available, or the information refer only to some limited area.

1.2 REST-COAST pilot site

The NBS restoration intervention in the Venice lagoon pilot focuses on some artificial saltmarshes located in the central/southern part of the Venice lagoon, in the Municipality of Campagna Lupia, with the aim of accelerating the naturalisation processes for increasing priority habitats and biodiversity and enhancing the ecosystem services provided by them.

In this pilot site, all the five ESS and the BDV targets (habitats and species of conservation interest), selected in the REST-COAST project, as representative of urgent coastal problems, are considered: FP: Food (fish) provisioning; CR: Climate change regulation; WP: Water quality purification; RF: Reduction of coastal flooding risk; RE: Reduction of coastal erosion risk. Effectively, the main problems (Figure 5) addressed by the specific upscaling NBS restoration interventions in the Venice Pilot are (see REST-COAST Task 3.3):

- erosion,
- relative sea-level rise,
- loss of sediments,
- loss of habitats,
- loss of biodiversity,
- solid waste accumulation.

According to the stakeholders' perception, erosion and relative sea-level rise are considered to be the primary issues, causing significant challenges for all, policy makers, scientists, stakeholders and inhabitants of the Venice lagoon. Specifically, they result in:

- Loss of land, threatening the stability and altering the shape and size of emerged territories.
- Morphological changes: coastal and lagoon erosion can cause significant changes in landscape, influencing sediment distribution and marine currents dynamics.
- Increased vulnerability to storms: eroded lagoon areas are more susceptible to storm impacts, including flooding, accelerated erosion, even due to wind, and damages to infrastructures.
- Damage to ecosystems: natural habitats are degraded, resulting in biodiversity loss and damage to delicate ecosystems such as saltmarshes.
- Impact on fishery activities: fishing activities, especially the traditional ones by local communities, may be affected by erosion, reducing habitat availability for fish community.
- Risk to buildings and infrastructures: the erosion creates risk to buildings and infrastructure, requiring costly protection and need for maintenance.

- Impact on tourism: eroded habitats can diminish the attractiveness of the environment, negatively impacting local economies and residents reliant on tourism.
- Loss of cultural heritage: erosion threatens historical and cultural sites, resulting in the irreversible loss of cultural and archaeological heritage and in the need of maintenance works.

Figure 5: Some examples of the main problems on the saltmarshes in the Venice lagoon: erosion (left) and solid waste accumulation (right).

1.2.1 REST-COAST Pilot actions

The REST-COAST NBS interventions concern 8 existing "artificial" saltmarshes, located within two protected zones, the ZPS IT 3250046 and the SIC IT3250030, and realized during the last 20 years in the central part of the lagoon. The chosen marshes were relatively mature, meaning the sediment initially pumped had the time to completely settle and consolidate and the natural processes of boundary degradation have already occurred. The "active maintenance" is essential in the long-term plan of maintaining the intertidal lagoon habitat and similar interventions will be extended also to other areas in the future.

The restoration plan in the Venice lagoon involves an overall surface of 103 ha of artificial saltmarshes (Figure 6, Table 4). In particular, 91 ha are related to the REST-COAST project (represented with green stripes on the map below), while 12 ha are related to the saltmarshes of the H2020 WATERLANDS project, which are located in the same area.

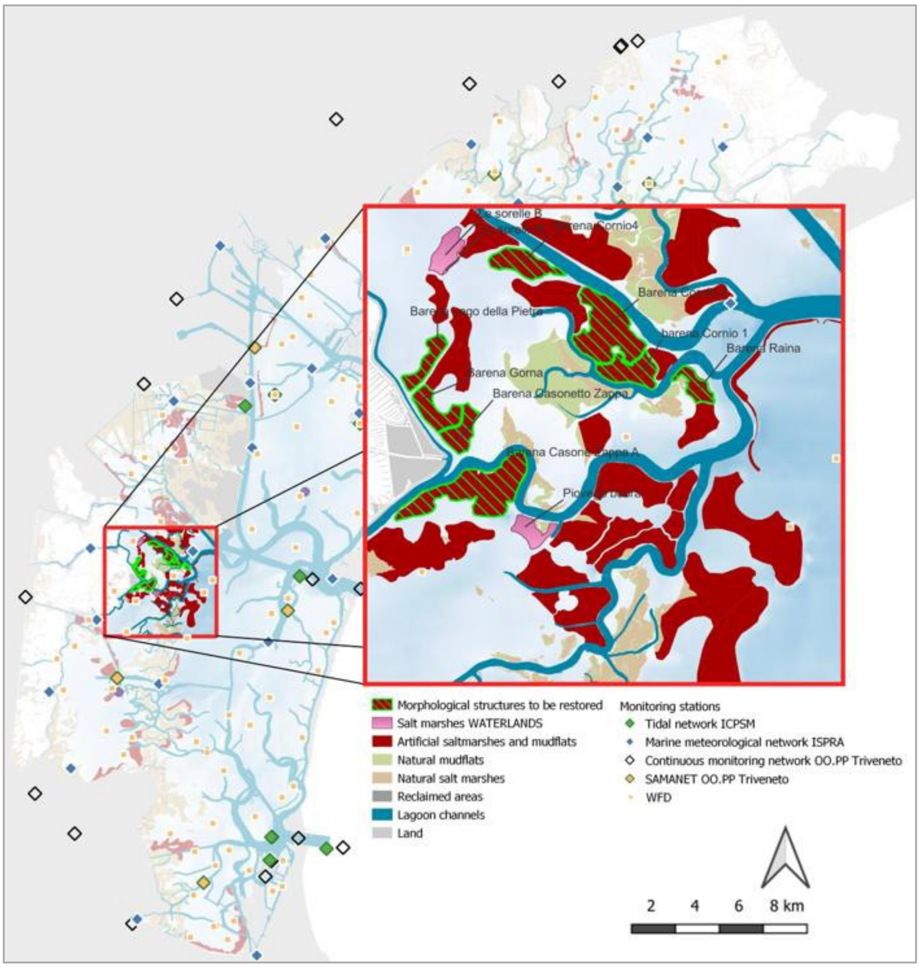

Figure 6: Location of the REST-COAST pilot site in the Venice Lagoon, highlighting the saltmarshes subjected to restoration within the REST-COAST project (in green), and the existing monitoring lagoon network.

The saltmarshes within the pilot site are interspersed with channels, shallow water areas and mudflats, deriving both from degraded artificial saltmarshes and natural mudflats originated along the borders of natural saltmarshes.

Before starting the restoration works in the saltmarshes, some preliminary investigations have been performed (topographic surveys, assessment of boundary conditions, and environmental surveys such as the monitoring of vegetation and bird species) to detect the "zero state", necessary for the comparison of the situation before (*pre* phase) and after (*post* phase) the intervention.

Restoration interventions planned in the Venice pilot, which started only last April and will last for 1 more year, are aimed at the active maintenance of already existing morphological structures to promote their re-naturalization process through the following activities:

- 0 phase (April 2023). Removal of solid waste, both abandoned ones arrived with the current and those deriving from the previous construction sites.
- 1st phase (May 2023 - April 2024). Interventions to protect the edges of the saltmarshes through:
    - replacement of part/sections of the piles and the use of gabions (hereafter called "burghe"),

    - creation of more water-permeable margins and openings to favour the entrance of the water and the consequent development of a tidal channel network (small creeks called “ghebi”),
    - reshaping of the areas of the saltmarshes with a higher elevation, as they are covered with a vegetation not typical of the natural saltmarshes and might host alien plant species.
- 2nd phase (Still not officially defined). Nourishment of the saltmarshes with sediments coming from the dredging of the canals.

According to the pilot team perspective, the level of relevance of the above described NBS is high not only because restoring artificial saltmarshes increases biodiversity and provides a number of ESS, but also for the possibility to use these interventions as “in-field experiments”, to introduce improvements in the techniques that can be adopted in future restoration works in the lagoon. In addition, the monitoring measurements taken during this restoration activity will provide the basis of modelling activity that in the future can be used to better understand the NBS upscaling potential.
In particular, the restoration of the saltmarshes (e.g. the REST-COAST artificial saltmarshes) will contribute to facing the main issues listed above by:

- avoiding the disappearance of the degraded morphological structures (both natural and artificial);
- contrasting the erosion process and the negative trend of loss of sediments in the lagoon;
- attenuating the wave motion and reducing its effects on the shores;
- creating new habitats for wildlife, e.g. for birds, thus improving biodiversity.

1.3 Indicators used for assessing the restoration benefits, and some preliminary results

A set of indicators was selected to identify those that can be used in the field to measure the effectiveness of the restoration activities performed in the lagoon (i.e., restoration of artificial saltmarshes) and their impact on the five selected ecosystem services. These indicators include marsh elevation, erosion rates, sedimentation, sediment compaction, loss on ignition, soil granulometry, vegetation cover and diversity, bird species presence, water quality (dissolved oxygen, turbidity, temperature, and nutrients), and seagrass cover and abundance, and are shown in the table below grouped by the related ESS.
Additionally, the possible influence of the restoration interventions on the ES food provisioning will be evaluated through expert-based estimate, based on both expert opinion and available data reported in scientific literature.

Subsequently, the monitoring protocols have been developed, building on experience from previous monitoring activities carried on in the Venice Lagoon, to ensure continuity and comparability in the data to be obtained. These protocols are collected and summarized in the next table detailing the links between the ecosystem services, the indicators (e.g. assessment metric), and monitoring approach (including technical details) (Table 1).

According to these protocols, the field survey and geospatial exploratory analysis began in 2023, but not simultaneously, and are still in progress. Preliminary results for activities started earlier (such as seagrasses and birds monitoring) are already available and should be considered as information related to “pre” and “during” restoration activities. Other monitoring activities (e.g. sediments analysis and vegetation cover) started only last December, due to bureaucratic delays related to the tenders, and the data analysis is still on going.

Table 1: Indicators, monitoring methodology and starting date.

ESS	Indicator	Monitoring tool	Monitoring description
Reduction of coastal erosion and flooding risk	Erosion / elevation	GNSS survey	High precision GNSS/GPS survey of r micromorphology such as creeks) ar
	Sedimentation	Field surveys (Transect of sediment traps measured by walking from marsh edge to interior)	Circular sediment traps placed in a t interior whose content should be we
	Sediment compaction	Field surveys (5 markers per marsh at plots with originally no or scarse vegetation	Metal markers (50x50cm) that allow of the tickness of the sediment with marker, or kaoline markers (40x40cr measurement of the tickness of the
Climate change mitigation	Vegetation cover	Field surveys + high-definition flight images (drone)	Surveys by foot within the marshes t by plants as well as the presence, di the plant species
	Loss of Ignition and soil granulometry	Field surveys (12 locations per marsh distributed over the edges and interior)	Soil samples (8 cm^3) collected at 3 cr (for granulometry) using fixed GPS lo dried at 60 °C for 36h after which th performed (temperature increase of °C, and continues at a constant temp difference in weight is used to estim the subsequent organic carbon thro by Craft et al (or the Venice adaptati
Water quality purification	Water quality (temperature, salinity, turbidity, dissolved oxygen). The monitoring of chlorophyll-a, nutrients, pH is envisioned for the future, based on the requirements for the future modelling activities	In continuous probes or sampling campaigns	

This project receives funding from the European Union’s Horizon 2020 research and innovation programme, und

ESS	Indicator	Monitoring tool	Monitoring description	Starting time
	Bird species presence abundance and distribution	Field surveys (Visual censuses + high-definition drone images)	Surveys in both the lagoon basins by boat at the tide peaks to detect the position and composition of the flocks, with particular attention to roosting and feeding sites. For breeders, focus only on the central lagoon. Surveys by boat to detect the colony and visits to the colonies 3 times x breeding period by walking inside the marsh to count the active nests	February 2023
	Seagrasses coverage	Field surveys + samples analysis in lab.	Samples in the selected area and taxonomical determination, the relative coverage percentage and the total biomass. Mapping of the spatial distribution of the different species in the area	May 2023

This project receives funding from the European Union's Horizon 2020 research and innovation programme, under Grant Agreement 101037097

The restoration activities in the selected artificial saltmarshes are still ongoing, with an estimated completion time in 2025 (cfr. Cap. 3.1).

1.3.1 Ongoing REST-COAST monitoring activities, methods and some preliminary results

1.3.1.1 Sedimentary dynamics and vegetation cover

The data collection aims to capture differences in sedimentary and vegetational dynamics across various morphological types within the study area, before and after planned environmental restoration interventions.

The investigations are conducted across 10 study areas (sampling stations), each with an identified transect covering different elevation, inundation, and vegetation conditions. Along each transect, 3 monitoring stations will be established, with measurements taken at each station replicated three times.

