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D6.10 Restoration Demo at Arcachon Basin

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WP6

Lead beneficiary: SEA (EGIS)

Authors: Julien Dalle, Mathis Cognat

REST-COAST

Large Scale RESToration of COASTal Ecosystems through Rivers to Sea Connectivity

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Table of contents

Preface 4
Summary 4
1 Introduction to Pilot Site 6
2 Benefits of restoration (perceived, achieved, not achievable, expected) 8
3 Demonstrative material of restoration benefits (explanatory text, maps, schematic illustrations, photos) 10
3.1 Restoration demo video 10
3.2 Maps and results illustration to onboard local institutions 14
3.3 Scientific communication 16
4 Demonstration activities 21
4.1 Hands-on restoration actions 21
4.1.1 Field surveys 21
4.1.2 Field deployment 26
4.1.3 Demonstration value and replication 31

Preface

This document presents the actions implemented as part of the pilot project in the Arcachon Basin to valorize large-scale ecological restoration operations carried out on this site and promote the use of Nature-Based Solutions.

To this end, several actions have been undertaken, including:

- The production of video content, soon to be edited, to illustrate the operation and its benefits, including aerial footage and interviews to provide educational and accessible content, especially for the general public.
- Modeling at different scales, allowing for projections of restoration actions with a logic of results and generated services, targeting local stakeholders in particular.
- Scientific communications and participation in events for presentation or awareness-raising on this type of action. These actions aim to share the project and its results with the scientific and academic community.

Communication and dissemination actions on this pilot site are complex, mainly due to the private status of the lead pilot, which limits the ability to mobilize actors from the public sphere, and due to its location more than 600km from the project area, which also reduces on-site presence in contact with users. To address this challenge, close collaboration has been initiated with the local manager of the marine area, both operationally through the launch of a "sister" project to REST-COAST called PROSPERE, and communication actions, relying on the presence and actions of the PNMBA to communicate about the results of the REST-COAST project.

Summary

This report details the nature of the various communication and dissemination actions conducted. These actions aim to describe the restoration activities carried out in the Arcachon Basin, to explain the sequence and perspectives of these activities, and to solicit feedback from local stakeholders (users, scientists, institutional actors, etc.) to identify and address barriers to scaling up.

The document is structured to present the nature of the different communication means used and the associated content, but also to detail the objectives of each action and how we intend to use and valorize these actions in a logic of scaling up restoration activities. Through these communication actions, several key phases of the project are documented, including field actions, modeling which opens up a number of application perspectives, and ecosystem service evaluation actions that we wish to bring to the attention of local decision-makers.

1 Introduction to Pilot Site

The Arcachon Bay, located on France's southern Atlantic coast, is the home to the largest Zostera noltei seagrass meadow in Europe as well as Zostera marina beds in the subtidal area. Z. noltei have lost 45% of their surface in the last two decades and Z. marina 89%. Therefore, one of the Arcachon Bay Natural Park's main and pressing objective is to attempt rapid and large-scale restoration through innovative processes. Ifremer recent research programs led in the area (Cognat et al., 2018; Cognat, 2019) have concluded that restoring adequate hydrodynamic conditions would help seagrasses to expand, thus priming positive feedback processes and working towards a reversion of the actual trend. EGIS and Ifremer are currently involved in a pilot experiment in the Arcachon bay based on the deployment of a tide and current attenuation device adjacent to regressing Z. noltei beds. Designed by Seaboost, an Egis-subsidiary, the device aims at reducing current flow velocities leading to sediment stabilization and spontaneous recovery of seagrass meadows.