The monitoring plan involves:

- tracking sedimentation rates using devices over 2-week periods, with analysis focusing on weight and organic content, repeated 10-14 times annually over three years;
- assessing sediment compaction through reference markers, allowing measurements of sediment thickness in relation to transects;
- collecting surface samples for sediment analysis before and after restoration interventions, with granulometric and organic carbon analyses;
- mapping vegetation cover dynamics using detailed methods, supplemented by drone flights, and conducting surveys at different scales depending on vegetation cover.

The sampling stations are located in (Figure 7):

- Natural control stations, consisting in two saltmarsh areas: one exposed site and another protected and far from the main channels, showcasing a more natural morphological sequence.
- Artificial stations, located on existing structures slated for recovery, identified as representative sites with varied conditions, prioritizing those at higher elevations and with limited vegetative cover.

The result is a total of 8 transects on artificial saltmarshes (represented with yellow circles in the map) plus 2 in the natural area (white circles).

The initial samples have been gathered; however, the chemical analysis is still in progress.

The vegetational analyses are scheduled to commence with the onset of the next vegetative season and will continue until autumn. This timing is essential as observations need to be conducted during periods of active growth and development to yield accurate results. By aligning the monitoring activities with the natural growth cycles, we ensure that the analyses capture the full spectrum of vegetation dynamics, thereby providing valuable insights into ecological processes.

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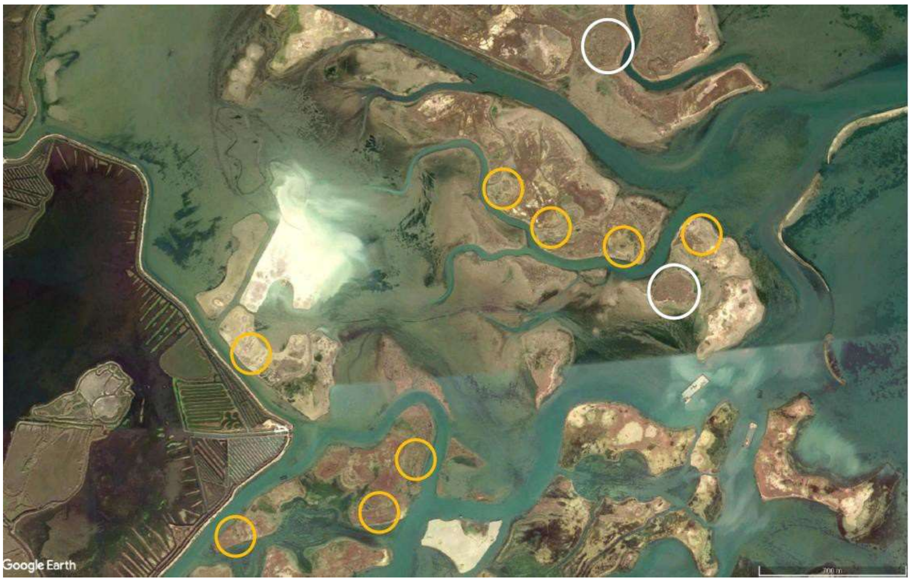

Figure 7: Location of the transects in the artificial saltmarshes (in yellow) and 2 in the natural ones (in white).

Figure 8: Sedimentation field activities: compaction measurement plates (about one month after installation); Petri dishes for deposition measurement are also visible.

1.3.1.2 Water quality monitoring

Within the REST-COAST pilot area, between April and July 2023 three probes have been installed for measuring dissolved oxygen and three for measuring turbidity, with both types of probes also measuring water temperature (Figure 9). This monitoring is conducted to assess the effects of construction activities on the surrounding waters and, where possible, the medium to long-term effects of the morphological restoration itself. In addition to these monitoring activities, some modelling is envisioned that focuses in particular on the water quality purification service provided by saltmarshes through the interaction between vegetation and nutrient dynamics. Additional future monitoring is expected, allowing for the evaluation of the impact of saltmarsh restoration during and after the naturalisation process occurs.

Figure 9: The 3 sites for water quality monitoring.

Figure 10: The positioning of the probes for measuring dissolved oxygen and turbidity.

Dissolved oxygen values exhibit predictable trends throughout the year, with a decrease in average dissolved oxygen levels from mid-summer to early autumn and significant daily fluctuations.
However, issues have been encountered with turbidity data. The sensors have been temporarily removed from the field for calibration and will be repositioned as soon as possible.

1.3.1.3 Birds' monitoring

The first bird surveys in the REST-COAST pilot area were carried out in spring-summer 2023, that corresponds to the reproductive period for most of the species. The surveys focused on the 8 artificial saltmarshes and on the natural saltmarshes nearby. and they have been carried out by boat by two experienced ornithologists, estimating the number of nesting pairs of each species of waterbirds, i.e., waders, ducks, gulls and terns. Once identified the colonies, a count of the "active nests", with particular

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attention to the species of conservation interest, has been performed by walking inside the saltmarsh. Each colony has been visited three times in the period May-July. To support the visual censuses, high-definition drone images have been also used.

The preliminary results showed that, among the 8 studied artificial saltmarshes, those named Cornio 2 and Casone Zappa A hosted the largest number of breeding pairs, mainly belonging to the Yellow-legged Gull, *Larus michahellis*, representing the 86% of the pairs recorded. These two saltmarshes are both characterized by vast extensions of halophilic vegetation. The remaining sites had less than 30 pairs, with Cornio 4, hosting just two. The second most abundant species was the Oystercatcher, *Haematopus ostralegus,* (15 pairs detected) that was found at seven out of 8 artificial saltmarshes, thus becoming the most widespread species. The remaining five nesting species occurred with very few pairs, ranging from 12 pairs for Redshank, *Tringa totanus*, to just one pair of Shelduck, *Tadorna tadorna*.
With regards to the nearby natural saltmarshes, results showed that a few species were nesting in these sites, with a limited number of pairs. The most abundant species was the Redshank, with around 30 pairs, followed by Little Tern, *Sternula albifrons*, with similar numbers. All the remaining species had less than 25 pairs each.

Figure 11: On the left, a Redshank while brooding the eggs. On the right side, some Little Terns in the colony settled on a natural saltmarsh. Frame from the videos recorded in June 2023.

The map of distribution and relative abundance of Oystercatcher, as an example is shown in Figure 12. The whole population of the Oystercatcher in the open basin of the Venice lagoon was estimated in around 180 pairs in 2018 (Scarton & Valle, 2021), while in Italy the value ranges between 300 and 400 pairs (Scarton, 2022); thus, in the study area nests between 5-10% of the Italian population of this species.
During monitoring activities, twenty-eight pairs of this species were estimated, about half in the artificial saltmarshes, while the remaining in the natural ones. On artificial saltmarshes, the Oystercatcher nests are usually on the top of small mounds, slightly more elevated than the remaining surface; this choice allows to avoid the exceptional high tides, such as the one occurred the 14th of June that swept away most of the colonies of the other species.

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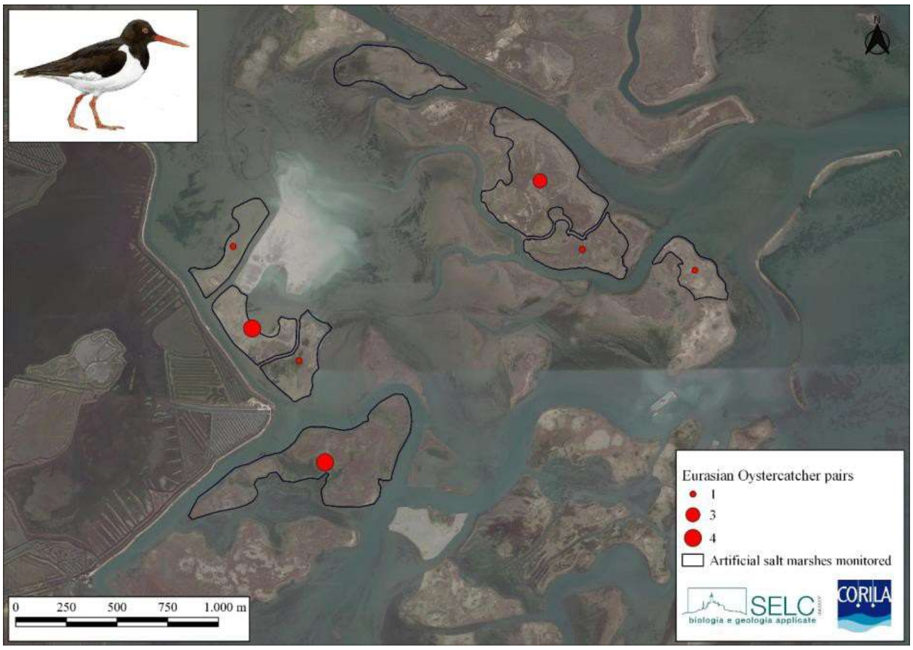

Figure 12: Number of Oystercatcher pairs nesting at the eight artificial saltmarshes.

Other monitoring activities carried out so far involved the counts of birds at the roosts present in the northern and southern lagoon. In the same period (February to July 2023), bird monitoring campaigns, revealed a significant presence of birds in both the basins (Figure 13).
In the northern lagoon, there was a considerable decrease in the abundance of individuals counted at the roosts during the reproductive period compared to the results obtained in the previous months. During the nesting period certain roosts were notably preferred to others, likely due to factors such as low predation risk and disturbance levels, distance from feeding sites, and habitat structure. In the southern lagoon, some roosts appeared slightly more frequented during the nesting period due to favourable nesting characteristics for certain species. A clear decrease in bird numbers was observed after the pre-breeding migration, similar to the pattern observed in the northern lagoon.

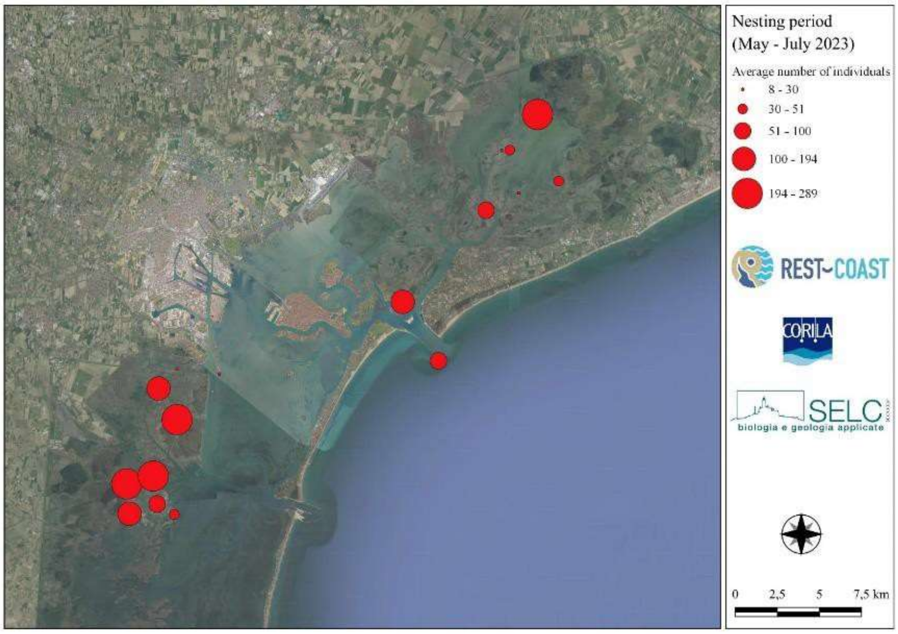

Figure 13: Average abundances recorded at roosts during the nesting period (May-July 2023).

In total, 46 species were counted in the target period. Among the waders, the most abundant species in the roost counts was the dunlin, *Calidris alpina*, with an average of 12.793 individuals for the entire period and 25.572 if we only consider the months of pre-reproductive migration (February-April), followed by the Grey plover, *Pluvialis squatarola*, with an average for the entire period of 401 individuals, and the Eurasian curlew, *Numenius arquata,* with 336 individuals.

Apart from roosts, four tidal flats were also surveyed. Here, almost all the individuals observed were engaged in feeding activities, while only a small number were resting or engaged in other activities.

The findings of this first survey period, although very preliminary, confirm the importance of the tidal flats of the lagoon for the feeding and sustenance of various species of waders and other aquatic birds, as observed often elsewhere (Masero et al., 2000; Zöckler et al., 2019). More recent surveys were done between August 2023 and February 2024; the preliminary results indicate a density of 5-15 birds/ha, a value comparable with that of other European wetlands.
Most of the times at every tidal flat, a few clam collectors were found; the effects of the artisanal or professional clam collecting on birds using the same tidal flats has been studied elsewhere (Dias et al., 2008), while this topic has received very little attention so far in the lagoon of Venice and should be investigated. However, further information on factors affecting the abundance and distribution of the birds in the Venice lagoon is summarised in Annex 2.

1.3.1.4 Seagrasses coverage monitoring

The 2023 mapping of the project's area included mudflats, shallows, natural and artificial saltmarshes and navigable channels (the last ones not mapped) and highlighted a seagrass meadows extension of 347,9 ha (288,4 ha of pure meadows and 59,5 ha of mixed ones), corresponding approximately to 24% of the investigated area (Figure 14), with various species such as *Zostera marina*, *Z. noltei*, *Cymodcea nodosa*, and *Ruppia* identified.
These meadows exhibited distinct distribution patterns, with *Zostera noltei* thriving in both open lagoon areas and internal zones, while *Ruppia* preferred shallower habitats within artificial or natural saltmarshes.

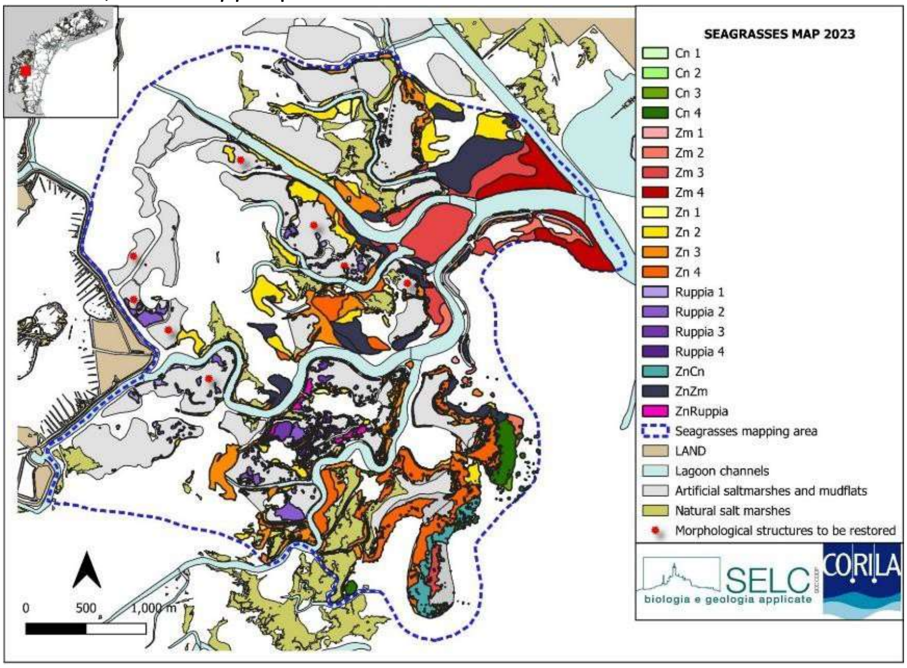

Figure 14: Marine seagrasses distribution map: 2023 survey.

Over the years, changes in habitat morphology due to natural and anthropic factors have influenced seagrass coverage, with a notable decline observed until 2010 followed by a significant recovery by 2023, particularly in *Zostera noltei* meadows. This resurgence highlights the potential for restoration efforts, with *Ruppia* showing promising colonization in planned REST-COAST restoration sites like the Casone Zappa and other saltmarshes. Overall, the 2023 mapping underscores the dynamic nature of marine habitats in the Venice lagoon and the importance of ongoing conservation and restoration initiatives.

Table 2: Main characteristics of marine seagrasses meadows distribution in the survey area in 2023.

Zostera noltei	Wide distribution range, from the "open lagoon" areas to the more internal ones, especially on low bathymetric levels: primarily the mudflats and secondarily the connecting sections between the always-submerged shallows and the mudflats. It can colonize even large sectors of artificial saltmarshes with bathymetric levels similar to mudflats' ones, adequately vivified by tidal channel network ("ghebi") or tides. Often in mixed meadows with other species.
Zostera marina	Widespread particularly at depths of 1-2 m in the "open lagoon", up to the edges of the saltmarshes or the gabions ("burghe"). *Z. marina* mixed meadows, especially associated with *Z. noltei*, were located from the always-submerged shallows up to the transition areas between shallows (always submerged) and mudflats.
Cymodocea nodosa	Limited distribution area of pure meadows: almost exclusively located in the "open lagoon" on the always-submerged seabed and, in particular, on the mudflats of Punta Vecia north and south. In mixed meadows almost exclusively with *Zostera noltei* or in round-shaped patches inside *Z. noltei* pure meadows.
Ruppia spp. (*Ruppia cirrhosa* and *R. maritima*)	From the intermediate sector and extending up to the more internal one (closest to the mainland). Rarely present on mudflats, its most suitable habitat are the depressions, pools or "ghebi" in the artificial or natural saltmarshes (on medium-low bathymetry), so much that it often coexisted even with *Salicornia veneta* in internal depressions or larger pools.

Figure 15: Example of tidal channel network ("ghebo"), in an artificial saltmarsh, colonized by *Zostera noltei* (left). Example of *Zostera marina* meadows, species that colonizes lagoon seabed up to the edge of the mudflats (right).

1.3.4 Benefits of restoration as perceived by stakeholders: the CORE-PLAT

Since October 2022, the REST-COAST project has established a Coastal Restoration Platform (CORE-PLAT) within the Venice Lagoon. Initially, a total of 73 stakeholders were identified, categorized and visualized in

Figure 16, including public administrators, universities, research centres, private entities, NGOs, and local organizations with specific interests in safeguarding and/or managing the Venice Lagoon (Figure 16).
The overarching goal of CORE-PLAT is to initiate a participatory process, fostering dialogue aimed at co-managing/co-designing present and future restoration efforts in the Venice Lagoon. Additionally, the platform serves to collect suggestions and "lessons learned" from various experts and previous experiences.

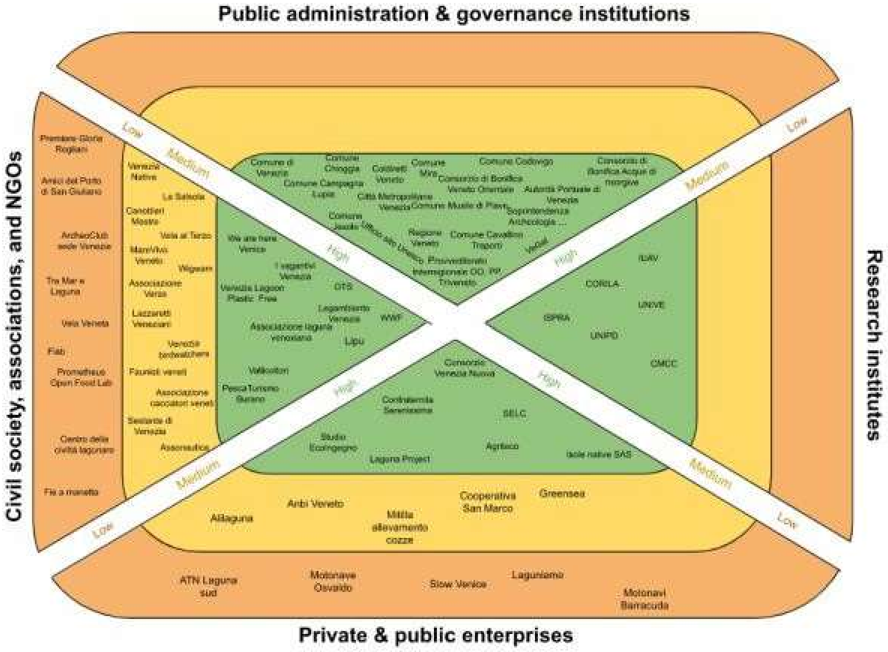

Figure 16: Visualisation of the stakeholders, according to stakeholder type and "power"[2], invited to join the CORE-PLAT in the Venice lagoon (extract from REST-COAST Milestone 40).

The mapped stakeholders were invited to participate at in-presence meetings. So far, two meetings have been organised, with representatives from 26 different entities (Figure 17). These workshops played a pivotal role in fostering a shared vision for upscaling restoration activities in the Venice Lagoon. In general, none of the stakeholders oppose to the restoration interventions implemented in the lagoon; they are all conscious about the importance of active maintenance of the lagoon habitats to counteract the negative erosion trend and loss of habitats and they support the NBS restoration interventions. However, the only stakeholder that really has the power of decision in implementing the restoration interventions is PROVV as local office of the Ministry of Infrastructure: the safeguard of Venice and its lagoon is of national interest.

[2] The term "power" here stands both as the weight of the stakeholder to influence the local decision and as their capability to provide useful knowledge, even based on the direct experience, for a better planning of the restoration activities in the lagoon. As an example, a maximum weight is given to those actors who have the power to decide what kind of works should be done in the lagoon (for example the PROVV. or the Port Authority), while low weight will be given to those actors who are present in the lagoon but not actively participate to the decision process for the lagoon's future.

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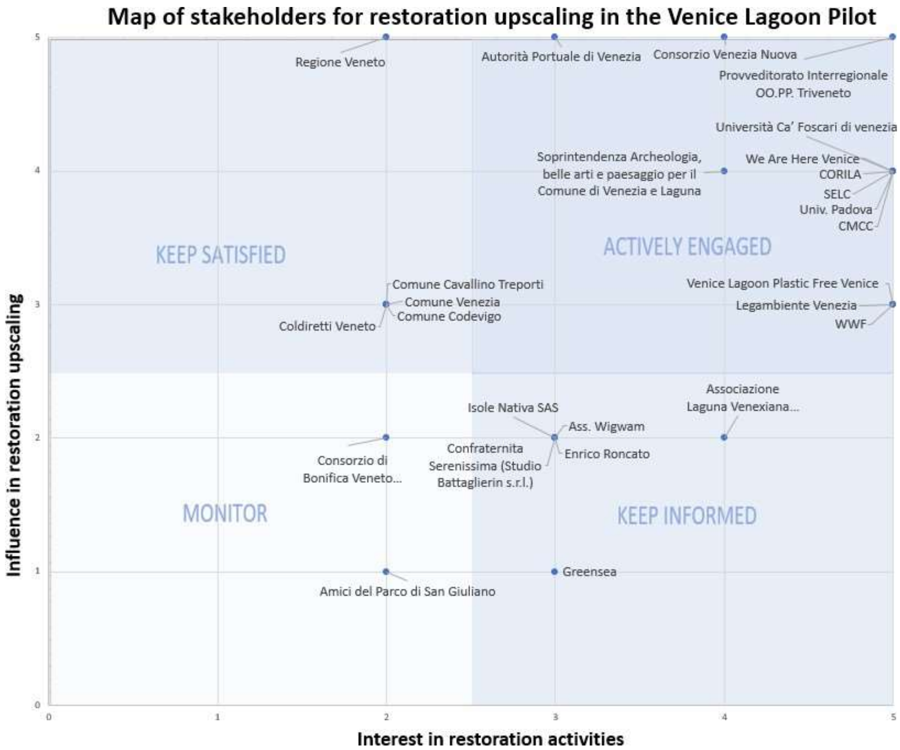

Figure 17: Map of stakeholders for restoration upscaling in the Venice Lagoon Pilot, showing their interest and influence in restoration activities (map elaborated in REST-COAST Task 3.3).

The discussion during the meetings allowed for an increase of the participants' understanding of the potential environmental, economic, and socio-cultural benefits of NBS restoration activities, and brainstorming sessions addressed environmental, socio-economic, and technological barriers and enablers to upscaling restoration activities, proposing solutions to overcome these challenges.

A prioritized list of recovery interventions for the Venice Lagoon, according to the stakeholders' perception and interests, was developed. Examples include conducting monitoring of plastics and waste within the lagoon to facilitate specific removal interventions and the creation of barriers/infrastructures to block waste coming from the rivers; implementing current reduction measures to protect the natural ecosystem; managing interventions that may impact morphological features, such as new mainland-island connections; restoring specific areas like the B/D-E filling basin; reinstating mudflats along the petroleum channel; controlling turbidity to maintain good water quality in fishing valleys; restoring natural mudflats, now nearly vanished; and protecting natural barriers from erosion.

Figure 18: A stakeholder meeting (left, December 2033) and best practices to overcome the challenges (right) emerged and discussed during the second CORE-PLAT meeting in Venice.

To broaden stakeholder engagement in the participatory process and assess the effectiveness of different restoration techniques based on established indicators, an online questionnaire was prepared. This questionnaire aimed to understand the priorities and main interests of individuals inhabiting and animating the delicate Venice Lagoon, gathering information to guide protection and restoration efforts in this complex environment. The approach seeks to weigh indicators (environmental, economic, and social indicators) according to diverse stakeholder perspectives, starting and extending beyond the scientific community.