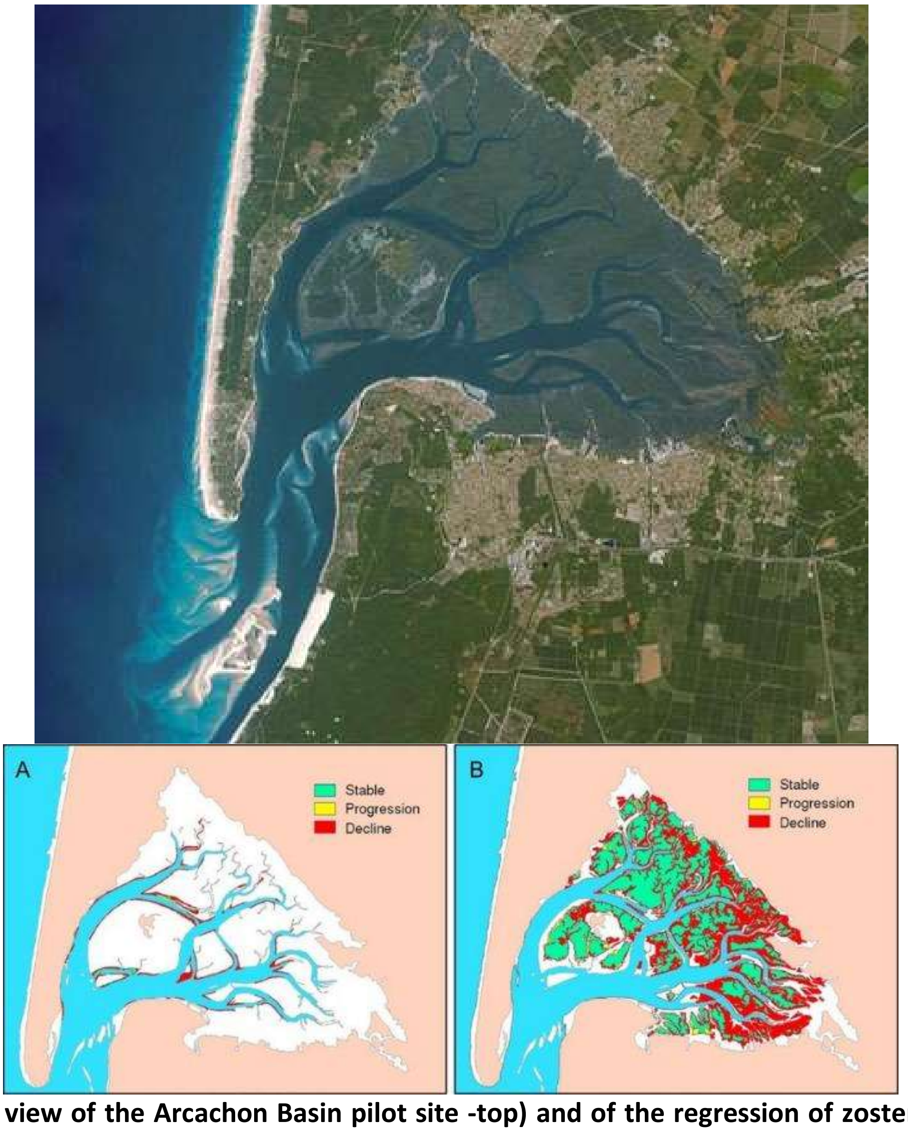


Figure 1. Aerial view of the Arcachon Basin pilot site -top) and of the regression of zostera marina (left) and zostera noltei (right) between 1989 and 2007/2008

As part of the restoration action undertaken in the Arcachon Basin, the objective is to demonstrate the relevance of implementing local hydrodynamic control to create favorable conditions for the recovery of seagrasses in areas where they have declined. This action unfolds in three phases: a demonstration phase in situ of the effects of the reed bed on the hydro-sedimentary aspect, a large-scale demonstration phase (>1ha) of the effects of calibrated reed bed on seagrass restoration, and a modeling action at the basin scale aimed at illustrating the expected results of this type of large-scale action on seagrass coverage and associated ecosystem service production.

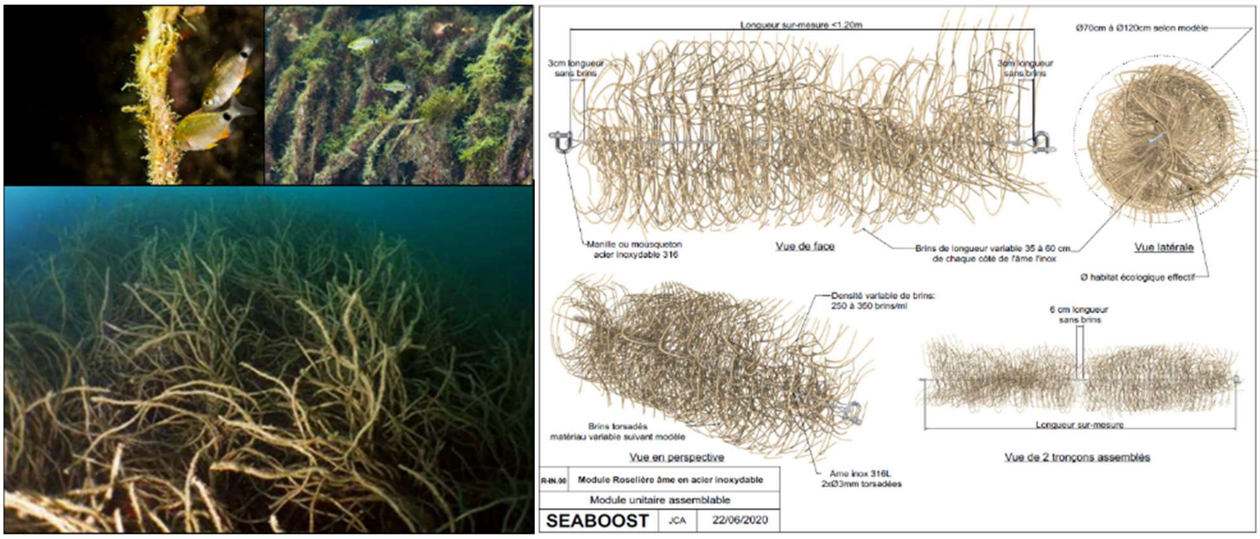


FIGURE 2. ILLUSTRATIONS OF THE ROSELIÈRE DEVICE

2 Benefits of restoration (perceived, achieved, not achievable, expected)

Introduction to the restoration project initiated under REST-COAST is not universally seen as inherently virtuous or beneficial in the Arcachon Bay area. Firstly, some stakeholders perceive it as a potential hindrance to certain activities, given that it is a heavily anthropized zone with numerous socio-economic activities reliant on the marine environment (oyster farming, tourism, fishing, boating). Consequently, ecological restoration faces the challenge of competing for space. Furthermore, certain activities, particularly those related to fisheries, are concerned about potential alterations to environmental or hydrodynamic conditions in Arcachon Bay, fearing it could impact the performance of their operations.

Therefore, one of the anticipated benefits of REST-COAST is to demonstrate the viability of large-scale ecological restoration alongside existing activities. While this goal has been partially achieved, notably through the involvement of oyster farmers and volunteers in the project and its sister project PROSPERE, translating the cross-functional nature of ecological restoration actions into the strategies of local managers will prove much more challenging due to the compartmentalized governance. At this stage, it is likely that we will not be able to establish a unified strategy for ecological restoration at the scale of the bay, including regulatory developments, within the REST-COAST project, and that this benefit will be achieved later on. However, it is realistic to envision the implementation of a large-scale restoration strategy led by the local MPA manager.

On a technical level, the restoration action undertaken in Arcachon Bay is primarily a technical demonstration aimed at establishing the relevance of hydro sedimentary control approaches to address one of the major obstacles to eelgrass restoration. In this regard, one of the main benefits of the REST-COAST project in Arcachon Bay lies in the development and testing of a restoration technique, as well as the ability to project future trends using dedicated tools (numerical models and quick scan tool). Therefore, producing results from the operation and strategic decision-making tools is clearly one of the project's benefits. Defining a restoration strategy and sharing it are among the expectations for the end of the project.

Through ecological restoration action, one of the major benefits is the production of results in terms of biodiversity and ecosystem services. In this regard, biodiversity restoration has clearly closely involved the local manager, who participates in the project, seizes the shared tools and results, and shares the benefits at local governance meetings. Moreover, the production of ecosystem services such as climate regulation (carbon capture in particular) and erosion control, especially against siltation in navigation channels, are of great interest to local managers whose responsibilities do not include biodiversity. The low-carbon label, soon to be implemented for zostera noltei, would also involve private industry in financing eelgrass restoration, which is one of the targeted benefits of REST-COAST, particularly through the implementation of WP3 in Arcachon Bay.

In summary, here is a table summarizing the benefits obtained, expected, and unattainable in the case of the Arcachon pilot site under the REST-COAST project.