Main results of 1st part of the questionnaire, "Priorities evaluation", are:

1. Respondent Profile
   - Dominated by amateur fishers, recreational boaters, and non-professional users of the lagoon.
   - Highlights the significance of the lagoon for a diverse range of people and the deep connection between the local population and the natural environment.
2. Importance of Lagoon Features
   - Saltmarshes and their vegetation rated highest in importance.
   - Surprisingly, navigable channel width and fish presence were rated least important, despite the high number of fishers and boaters among respondents.
3. Perceived Threats to the Lagoon
   - Identified chemical pollution, erosion, and plastic pollution as the most dangerous threats.
   - Turbidity, acoustic pollution, and marinization were considered less harmful.
4. Economic Aspects of Restoration
   - Reduction of initial costs ranked as the most important economic aspect.
   - Job creation related to restoration works ranked lower in importance.
5. Stakeholders' Visions for the Future
   - Preference for durable and stable interventions, even if more expensive.
   - Interest in minimizing impacts of works.
   - Strong emphasis on naturalness of saltmarshes and importance of restoring and protecting degraded areas, even if it compromises durability.

From the questionnaire, it's evident that respondents generally prioritize preserving a more "pristine" and regulated lagoon environment. A common suggestion is to limit wave energy and erosion, often by

enforcing speed restrictions on boats. Additionally, there is a strong emphasis on the restoration and protection of saltmarshes, including maintaining their natural internal morphology.
Respondents also emphasized concerns about pollution, both solid and chemical waste.
In terms of technics for restoration, respondents tend to prioritize durable and low-impact solutions, even if they entail higher costs and longer implementation times.

1.3.5 Restoration barriers that have been overcome and explain how this was achieved

The REST-COAST project has successfully addressed numerous barriers through collaborative efforts and innovative approaches. By fostering synergies among the scientific community, authorities, and stakeholders, we have been able to tackle technical challenges effectively. Active discussions have been instrumental in designing restoration works that address issues identified in previous efforts. Notably, the new designs prioritize the development of natural-like internal morphologies within artificial salt marshes and address elevation disparities that previously hindered renaturalization efforts at the pilot site.

Furthermore, the COREPLAT meetings provided a platform for joint discussions on enhancing interactions among academia, institutions, enterprises, and local communities. These discussions have illuminated pathways to transcend existing silos and overcome the fragmentation prevalent in natural resource governance and coastal restoration efforts.

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2 Venice lagoon videos and communication/dissemination materials

To engage stakeholders and disseminate crucial information regarding the Venice Lagoon restoration efforts, a series of videos and communication materials have been crafted, clearly defined for each typology of audience. These resources serve as powerful tools not only to illuminate the complexities of REST-COAST restoration activities but also to foster collaboration, raise awareness, and inspire action among diverse audiences.

2.1 Material for civil society, policy makers, stakeholders

To date, three videos have been created to introduce to the stakeholder the Venice Lagoon pilot site and the REST-COAST restoration activities.

The initial two videos of our communication campaign focused on stakeholder meetings held on October 11, 2022[3], and December 11, 2023[4], respectively. These gatherings marked significant milestones in our engagement efforts, facilitating dialogue and collaboration among diverse stakeholders.
Through the CORE-PLAT initiative, they are coming together to develop a shared long-term vision for the Venice Lagoon, a groundbreaking achievement in fostering collaboration among stakeholders with differing perspectives. The CORE-PLAT represents a significant advancement and a testament to the success of the REST-COAST project.

These videos vividly illustrate the organizational efforts and community engagement in identifying key environmental challenges within the Lagoon, emphasizing transparency in pursuing project objectives and showcasing the effective collaboration among project partners and stakeholders.

These videos were crafted using footage captured by CORILA staff during the meetings, edited to sequence different chapters with overlay text and images. The second video employed graphic animation to illustrate the outcomes of stakeholder involvement, mapping the identified lagoon needs and best practices.

The third video[5] provides a comprehensive overview of the Venice lagoon pilot site and it's aimed to be presented to the local widest possible community (https://www.youtube.com/watch?v=pIH1JSalpWs). It provides an explanation of the history of the Venice lagoon, the challenges it faces today, and future aspirations for the lagoon habitat, alongside outlining theactivities and objectives of the REST-COAST project. The video features a narrative in Italian that strikes a balance between being easy to understand and including technical-scientific information, guiding viewers through the visual story.

Technical aspects: the video recordings were made using two mirrorless cameras: Fujifilm x-h1 and Sony alpha 7 III. All the materials for the videos belong to the CORILA archive, except for one clip present in the video of the pilot site, downloaded for free at the following link: https://www.vecteezy.com/video/33642459-venice-italy-february-19-2022 -day-to-night-time-lapse-of-grand-canal-in-venice-tourists-buildings-ships-and-gondolas-view-from-rialto-bridge. Copy-free music and recordings by CORILA personnel using professional equipment (Scarlet 2i2 sound card and a Shure SM 58 microphone) were integrated into the videos, edited with DaVinci Resolve 18.6 software.

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[3] REST-COAST: First stakeholder meeting in the Venice Lagoon published on 11/15/2022.
[4] REST-COAST: Second stakeholder meeting at the Venice Lagoon published on 01/22/2024.
[5] REST-COAST: Venice Lagoon Demo published on 29/03/2024.

Currently, the two stakeholder meeting videos have been shared on the project's YouTube channel and Facebook page, as well as in CORILA's web pages and social channels. However, the video related to the pilot site is pending publication.

In addition, a short video was crafted for World Wetlands Day in February 2023, underscoring the importance of wetland preservation.

Future plans encompass various communication initiatives, including a video presentation outlining recommendations to the Competent Authority PROVV by the REST-COAST team of experts (as detailed in Chapter 3.1). This video will serve as an example of our ongoing efforts to engage stakeholders and advocate for effective strategies in lagoon restoration and protection.

On the occasion of each project meeting, posts were created and published on the project and partners' social pages. These social pages served as showcases for presenting the multimedia content created to introduce the pilot sites and outline the main activities planned for the Rest Coast project. Simultaneously, web content was developed and published on the institutional project website and the CORILA website. The traffic generated by the social pages plays a crucial role in promoting the more scientific and in-depth content available on the websites. Unfortunately, despite our efforts and the numerous posts published, the project's social pages, as well as the posts shared on the partners' social pages, struggle to generate measurable interest. They often remain as simple representations of the activities carried out. To enhance attractiveness, our goal is to create more original content by seeking shares from and to European pages and projects with scientific content similar to that covered in REST-COAST.

Below are the posts on the project Facebook page relating to the two video stakeholder meetings and the video created for the World Wetlands Day.

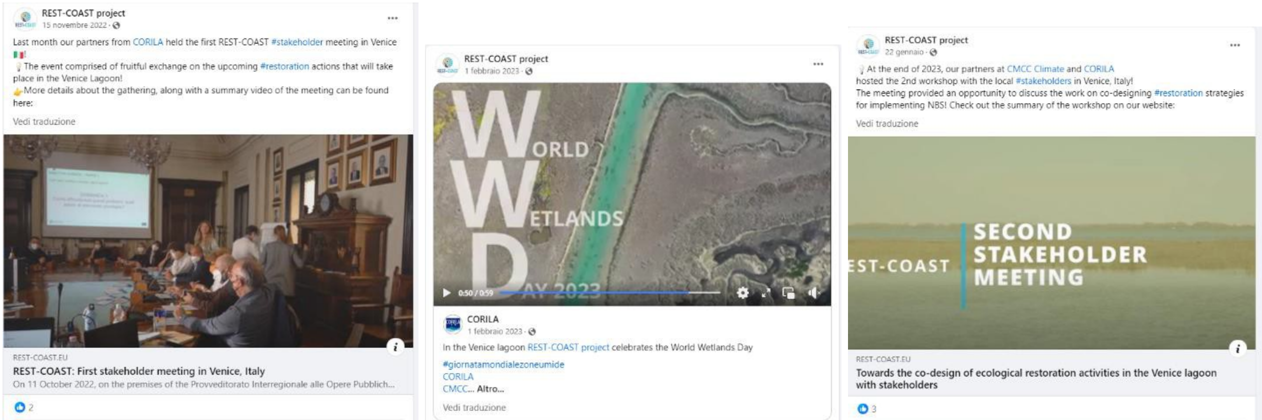

Figure 19: Posts on the Facebook REST-COAST page relating to the two stakeholder meetings' video (right and left) and the video created for the World Wetlands Day (center).

In addition to the video initiatives, the project team has prepared presentations tailored for various types of audiences, from university students to general public. These presentations aim to disseminate knowledge and foster collaboration in the field of coastal restoration and climate change adaptation at different conferences and workshops. Among these:

1. ECSA Conference 2022
   - Location and date: Berlin (DE), 5-8 October 2022
   - The ECSA 2022 Conference brought together researchers, civil society actors, policymakers, and stakeholders from around the world to discuss Citizen Science for Planetary Health. During this event, our team presented a systematic literature review on identifying indicators to assess the performance of nature-based solutions for climate change adaptation.

- Title of the presentation: Identifying indicators to assess the performance of nature-based solutions for climate change adaptation: A systematic literature review
- Autors: Fabienne Horneman, Silvia Torresan, Elisa Furlan, Andrea Critto (CMCC), Caterina Dabalà (CORILA)
- Target: Researchers

2. Forth RI-PARTY-AMO workshop
   - Location and date: University Ca' Foscari, Venice (IT), 1 December 2022
   - This workshop, part of the RI-PARTY-AMO project, focused on environmental themes and involved discussions on biodiversity conservation, ecosystem restoration, and promoting natural processes for resilient environmental evolution. Our contribution to this event included a presentation on the restoration of shallow lagoon habitats and its effects on fish fauna.
   - Title of the presentation: Il progetto Rest-Coast; un contributo pratico al recupero ambientale in laguna di Venezia
   - Autor: Caterina Dabalà, CORILA
   - Target: University students

1. EUROLAG10 Conference
   - Location and date: Gdynia (Poland), 19-23 June 2023
   - The conference focuses on the critical role played by lagoons and estuaries as essential transitional zones between terrestrial and marine ecosystems. These complex and diverse waterbodies serve as buffers against anthropogenic pressures, owing to their high productivity and strategic coastal positioning. Traditionally, lagoons and estuaries have provided a multitude of goods and services. The conference is particularly interested in assessing the buffering function of lagoons and estuaries, as well as exploring new developments in conservation objectives, management strategies, and environmental status assessments. This includes discussions on monitoring designs, indicators, and modeling tools for integrated assessments.
   - Title of the poster (Figure 20): The effort of the Italian research community for the Venice Lagoon supersite: toward the integration of National and European fundings to build DANUBIUS-RI
   - Autors: Caterina Dabalà, Andrea Rosina, Francesca Coccon (CORILA, Venice, Italy), Debora Bellafiore, Francesca De Pascalis, Georg Umgiesser (CNR-ISMAR, Venice, Italy)
   - Target: Researchers

3. ECO2SMART Project Conference
   - Location and date: Capodistria (SLO), 14 November 2023
   - The ECO2SMART Project Conference aimed to promote ecosystem-based approaches for climate change adaptation and disaster risk reduction. Our participation in this conference highlighted the application of nature-based solutions for climate adaptation and biodiversity conservation in the Venice Lagoon, showcasing the contributions of the Rest-Coast project. These conferences provided valuable platforms for sharing insights, exchanging ideas, and advancing collaborative efforts towards sustainable coastal management and environmental resilience.
   - Title of the presentation: L'applicazione di soluzioni basate sulla natura per l'adattamento ai cambiamenti climatici e la conservazione della biodiversità nella laguna di Venezia: il contributo del progetto Rest-Coast
   - Autor(s): Caterina Dabalà, CORILA
   - Target: General pubblic