		ACHIEVED	EXPECTED	NOT ACHIEVABLE
Technical	Demonstration of a large-scale innovative restoration methodology for zostera seagrass meadows		**X**	
Technical	Demonstration of hydrodynamic control performance of seagrass-inspired solution	**X**		
Technical	Demonstrate the interest of Arcachon Basin zostera for carbon capture and storage		**X**	
Upscalling	Design of long-term scenarios for large scale ecological restoration, including ESS and BDV trends	**X**		
Upscalling	Design of a restoration strategy for zostera seagrass at basin scale		**X**	
Upscalling	Obtainment of a global commitment with all stakeholders about the restoration strategy defined by MPA manager			**X**
Upscalling	Introduction of new funding/ financing perspective through carbon and biodiversity carbon to enhance ecological restoration			**X**
Social	Raising awareness of the benefits of ecological restoration and its compatibility with local activities	**X**		
Social	Involving local stakeholders on hands-on restoration operations	**X**		
Governance	Onboarding local MPA manager on REST-COAST, including upscaling perspectives	**X**		
Governance	Creating a restoration dedicated transversal committee involving all key decision-makers			**X**
Governance	Impulse evolution of the regulatory framework to support and enhance large scale ecological restoration perspective at local / regional scale			**X**

3 Demonstrative material of restoration benefits (explanatory text, maps, schematic illustrations, photos)

In the Arcachon Basin, one of the key challenges in communicating the results and benefits of ecological restoration is the appropriation of these results by local institutional and public stakeholders. The site is subject to complex and highly fragmented governance, with very strong socio-economic interests, particularly in tourism, oyster production, and boating. Each of these interests can lead, in isolation, to very divergent orientations regarding space management. In the context of our dissemination action, it is essential for us to illustrate the perspectives of large-scale restoration in terms of the benefits they can produce, the services generated, and their relevance to each of the key activities of this site.

The specificity of this site is that the lead pilot is neither involved nor consulted in the framework of local governance. Therefore, our communication strategy must clearly and convincingly present results of interest so that the benefits of large-scale ecological restoration are shared, and these actions can be integrated into the strategies of various local decision-makers and funders in a cross-cutting manner.
Thus, we proposed 3 types of content, in order to achieve our goal, targeting several specific stakeholders and needs:

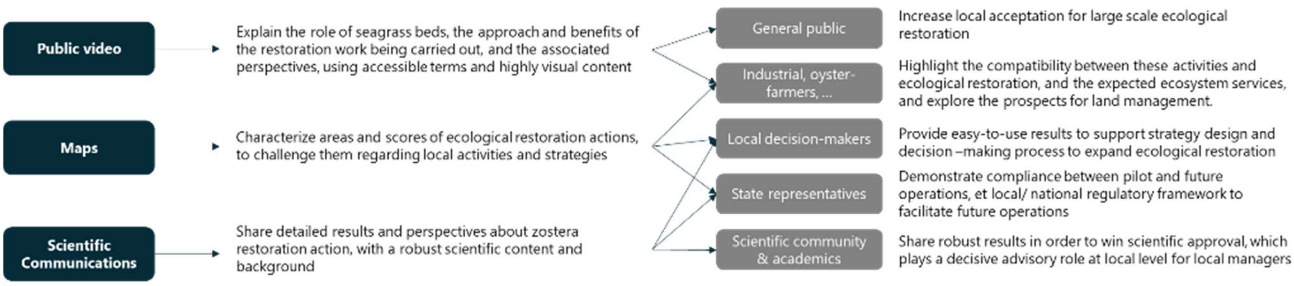


FIGURE 3. SIMPLIFIED SCHEME OF ARVCACHON BASIN COMMUNCIATION STRATEGY ACCORDING TO TARGETS AND BARRIERS

3.1 Restoration demo video

On REST-COAST project, the creation of a public video to explain the results of the ecological restoration of seagrass and to share these results serves multiple important purposes in the frame of Arcachon Basin fellow pilot.
Firstly, it provides an accessible and engaging medium through which complex scientific findings and restoration outcomes can be communicated to a wide audience, including local residents, stakeholders, and decision-makers. By visually showcasing the before-and-after effects of the restoration efforts, including the recovery of seagrass habitats and associated biodiversity, the video can effectively convey the tangible benefits of the restoration project.

Moreover, a public video can help raise awareness and foster appreciation for the importance of seagrass ecosystems and the broader concept of ecological restoration. By highlighting the ecological functions and services provided by seagrasses, such as coastal protection, carbon sequestration, and habitat provision for marine species, the video can inspire greater support and engagement from the community.

Furthermore, the video can serve as a valuable educational tool, providing insights into the scientific methods employed in the restoration process, the challenges encountered, and the lessons learned. This can help build public trust and confidence in the effectiveness of restoration efforts, as well as promote transparency and accountability in environmental management practices.