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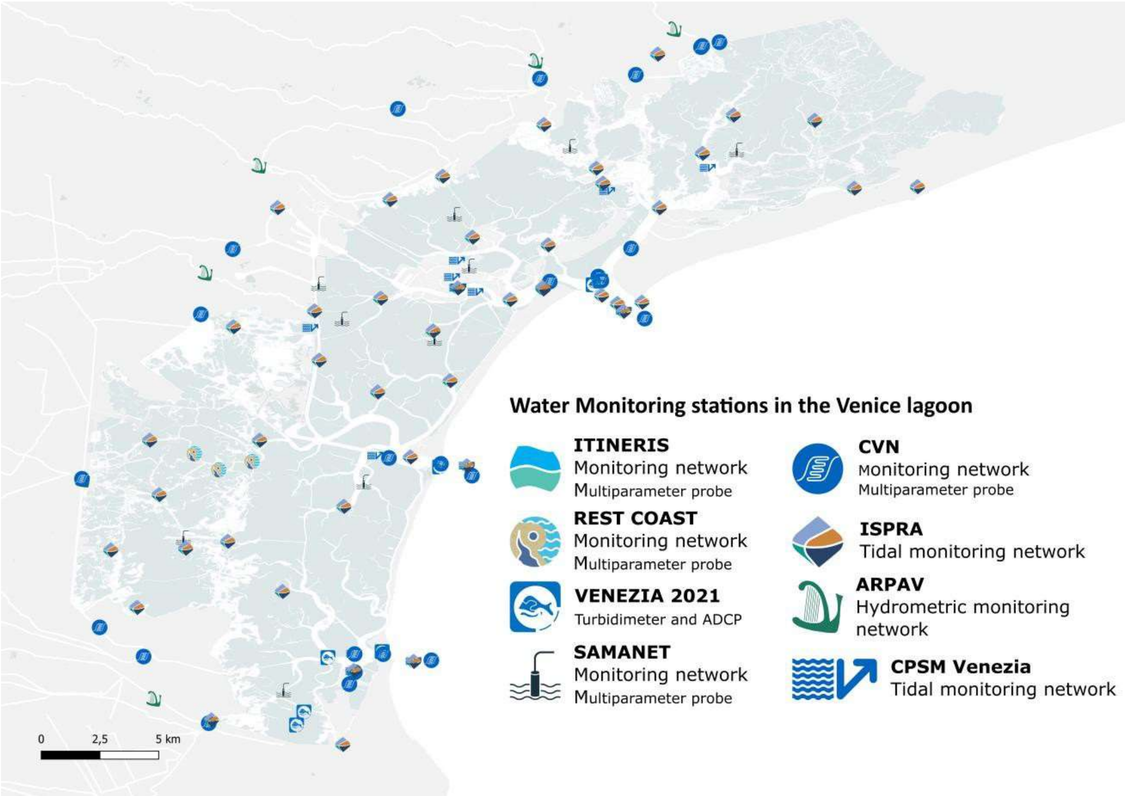

Figure 20: The Monitoring stations' map of the lagoon of Venice.

2.2 Material for education community

In the REST-COAST research group, both Ca' Foscari University of Venice and the University of Padua are involved. To date, the project, its objectives, and the area of investigation have been repeatedly presented to students. At Ca' Foscari University, these presentations have occurred in two courses: Ecosystem Services and Sustainability (Master's degree program in Environmental Sciences); Structure and Functioning of the Living Environment (Master's degree program in Environmental Humanities). Additional materials will be incorporated into the lessons once the initial results of the ESS are available.

UNIPD team will organize a two hour seminar for the students of the Marine Biology Masters course of the University Padova held in Chioggia in the context of the course "Marine conservation: Principles and Applications". The seminar will start from the history of ecological restoration to then focus on the specific case study represented by the Lagoon of Venice. In this context the activities and objectives of the REST-COAST project will be presented and described with particular attention to concepts such as ESS and Disaster Risk Reduction. The lesson will also investigate the concept of Nature Based Solution both in a general sense and in the specific concept of the REST-COAST project.

3 Demo activities

3.1 Hands-on restoration actions adopted in REST-COAST pilot site in the Venice Lagoon

In the Venice Lagoon, characterized by diverse conditions in terms of wave energy, sediment balance, and hydrodynamics, the protection and restoration of natural structures require tailored solutions. All recovery intervention structures here adoptable are modular and removable but vary in costs, magnitude, and long-term reliability. These factors must be carefully considered when planning interventions to ensure informed restoration technique selection aligned with project goals.

Saltmarsh restoration in the Venice lagoon encompasses a range of activities, including rebuilding eroded sections, protecting vulnerable edges, elevating low marshes, and constructing new marshes. Construction techniques involve creating containment barriers along designated perimeters and pumping fluidized mud to achieve desired elevations. Adaptation to diverse lagoon morphologies has led to a modular approach, with experimentation involving various module structures, often used in combination. These modules primarily consist of barriers for containment, edge protection, or breakwater functions, employing different designs, materials, and setups depending on environmental characteristics (Tagliapietra et al., 2018).

The design and execution of saltmarsh restoration methods in the Venice lagoon depend on various factors, including the existing state of intertidal surfaces and the potential for restoration. Saltmarsh restoration prioritizes restoring conditions conducive to habitat formation, allowing sufficient time for soil genesis and the establishment of complex hydrobiology (Tagliapietra et al., 2018).

The REST-COAST project focuses on improving 8 artificial saltmarshes in the central-southern part of the Venice Lagoon, namely Casone Zappa A, Casonetto Zappa, Gorna, Lago della Pietra, Raina, Cornio 1, Cornio 2, and Cornio 4 (Figure 21). These marshes were previously created as part of earlier interventions, less than 20 years ago. Recent surveys have shown that their surface elevations range between +0.10/0.15 meters above sea level (m.s.l.m.), which is lower than the intended elevation of +0.40 m.s.l.m., preventing them from fully developing into saltmarsh environments.
To address this, the proposed interventions focus on repairing their boundaries to allow for new sediment inflows: the goal is to raise the surface elevation to +0.70 m above sea level by the end of the inflow period, stabilizing at +0.40/0.50 m above sea level after natural consolidation.

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Figure 21: REST-COAST pilot area, materials and methods used for the saltmarsh restoration.

Considering the ongoing need for structures capable of receiving "clean" materials in compliance with established environmental safety criteria, to support Port Authority refilling interventions, maintenance work is necessary. This maintenance will involve:

- targeted interventions at the boundaries, restoring structures using adjacent poles, as originally designed, and improving hydraulic networks where partial boundary integrity is identified.
- removing part of existing piling and the entire filtering wall of the original boundary. This will be followed by constructing a new boundary to facilitate inflow of new material from excavations.

While the works described here are currently underway by PROVV, the planning and funding Public Body for the project, the actual sediment reclamation activity, which will form the saltmarsh structure itself (with a targeted sediment elevation of +70 cm above mean sea level), will be carried out by the Port Authority.

Table 3: The restoration works in the REST-COAST pilot site in the Venice Lagoon.

Phase 1: Contermination	
Responsible Public Body	Provveditorato Interregionale per le Opere Pubbliche per il Veneto, Trentino Alto Adige e Friuli Venezia Giulia
Delivery of works	Aprile 2023
Duration of works	1 year
Estimated end	Presumably April 2024
Phase 2: Refill	
Responsible Public Body	Port Authority
Delivery of works	Presumably July 2024

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Table 4: Characteristics of the artificial saltmarshes before the restoration activities.

Artificial Saltmarches	Year of construction	Area (ha)	Refilling program	Status of quotas
Lago della Pietra	2015	5,77	37.000	Predominantly low and submerged
Gorna	2015	7,45	52.600	Partially low and submerged
Casonetto Zappa	2015	6,31	59.000	Velma low at 90%
Casone Zappa A	2006	26,78	not known	Emerged, also vegetated with ruderal species
Raina	1989 and 2012	4,88	not known	Partially low
Cornio 1	2009	9,15	not known	Partially low and submerged
Cornio 2	2010	21,7	not known	Partially low and submerged
Cornio 4	2010	9,13	92.300	Medium low altitude, bare of vegetation

For phase 1, the most effective modular solutions, selected from various techniques tested in the past (see Annex 1, Figure 21), and considering economic feasibility, have been evaluated and chosen for each specific section of the saltmarsh. This decision takes into account the area's characteristics, including hydraulic conditions, exposure to prevailing winds, and environmental factors (e.g., the presence of tidal flats).
To optimize the efficiency and sustainability of the restoration efforts, a comprehensive set of measures has been recommended to the Competent Authority PROVV by the REST-COAST team of experts, regarding best practices and potential adjustments to be implemented throughout the various stages of saltmarsh restoration, encompassing both ecological and logistical considerations. These measures include:

- Cleaning of the pilot site prior to restoration activities, with a focus on removing materials such as plastic debris, as well as conducting pre- and post-worksite cleanups to ensure minimal environmental impact (Figure 22).
- Implementation of areas with lighter marginal structures to facilitate the natural formation of internal creeks and ponds, along with creating permeable margins (e.g. geotextile composed of natural fibres-viscose) where feasible to encourage the formation of natural tidal channels.
- Minimization of plastic usage during construction, coupled with the testing of degradable non-plastic materials for the marginal structures, to reduce the long-term environmental footprint of the project.
- Remodelling of areas of the saltmarsh that have become excessively elevated over time, restoring them to more natural characteristics and removing vegetation not typical of natural marshes from higher areas (e.g. shrubs, allochthonous plant species).
- Promotion of the establishment of mudflats adjacent to the saltmarsh, aimed at enhancing biodiversity and habitat diversity within the ecosystem.
- Restoration of the initial depth of channels to promote natural recolonization by seagrasses, facilitating ecosystem recovery and resilience.
- Implementation of measures to minimize turbidity dispersion in water, monitored using probes, to preserve water quality and minimize disturbance to aquatic life.
- Logistic adaptations to limit the impact of the works, including strategies to reduce turbidity and avoid damage to seagrass beds in the area.

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- Placement of higher poles in the marginal structure to serve as roosts for birds, particularly waders and terns, even during high tide, enhancing habitat availability for avian species.


Figure 22: Waste collection and disposal on the REST-COAST artificial saltmarshes.

The application of these suggestions in practice was evaluated with ad hoc field trips. Degradable materials for example present an obvious advantage reducing plastic pollution in the lagoon and allowing the spontaneous degradation of the artificial structures but proved unsuitable for high energy areas due to their low resistance (Barausse et al., 2015).
The result is a comprehensive and detailed program comprising customized activities, meticulously designed to address the unique characteristics and requirements of each area slated for restoration. In Figure 23 is reported, by way of example, the case of the artificial saltmarsh “Lago della Pietra”, as well as the description of the individual interventions planned.

The application of the suggested modifications represents a remarkable step forward in the innovation of restoration activities compared to previous approaches and is result of the joint effort between the competent authority for the works, entrusted companies and experts from the world of scientific research.

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Figure 23: Map of the "Lago della Pietra" saltmarsh, detailing the types of structures and measures implemented: reconstruction of the perimeter piles using 2 different technical schemes (red and orange lines); construction of new embankments within the mudflat surface (green lines), to delimitate the two areas to be filled with new sediments; eradication of shrub vegetation in the higher areas (blue dots); use of geotextile composed of natural fibres (light blue dots); higher piles in order to ensure accessibility for birdlife even during high tide conditions (yellow dots).

Future perspectives:

- Continuation of environmental monitoring to detect changes and improvements in ecosystem services in the area.
- Ensuring funding for extending morphological recovery activities to other lagoon areas where needed (referring to the work being carried out in REST-COAST Task 3.3).
- Implementation of awareness campaigns, including involvement of non-profit associations, as seen in the collection of stranded waste on the lagoons.
- Communication campaign on activities and achieved results, and to raise awareness about the value of NBS in combating climate change and increasing biodiversity (including through graphic novels, as suggested during CORE-PLAT meetings).

3.2 Demonstration value and replication

Saltmarshes and mudflats, whether natural or man-made, offer a range of vital ecosystem services, including hydrodynamic exchanges, water quality improvement through nutrient and pollutant filtration, wave dissipation, biodiversity enhancement, coastal primary production support, fish habitat provision, tourism attractiveness, and carbon sequestration (blue carbon). The upscaling plan aims to extend the successful restoration strategies implemented at the REST-COAST pilot site to cover the entire Venice Lagoon, specifically targeting the 1,600 hectares of artificial saltmarshes and mudflats. Based on the prioritization of ecosystem services, the main objectives for upscaling restoration in the pilot area have been established. These include preventing the degradation of morphological structures, combating erosion, reducing wave impacts, facilitating hydrodynamic exchanges, improving water quality, enhancing biodiversity, supporting fisheries, attracting tourists, and sequestering atmospheric carbon.

The restoration activities in the REST-COAST artificial saltmarshes are still underway, with an estimated completion time of approximately one year (foreseen end in 2025). However, to comprehensively assess the impacts on ecosystem services and biodiversity through field-recorded data, it will be necessary to wait for at least an additional three years after the conclusion of the field works before natural processes of re-naturalization and spontaneous colonization of the saltmarshes can take place.
To overcome this delay in progress of the restoration works, a dual approach has been adopted. This approach involves modelling and experts' evaluation:

- drawing upon available knowledge and leveraging the extensive experience gained in the Venice Lagoon (even thanks to LIFE Projects) regarding the impacts of restoration interventions on biodiversity (see chapter 3.2.1).
- employing high-resolution spatial models (at a scale of a few meters) on a lagoon-wide basis to assess the effects of restoration interventions on ecosystem services (see chapter 3.2.2 and 3.2.3).