Given our communication objectives through this media, which are to overcome barriers to large-scale restoration among the general public and industrial/tourism/aquaculture stakeholders in the basin, this tool appears particularly suited to convey messages accessible to a wide audience.

At this stage, all the content for the production of this video has been acquired. A storyline has been developed, and a selection must now be made to illustrate as effectively as possible all the statements and messages of the video with appropriate content for editing. The storyline of the video is available below, along with some screenshots of the video rushes that will be used in this film. We can also provide all the raw video content if needed.

REST-COAST – ARCACHON BAY STORYLINE

Storyline	Video/ Picture
Seagrass meadows are key engineering ecosystems, providing several ecological functions like nursery, habitat, production, … and several ecosystem services, like erosion control, food provisioning, water purification and carbon capture for instance.	Stockshot herbier Voice-over
The spatial variability of seagrass meadows in Arcachon Bay, was studied between 1988 and 2008 using a combination of mapping techniques based on aerial photographs for intertidal dwarf-grass (***Zostera noltei***) beds and acoustic sonar for permanently submerged eelgrass (***Zostera marina***) populations. The results show a severe decline over the period for both species, as well as an acceleration of the decline since 2005 for ***Z. noltei***. The total surface regression over the studied period is estimated to be 25.8 km2 for ***Z. noltei*** and 2.7 km2 for ***Z. marina***, which represent declines of 33 and 74% respectively.	Maps from Mathis PhD work and Florian Ganthy (Ifremer) to illustrate seagrass regression. Large scale drone aerial views
Several factors have been identified as potential causes of the decline in these meadows. Increased frequentation of the Arcachon basin and the development of associated socio-economic activities, the intensification of certain agricultural practices, the impact of anchoring, rising temperatures, etc. are all factors that may be correlated with this regression dynamic.	ITW Mathis
Among these parameters, Mathis Cognat's thesis identified hydrodynamics as the main factor in their regression, and a major brake on the resilience of these species. Indeed, the regression of seagrass leads to an increase in bottom current velocities, which can result in the mechanical uprooting of near plants. Additionally, this rise in currents induces erosion, consequently elevating suspended sediment concentrations, thus reducing available light – the primary controlling factor for plant growth. This weakening in turn reduces their ability to reduce near-bottom currents, which in turn increases sediment remobilization processes, further weakening this ecosystem and leading to the observed collapse of seagrass populations in the basin.	ITW Mathis
Rôle et importance des herbiers de zostères	ITW Thomas
As part of the Rest-Coast project, Seaboost's aim is to design, deploy and test a large-scale solution for controlling local hydrodynamic forcing. The aim is to reproduce the effects of the seagrass on its environment, so as to stem this negative effect (regression) of the feedback and create a context favorable to seagrass resilience. In a way, we aim to initiate a positive effect (progression) of feedback loop by controlling flow velocities close to the bottom. During the project, we built a string relationship with the local MAP Manager, the PNMBA (Parc Naturel Marin du Bassin D'Arcachon, and built together another project on the same area in order to merge our approach, focusing on hydrodynamics, with the introduction of biological material as seedlings or rhizomes.	