3.2.1 The natural evolution scheme of artificial saltmarshes in the Venice lagoon[6]

Over the past 30 years, the PROVV, through its concessionaire Consorzio Venezia Nuova, has undertaken extensive morphological reconstruction works in the Venice lagoon and has been monitoring the morphological and biological evolution of the artificial structures over time. As a result, a theoretical model of the evolution of saltmarsh structures has been developed to evaluate morphological changes over time and the development of biological communities, facilitating the identification of interventions to expedite naturalization processes.
However, within this theoretical framework, it is important to note that in practice, the delay in achieving the evolutionary stage corresponding to the age of the artificial saltmarshes should not necessarily be perceived as a negative aspect. This is because the microhabitats characteristics of each stage contribute to colonization and the presence of certain species, thereby enhancing biodiversity.

The six identified evolutionary stages (from 0 to 5) are briefly described below (Table 5) and represented in Figure 24.

- Stage 0 encompasses approximately the two to four months following the end of the tidal ebb, during which the structure consists of incoherent sediment, characterized by a relatively high elevation compared to mean sea level (from +70 cm to +100 cm), and the complete absence of vegetation and a network of tidal channel.
- Stage 1 concerns artificial saltmarshes aged between two to four months and one year, characterized by the absence of an internal water network. The average elevation begins to decrease (from +60 cm to +70 cm), and colonization by annual plant species, especially in lower areas, begins. Large areas of bare soil are used for nesting by some species.

[6] Source: Studio C.8.6. MAG.ACQUE-SELC, 2008. extract from PROVV-CVN, 2019

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- Stage 2 (from one to three years after tidal ebb cessation) involves a progressive loss of elevation to around +45 cm. Annual vegetation is gradually replaced by perennial species. The coverage of halophytic vegetation species extends over 10% of the saltmarshes surface. More avian species are present than in stage 1.
- Stage 3 (from three to six years after tidal ebb cessation) is characterized by a drastic slowdown in evolutionary dynamics. Elevation decreases to around 40 cm above mean sea level, and a first tidal network begins to develop, consisting of small creeks and clearings within the saltmarshes, following the structure of depressions. The coverage of halophytic vegetation ranges between 20 and 40% of the emergent surface, including a significant coverage of perennial species, which favours the presence of other avian species.
- From stage 4 (from the sixth to the tenth year), the average elevation stabilizes around +0.30 – +0.40 m, while the hydrographic network, reaching 10-15% coverage, takes the form of a well-defined network of ponds (called “laghi”) and creeks. Halophytic vegetation covers at least 50% of the surface, with between 40 and 90% consisting of perennial species; the community is well-structured. Avian species characteristic of stage 4 are the same as stage 3. The presence of clearings provides ideal conditions for the nesting of Oystercatchers and Avocets.
- The final evolutionary stage (stage 5) is theoretically reached when, after ten years from the tidal ebb cessation, the coverage of the water network composed of ponds and creeks is approximately 15-25% of the total surface area, and the vegetation is almost exclusively composed of perennial species. The increase in vegetation coverage leads to a decrease in suitable habitats for nesting of many species.

Table 5: Description of the six identified evolutionary stages of the artificial saltmarshes in the Venice lagoon.

Stage	Time since construction	Altitude (m.s.l.m.m)	Dominant vegetation (%)	Dominant bird species
0	<2 months	70 cm	Absent	Herring gull (*Larus michahellis*).
1	2 months - 1 year	60-70 cm	Salicornia	Kentish plover (*Charadrius alexandrinus*), Little tern (*Sterna albifrons*), Oystercatcher (*Haematopus ostralegus*), Herring gull (*Larus michahellis*).
2	1 to 3 years	45 cm	*Puccinellia palustris*, *Sarcocornia fruticosa*	Kentish plover (*Charadrius alexandrinus*), Little tern (*Sterna albifrons*), Oystercatcher (*Haematopus ostralegus*), Herring gull (*Larus michahellis*), Redshank (*Tringa totanus*).
3	3 to 6 years	40 cm	*Sarcocornia fruticosa*, *Limonium narbonese*, *Halimione portulacoides*	Shelduck (*Tadorna tadorna*), the Avocet (*Recurvirostra avosetta*), the Black-winged Stilt (*Heamatopus heamatopus*) and the Mallard (*Anas platyrhynchos*).
4	6 to 10 years	20-40 cm	Sarcocornieto, *Halimione portulacoides* (+ Stage 3)	Shelduck (*Tadorna tadorna*), the Avocet (*Recurvirostra avosetta*), the Black-winged Stilt (*Heamatopus heamatopus*) and the Mallard (Anas platyrhynchos). Nesting of the Black-winged Stilt and the Avocet.

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Stage	Time since construction	Altitude (m.s.l.m.m)	Dominant vegetation (%)	Dominant bird species
5	> 10 years	NA	Salicornia	Shelduck (*Tadorna tadorna*), Oystercatcher (*Haematopus ostralegus*), Avocet (*Recurvirostra avosetta*), Black-winged Stilt (*Haematopus haematopus*), Redshank (*Tringa totanus*) and Herring Gull (*Larus michahellis*).

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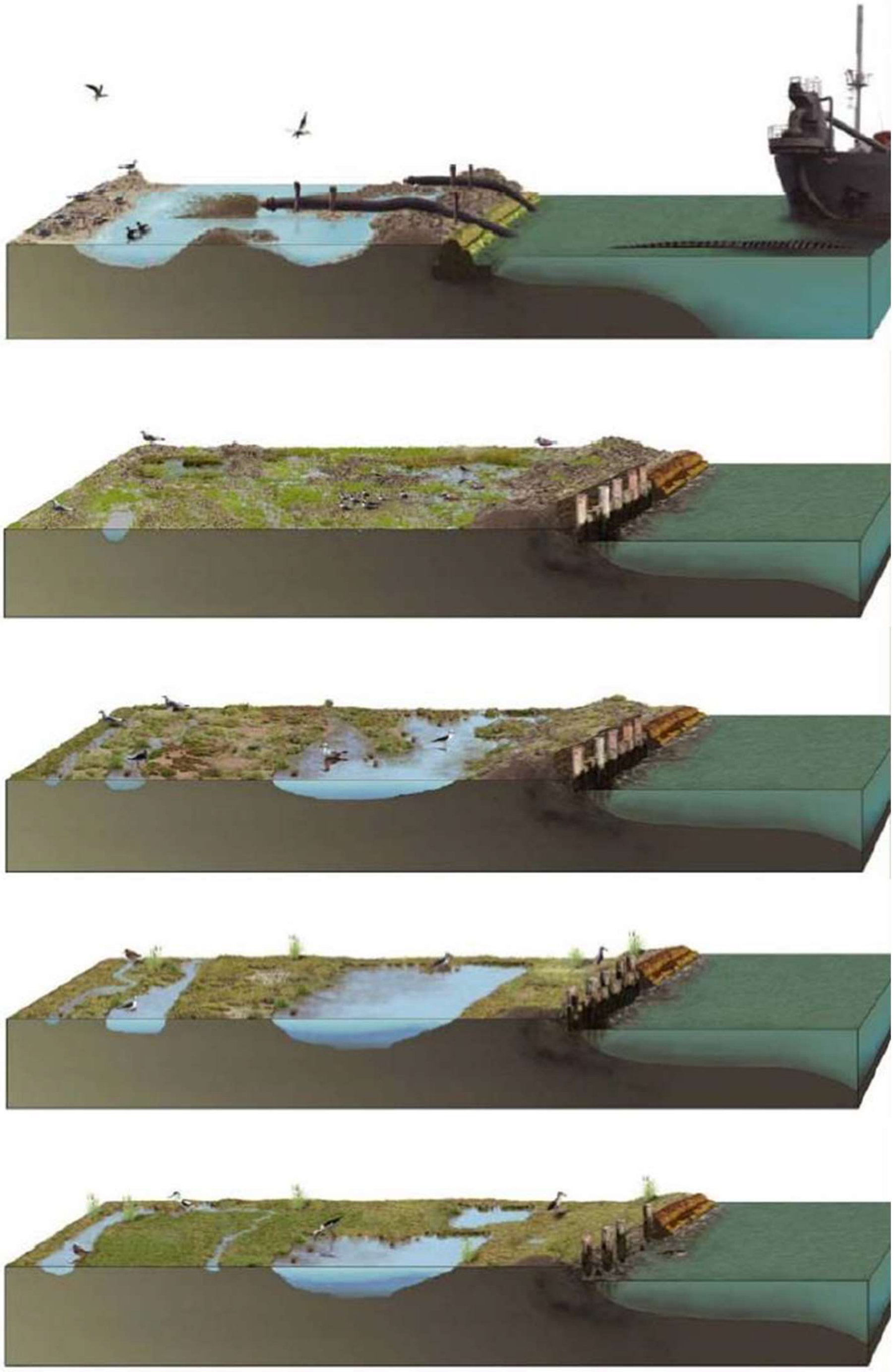

Figure 24: Representation of the 6 stages in the evolutionary scheme of artificial saltmarches (source: Studio C.8.6. MAG.ACQUE-SELC, 2008).

3.2.2 Benefits of restoration interventions on ecosystem services: results from modelling elaborations[7]

CMCC developed a hydrodynamic-wave modelling system to simulate near past conditions at the Venice lagoon pilot for the assessment of ESS. Models have been validated using data from the CNR "Acqua Alta" platform, providing good accuracy and precision. Two configurations have been implemented: with wetlands and seagrasses, and without them. The comparison between the different configurations allowed to appreciate and quantify the ESS due to the inclusion of wetlands and seagrass in the lagoon. Their role has been assessed both for hydrodynamics, through water level and water velocity at bottom, and waves through the significant wave height (Figure 23).

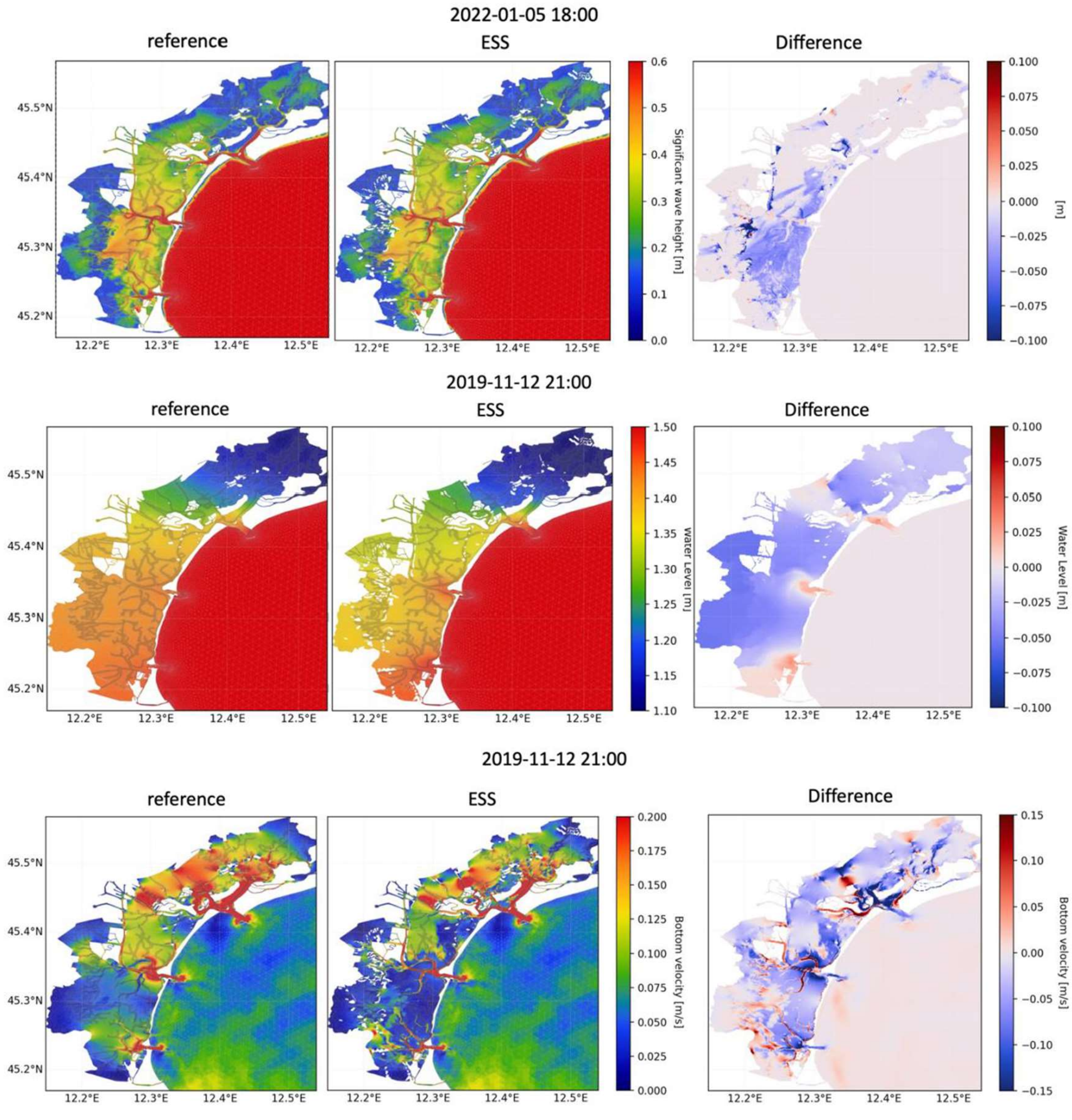

Figure 25: Model run results displaying the significant wave height (m) in the top row, the water level (m) in the middle row, and the water velocity at the bottom (m) in the bottom row stimulated for two storm events as indicated above the panels for the reference scenarios i.e., without vegetation, the ESS scenario i.e., with vegetation, and the difference between the reference and ESS scenario.

[7] Extract from REST-COAST Deliverable D2.1.

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In detail, the comparisons carried out highlighted the following ESS:

- a reduction of wave height due to the presence of seagrass (on average -15%, in some cases above 30%) and, as expected, on a greater extent, wetlands;
- a reduction of water level (up to 5%) in the vegetated zones;
- a general reduction of water velocity at the bottom in the vegetated zones.

The work also identified a side-effect given by the inclusion of wetlands and vegetation in the lagoon which could be considered during planning of restoration activities. In particular, the increased bottom friction brought in some cases to the increasing water level along the main mouths during the flooding phase. Even currents at the bottom showed an increase along the unvegetated deeper channels and where the wetlands presence reduced the section through which water flows.
For more info, see REST-COAST Deliverable 2.1.

3.2.3 Benefits of restoration on both hydrodynamics and wave conditions, for various storm surges approaching the REST-COAST pilot site during the 2041-2070 and 2071-2100 scenarios[8]

This study represents a comprehensive assessment of the effect of restoration intervention on both hydrodynamics and wave conditions, for various storm surges approaching the Venice pilot site during the 2041-2070 and 2071-2100 scenarios. Despite the primary focus of the study concerns the pilot site and the impact of the restoration activity, we recognize the broader importance of addressing the flooding risk for the entire Venice lagoon. The analysis of maximum floodable areas underscores the varying scenarios, with a range of approximately 60 Km2 observed for the period 2041-2070 and an expanded area of about 110 Km2 for the 2071-2100 scenarios. The restoration intervention manifests its influence on hydrodynamics through changes in currents, particularly during the flooding phase. Sea level experiences a slight adjustment, typically within the range of ±1cm, primarily attributed to the constrained water flow caused by the presence of saltmarshes.

Concerning the wave climate, the investigation of the projections suggests minimal alterations in wave conditions towards the end of the century. When examining the inclusion of restoration intervention, higher waves are more effectively attenuated by the restoration intervention. The placement of saltmarshes emerges as a critical factor, with those close to deeper channels inducing significant increases in significant wave height and currents. Notably, the western part of the northern group of saltmarshes of the REST-COAST pilot site and the area between the two southernmost saltmarshes present the lowest currents in the REST configuration. In addition, the southern group is identified as affected by wave reduction.

[8] Extract from REST-COAST Deliverable D2.2.

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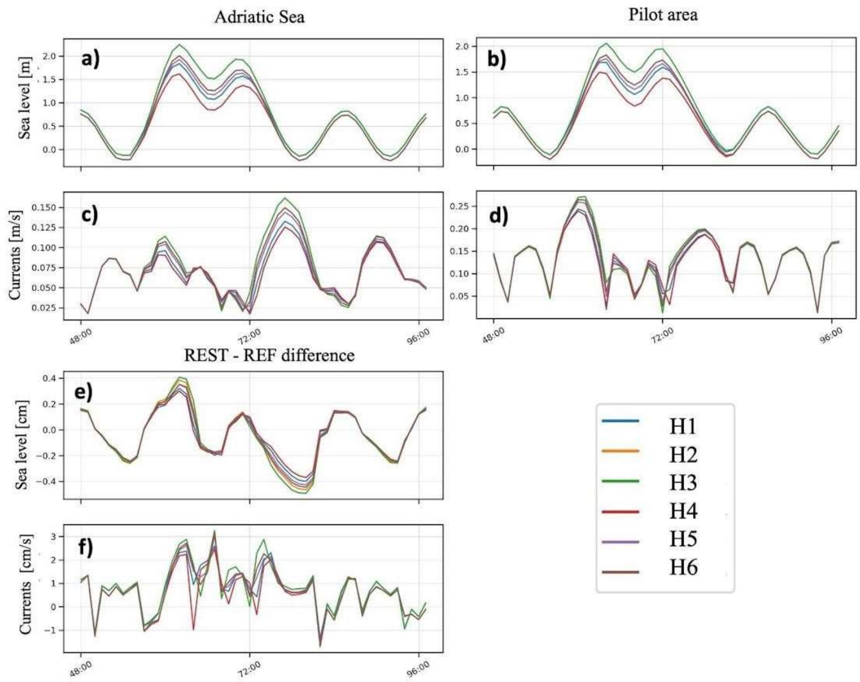

Figure 26: Timeseries of water level (a-b) and currents (c-d) at Adriatic Sea (a-c) and the pilot site (b-d) for the six hydrodynamic scenarios. The difference between restoration and reference (herefore called ESS) configurations is shown in sub-plots (e) for sea level and (f) for currents.

When the MOSE barriers are closed the lagoon undergoes to a remarkable reduction in currents by one order of magnitude. However, during the MOSE closure, the restoration intervention induces a general low (~1 cm s-1) increase in currents at the pilot site, with a few small exceptions. This observation holds significance as it mitigates the anticipated reduction in currents induced by the barrier closure. The northern side of the northern saltmarshes group in REST-COAST pilot site stands out as the most exposed area, experiencing an increase in significant wave height and currents velocity, whether MOSE is open or closed. This underscores the importance of meticulous positioning of saltmarshes during restoration activities, especially considering their proximity to deep canals or channels, as it could lead to a significant increase in SWH and currents. Such insights are pivotal in refining restoration strategies for the Venice lagoon, ensuring a balanced and effective approach to hydrodynamic management.
For more info, see REST-COAST Deliverable 2.2.

This project receives funding from the European Union's Horizon 2020 research and innovation programme, under Grant Agreement 101037097

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This project receives funding from the European Union's Horizon 2020 research and innovation programme, under Grant Agreement 101037097

Annex 1: Main perimetral artificial marsh wall applied in the Venice Lagoon and evaluation, based on experts' opinion

The complexity of the Venice Lagoon demands careful consideration when selecting methods and materials for defending and restoring natural environments. This selection process must account for the varying intensity of disturbance factors across different territorial areas, including seabeds, tidal flats, saltmarshes, and reed beds.

Over the last 30 years, a range of boundary structures have been experimented with and implemented, each tailored to specific purposes and locations to address erosion and sedimentation issues. These efforts, with the focus on restoring degraded saltmarshes and constructing artificial ones as needed, involve reinforcing saltmarsh edges, depositing sediment, and utilizing modular structures to ensure sustainability and reversibility. The choice of techniques and materials is adapted to specific environmental conditions and project requirements.

For each type of boundary structure[9], the properties of the modules have been defined based on the environmental characteristics of their placement area, including exposure to meteorological and marine influences, vegetation, and the potential for reversibility of the works. This approach allows for the selection of structures that effectively mitigate erosion, contain sediment, and facilitate natural processes while remaining removable and adaptable to changing conditions (Table 4).

A. Poles. Until the late 1990s, boundary structures used for containing reclaimed materials and protecting the margins of natural saltmarshes were exclusively constructed using wooden piles. However, the use of wooden materials for boundary constructions did not always achieve the intended objectives in terms of adequately safeguarding natural saltmarshes, as they were often ineffective in dampening wave motion and prone to wave reflection. Additionally, wooden structures did not always blend well with the environmental characteristics of the intervention sites.
   Furthermore, the decreasing durability of wood in high salinity environments, coupled with high concentrations of marine organisms (xylotrophic parasites), contributed to the degradation of the piles. This degradation, characterized by thinning in the tidal zone ("hourglass effect"), led to structural breakage and potential drifting of the upper parts into channels, posing navigational risks.
   Considering the potential impact of wooden piles on archaeological sites and the need for a greater diversity of boundary types suited to different environmental conditions, experimentation was undertaken to explore boundary structures with varying degrees of durability and enhanced effectiveness in mitigating wave action, as well as better adaptation to diverse lagoon environments.

[9] Extract from Piano Morfologico, 2018

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Figure 27: Poles in the Venice lagoon.

B. Gabions (called “burghe”). Gabions with high-strength polyester geogrids are modular cylindrical structures of varying dimensions and diameters. Typically, modules of 3 meters in length and with a diameter ranging from 0.40 to 0.60 meters are utilized. These structures are deployed to protect the margins of saltmarshes or tidal flats in areas that experience moderate to high hydrodynamic stresses induced by wind or vessel passage.

Figure 28: Gabions in the Venice lagoon.

C. Fascines. Modular structures that facilitate the capture of suspended sediments consist of modules composed of a system of posts arranged in double rows, to which 2 or more fascines of tamarisk, willow, or poplar branches are tied. These structures promote the sedimentation of suspended sands and silts by creating zones of calm water in saltmarsh bays subject to erosive phenomena caused mainly by wave motion generated predominantly by wind.

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Figure 29: Fascines in the Venice lagoon.

D. Mattresses. Box-shaped structures with high-strength polyester geogrids are modular parallelepiped modules of varying dimensions. Typically, they have dimensions of 300x200 cm and a thickness of 30 or 10 cm. These structures serve to distribute loads and increase the bearing capacity of the seabed. They can be used as a base for supporting gabions (Figure 31), for constructing structures to protect and/or raise seabeds, and to dissipate wave energy.

Figure 30: Mattresses in the Venice lagoon.

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Figure 31: Example of a hybrid solution, with gabions on mattresses.

Table 6: Characteristics of different artificial edge structures utilized in the Venice Lagoon (extract from Nascimbeni, 2007).

	Resistance	Removable	Degradable	Materials	Notes	Placement
Gabions	High	Yes	No	Plastic net/natural fibers and different fillings	The use of degradable materials reduces the resistance considerably	Heavy machinery
Fascines	Low	Yes	Yes	Wood and natural fibers		Manual
Mattresses	High	Yes	No	Plastic grid and various fillings		Heavy machinery
Light mattresses	High	Yes	No	Plastic grid and various fillings		Heavy machinery
Poles	High	Yes	No	Wood		Heavy machinery

Through expert assessments, coming from past interventions analisys, and the application of a weighted evaluation, each restoration technique was assessed for performance indicators. The resultant scores are visually represented in Table 7-Table 9, using colors to offer broader perspective on technique performance.

While scores were assigned based on an idealized ‘average’ scenario, they also evaluated technique efficacy across environmental conditions. For instance, in high-energy environments like major navigable channels, more robust structures may be preferable, while lighter solutions like fascines are better suited to secluded, low-energy areas. It’s important to note that the construction of artificial salt marshes has been considered as a potential “technique”, and included in the weighted evaluation. This consideration arises from the fact that opting to build new morphological structures rather than solely focusing on protecting existing ones necessitates evaluation even before determining the most appropriate technique to employ.

Table 7: Scoring of the three main restoration techniques for each of the environmental criteria. Scores are represented by different colors: Orange= -2, Yellow= -1, Blue= 0, light green= +1; Dark green= +2

	Gabions	Fascines	Artificial saltmarshes	Poles
Elevation	Rigid structures	Precise elevation control	Rigid structures	Rigid structures
Creeks formation	Modular structures, possibility to facilitate creeks formation	Light and versatile margins	Modular structures, possibility to facilitate creeks formation	Modular structures, possibility to facilitate creeks formation
Vegetation	Depends on obtained elevation	Precise elevation control	Depends on obtained elevation	Depends on obtained elevation
Avifauna	Absence of emerging structures	Absence of emerging structures	Rigid emerging structures	Emerging structures, possibility to facilitate landing spots
Saltmarsh-mudflat continuity	Modular structures, partially permeable	Light and permeable margins	Limited by the rigidity of margins	Rigid structures, create a barrier
Turbidity	Heavy machinery	Small sediment quantities, manual labor	Huge sediment quantities, heavy machinery	Heavy machinery
Pollution	Heavy machinery, depends on the material	Light and manual interventions	Heavy machinery	Heavy machinery
Resistance	High resistance, depends on the materials	Permeable and degradable materials	Rigid structures	Rigid structures
CO2 Emissions	Heavy machinery	Light and manual interventions	Heavy machinery	Heavy machinery
Plastics	Depends on the materials	Degradable materials	Depends on the materials	Degradable materials
Erosion reduction	Rigid margins	Limited protection in high energy situations	Rigid margins	Rigid, but erosion can happen behind the poles
Hydrodynamic regulation	Rigid margins	Low resistance	High resistance, protection of nearby structures	Rigid structures

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Table 8: Scoring of the three main restoration techniques for each of the economical criteria. Scores are represented by different colors: Orange= -2, Yellow= -1, Blue= 0, light green= +1; Dark green= +2

	Gabions	Fascines	Artificial saltmarshes	Poles
Initial costs	Heavy machinery	Manual labor and light machinery	Big working sites with heavy machinery	Big working sites with heavy machinery
Long term costs	Limited maintenance	Continuous monitoring and maintenance	May need maintenance based on the used techniques	Relatively durable and limited maintenance
Materials availability	Depends on the quantity of sediment	Cheap and local materials, circular economy	Great quantities of sediments needed	Available materials

Table 9: Scoring of the three main restoration techniques for each of the social criteria. Scores are represented by different colors: Orange= -2, Yellow= -1, Blue= 0, light green= +1; Dark green= +2

	Gabions	Fascines	Artificial saltmarshes	Poles
Jobs created	Limited maintenance needed.	Local labor	Limited maintenance and mostly automated works	Limited maintenance and mostly automated works
Political prestige	Depends on the size of the interventions	Smaller and less impactful interventions	Visible and impactful interventions	Impactful but potential aesthetical issues
Leisure	Depends on the quantity of sediment	Involvement of the population in the works and monitoring	Birdwatching, creation of new environments	

This analysis reveals a nuanced network of trade-offs and associated barriers and facilitators that must be considered when planning interventions for recovery, adaptation, or protection in the Venice Lagoon. Identifying these key factors enhances the overall effectiveness of conservation efforts.
Some of the main trade-offs identified include:

- Costs vs. Duration and Resistance: durable interventions often require expensive heavy structures, with the balance affected by energy levels at the site, serving as a barrier in high hydrodynamic energy areas.
- Impact of Works vs. Duration and Resistance: durable interventions tend to be more impactful, with higher CO_2 emissions and turbidity, posing technical barriers in high energy zones.
- Rigidity of Artificial Edges vs. Natural Development: rigid edges hinder natural saltmarsh structure development, limiting connectivity with surrounding environments.
- Elevation Control vs. Long-Term Costs: maintaining correct elevation over time can be challenging, representing a barrier due to the lack of long-term funding.
- Scale of Interventions vs. Initial Costs: large-scale interventions require significant initial investment, hindered by limited funding and private involvement.
- Scale of Intervention vs. Availability of Materials: large-scale interventions demand substantial material quantities, constrained by limited material availability and governance issues.

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Focusing of the economical barriers, they are predominant, as funding for Venice Lagoon works relies mostly on inconsistent public funding, hindering long-term planning for monitoring and maintenance. Other barriers include reduced return of investment, limited data availability, negative societal perceptions, and a lack of a shared long-term vision among stakeholders.

The identification of main enablers for coastal restoration in the Venice Lagoon includes:

- Stakeholder Interaction: Collaboration among stakeholders, scientific communities, and institutions, facilitated by initiatives like LIFE projects (Vimine, Seresto, Refresh, REST-COAST), has been pivotal for successful interventions.
- Use of Manual and Local Labor: Involving local populations, such as fishers, in small-scale manual works, as seen in projects like SeResto and Vimine, reduces costs and enhances community perception of restoration efforts.
- Advancements in Knowledge and Models: Progress in understanding the Lagoon's processes, dynamics, and threats allows for better future intervention planning.
- Presence of Sheltered Areas: Operating in sheltered, low-energy zones improve the performance of less impactful interventions, offering better restoration outcomes.
- Local Material Sourcing: Utilizing locally sourced materials like wood and textiles reduces costs and promotes circular economy practices.
- Precise Hydrodynamic Modeling: Detailed understanding of water and sediment dynamics aids in planning interventions and selecting suitable sites and techniques for optimal restoration.
- Modularity of Techniques: Modular marginal structures enhance marsh complexity and facilitate natural creek network formation, promoting intervention reversibility and maintenance ease.

This analysis has played a crucial role in understanding the various factors associated with the restoration and protection efforts in the Venice lagoon. One key factor is the importance of establishing an integrated management structure, able to bring together funding agents (public or private), authorities, the scientific community, and other relevant stakeholders to collaborate closely to develop tailored solutions for each specific situation, considering the diverse needs and priorities of all the involved actors, while prioritizing the protection of this precious environment.
The REST-COAST platform will serve as the focal point for the stakeholders to synergize their efforts and drive collective action towards the Venice lagoon preservation.

Annex 2: Factors affecting the abundance and distribution of the birds in the Venice lagoon

Starting from February 2023, birds' communities (bird presence and abundance) have been investigated in the Venice lagoon as biodiversity ecological indicators of great importance (see Chapter 1.3).

Various factors influence the abundance and distribution of waterbirds within the Venice Lagoon. As observed globally (Paracuellos et al., 2004; Zhang et al., 2019), key determinants shaping their presence include the size and quality of feeding areas, characterized by prey abundance, the availability of suitable roosting and nesting sites, the degree of human disturbance, and the presence of predators. This article will delve into some of these factors, focusing on waterbirds utilizing the Venice Lagoon, particularly within the open lagoon environment encompassing both natural and artificial saltmarshes. Detailed examination of fish farms or the littoral strip will not be included.

Understanding which factors affect the distribution pattern of bird's species is essential to protect and favour the precious bird community in a such delicate context like the Venice lagoon. Important sites for birds, and in particular for waders, are the places where they refuge during high tides: the roosts.
The rise in water level during high tides inundates most potential feeding areas for waders in the Venice Lagoon (Fleischer, 1983; Ramli & Norazlimi, 2016), compelling them to aggregate in resting areas known as roosts or high tide roosts. These roost sites, typically located on slightly elevated supratidal areas such as sandbanks, saltmarshes, dikes, or near-coastal shallow lakes (Jackson et al., 2021), become crucial for waders during tidal events. Waders are forced to suspend feeding activities and seek out accessible sites until feeding grounds are re-exposed as water levels recede. Studies have demonstrated reduced foraging success during high tides (Matsunaga, 2000; Puttick, 1978), exacerbated by exceptional tide levels that may render some resting areas completely unavailable. These conditions occur selectively in specific sites based on geomorphological and climatic characteristics, resulting in only a few dry areas being utilized by waders during high tides. Despite the recognized importance of roosts due to the high concentration of birds (Lilleyman et al., 2016; Rehfisch et al., 1996; Rogers, 2003), conservation efforts in the Venice Lagoon remain limited.

In the highly anthropized Venice Lagoon, anthropic disturbance emerges as a significant factor influencing bird occurrence, encompassing various activities such as private and public boat traffic, clam and mussel collection, leisure pursuits like sunbathing, hunting, and fishing. For wintering birds, anthropic disturbance can hinder or diminish the use of tidal flats, critical feeding sites for many species. Roosts, often secluded within the lagoon, generally tolerate indirect disturbances, but immediate abandonment occurs in response to human proximity. Species exhibit varying degrees of tolerance, evident through metrics like flight initiation distance (FID). Studies within the Venice Lagoon reveal longer FIDs for species like the Eurasian Curlew, making them susceptible to disturbance from boat traffic, impacting feeding and roosting behaviors. Effects of clam and mussel collection on wintering waders remain poorly understood in the Venice Lagoon, with site-specific studies elsewhere suggesting variable impacts. Localized disturbance arises from unauthorized artificial structures like hunting hides and weekend huts, disrupting breeding bird habitats. Additionally, rising sea levels, particularly spring-summer high tides exceeding +0.80 m, increasingly inundate nesting sites, jeopardizing reproductive success and prompting species shifts to alternative habitats. The operational MOSE system may mitigate high tide impacts on nesting sites if raised adequately, highlighting the importance of effective flood prevention measures in safeguarding avian populations in the Venice Lagoon.

In Table 10 the most important key factors driving the occurrence and distribute of waterbirds in the open basin of the Venice lagoon are summarized.

Table 10: Some of the most important environmental and anthropic factors which may affect occurrence and distribution of waterbirds in the open basin of the Venice lagoon (fish farms and the littoral strips are not considered).

Factors	**Role and effect**
Occurrence of high tide roosts (natural saltmarshes edge, artificial saltmarshes, banks, breakwater-"lunata")	Allow birds to rest/sleep during high tides, particularly between November and February
Occurrence of feeding areas (natural tidal flats; lower sections of artificial saltmarshes)	Allow birds to find food during low tides, particularly between November and February
Occurrence of safe nesting sites (natural and artificial saltmarshes)	Allow birds to nest, in colonies of with isolated pairs
Anthropic disturbance (mostly boat traffic, but also clam/bait collecting)	It may cause birds to permanent or temporary leave important feeding/resting sites
Recent climate change	1) Probable reshuffling of waterbird species among the winter community. 2) Increase in storminess during spring-summer. 3) Nests made in natural saltmarshes are increasingly destroyed by sustained high tides, particularly between May and June

This project receives funding from the European Union's Horizon 2020 research and innovation programme, under Grant Agreement 101037097

Annex 3: Factors affecting the presence and distribution of the marine seagrasses in the Venice Lagoon

Starting from May 2023, marine seagrasses distribution in the Project pilot area have been investigated as biodiversity ecological indicators of great importance (see Chapter 1.3), playing an important role in sustaining biodiversity, providing habitat for various species, mitigating wave energy, enhancing sedimentation, and stabilizing sediments.

As globally recognized, the main factors that affect marine seagrasses' distribution are light reaching the seagrass bed, sediment characteristics and nutrients in the water column and in the sediment, water depth and exposure, turbidity, salinity, temperature, current and wave action. Considering the Venice Lagoon, the ecological factors related to the marine seagrasses' distribution are numerous even if not all of them have been sufficiently investigated. The main ones, in order of importance, seem to be granulometric distribution of the sediments, water column turbidity, temperature, local hydrodynamism, eutrophication and the related presence of macroalgae.

Table 11 shows a short overview of the most relevant factors affecting marine seagrasses distribution (in particular in the Venice lagoon).

Table 11: Parameters/factors affecting marine seagrasses distribution in Venice lagoon.

Parameter/factor	*C. nodosa*	*Z. marina*	*Z. noltei*	*Ruppia* spp.
Sediment texture and granulometry	Almost exclusively near the inlets or in sites where sediments are characterized by high percentage of sand and low percentage of clay.	In areas where sediments are characterized by low clay fraction, medium silty one and maximun sandy one.	This species appears to be present, overall, on mainly silty sediments.	*Ruppia* (*R. cirrhosa* and *R. maritima*) seems to colonize preferently fine nutrient-rich sediments and decomposing organic matter.
Sediment redox potential	NA	Sediments colonized by this species seem to be characterized by negative redox potentials.	NA	NA
Water turbidity and suspended sediments	NA	NA	The species seem to be the most resistant ones to the reduction of water transparency, also because they settle at shallower depths.	The species seem to be the most resistant ones to the reduction of water transparency, also because they settle at shallower depths.
Hydrodynamic vitality	Almost exclusively near the inlets or in sites characterized by strong hydrodynamics.	NA	NA	NA

Water temperature	Subtropical species with a strong seasonality linked to this parameter variations; foliar apparatus strongly regressed in winter months, strong growth of leaves and rhizomes in the late spring and summer.	Strong growth in the spring months and stop of development due to high summer temperatures (extensive death phenomena when the temperatures exceed 25-30°C).	Good resistance to changes in temperature due to the duration of emersion and exposure to which they are subjected.
Salinity	A typically stenohaline species that requires high salinity waters also characterized by a good purity level.	*Zostera marina*, *Z. noltei* and *Ruppia* spp. are euryhaline species.	
Eutrophication and Water and sediment pollution	The improvement of trophic and ecological status of the lagoon (concentrations of nutrients in the surface sediments and in the water column) highlighted the simultaneous increase of seagrass cover and the spreading of sensitive macroalgal taxa (Sfriso et al., 2019).		

This project receives funding from the European Union's Horizon 2020 research and innovation programme, under Grant Agreement 101037097