Our intervention is based primarily on the deployment of a system that reproduces the seagrass and mimics its effects on the local context. It is divided into 3 phases: **- a first, small-scale experimental phase, aimed at testing and measuring the effects of different seagrass configurations by varying the length of the strands, their density, and their position in the water column, so as to obtain the most relevant effects possible in the near field.** **- A second phase of large-scale deployment (>1ha) to assess the effects of the chosen configuration on the morphodynamical context and the meadow on a large scale.** - A third phase of basin-wide modeling of long-term seagrass restoration scenarios, to feed into the local management strategy for marine ecosystems.	ITW Mathis
During phase I, the settlement and in situ detailed measure allowed us to determinate the wake pattern of the roselière system, and to define the most relevant deployment pattern to optimize the flow attenuation effects per surface unit. We selected an area with seagrass meadows under regression and performed several tests and measures. Then, we defined with numerical model a settlement pattern that would be able to tackle both flood and ebb current effects and to optimize bed shear stress.	Pictures from Damien sous
During phase II, we settled our system at large scale in order to restore more than 1 ha of seagrass meadows and to assess the effects of different deployment pattern. The whole operation was settled in September 2023. This settlement involved a team of more than 20 people, including Seaboost team, local MPA manager team, oyster-farmers and NGO team that were involved for the occasion. Several sites were equipped, in order to assess both the effects of the experimentation in and out of the settlement pattern, and to check how we could take benefits from the wake of the system. We are also testing different configuration, to select the most relevant option for future basin scale application. **Several monitoring activities (hydrodynamic, morphodynamic and biological) were performed to access the ability of the solution to create a favorable context and restore seagrass meadow.** Moreover, we also performed in situ monitoring in order to characterize the performance of Arcachon Bay seagrass meadows to perform climate regulation service, meaning the ability to catch and store GHGs. This involved several samples on several sites to assess carbon content and GHG kinetics, associated with Pb isotopes analysis to perform a datation of the carbon stored in the soil. We are then able to assess accurately the stock and dynamic of carbon for that kind of ecosystem, and thus to build realistic scenarios. This work was performed jointly with Egis Environment team and INRAE-Lyon laboratory. In parallel, Egis Water and Maritime Team worked on setting up coupled hydro-morpho-ecological models for risk assessment (erosion, submersion, water quality) related to the ecosystem restoration at the pilot site. A model in which the ecosystem services of the areas to be restored must be taken into account and quantified by adapting them to current climatic conditions and future scenarios. Delft-FM hydro-morphological model chosen for Arcachon Bay: • 2D modeling on a curvilinear grid • D-Flow module: calculation of induced hydrodynamic components (tide, lapping, continental inputs) • Trachotype module: vegetation modeling • D-Mor module: calculation of morphological changes associated with sediment transport in the bay.	Drone views from settlement operation and large-scale implementation of the restoration action. ITW Mathis et Thomas Voice-over carbon picture from small scale numerical model to illustrate the attenuation wake of the devices. Animation from numerical model to show the effects of seagrass restoration scenarios on global hydrodynamics at basin scale

Modeling example: Representation of the evolution of currents in the Bay according to the period of the tidal cycle. Understand the hydrodynamics of the bay and see the effect of the presence of seagrass beds on current reduction, which modifies sediment transport and therefore potential morphological variations. Current conclusion on morphodynamic modeling: Restoration of vegetation could lead to a decrease of sediment deposition on the bottom on the Bay and an erosion of secondary channels (improving hydrodynamics)	
We initiated our phase III work in collaboration with Ifremer, one of the leading French laboratories on marine ecology. We are using MARS model for that purpose, which is a large-scale high-resolution model to characterize progression / regression trend of seagrass meadows according to multiple environmental parameters. We use this model in order to simulate basin scale scenarios, that will be used as a basis for strategy workshops, to challenge and optimize the restoration strategy for seagrass in Arcachon Basin. **The first results are very promising, as we are able to demonstrate that we should really reverse the positive feedback process on seagrass progression through our method. Equipping the limit of the channels should allow to restore seagrass that are immediately nearby, thus allowing to reduce flow velocities on large foreshore areas and enabling seagrass recovery from near to near.** we have scenarios allowing the restoration of several dozen hectares over time thanks to the equipment of the edges of the channels on long lines surrounding the foreshores in strong regression	Extraction from Ifremer model to show different restoration scenario based on seagrass growth model and describing the expected results of local hydrodynamic control (cf REST-COAST) on global seagrass restoration (cf perspectives) Voice-over
Through the work on ecological restoration and ecosystem services assessment, we should be able to demonstrate the relevancy of our approach to tackle large scale restoration issues in Arcachon Basin, and we will use these scenarios as a basis in workshops with local stakeholders define and adjust large scale seagrass restoration strategy.	Voice-over Plan drone large




FIGURE 4. SCREENSHOTS OF VIDEOS CAPTURED ON ARCACHON BASIN PILOT BEING PROCESSED TO PRODUCE A VIDEO TO COMMUNICATE ABOUT THE PROJECT AND ITS RESULTS

3.2 Maps and results illustration to onboard local institutions

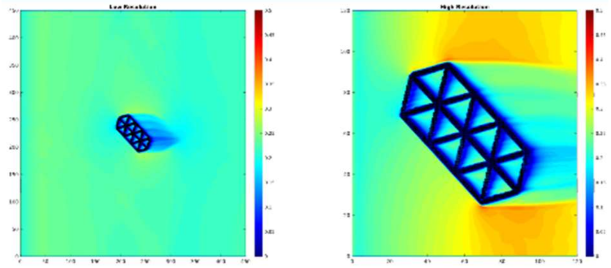
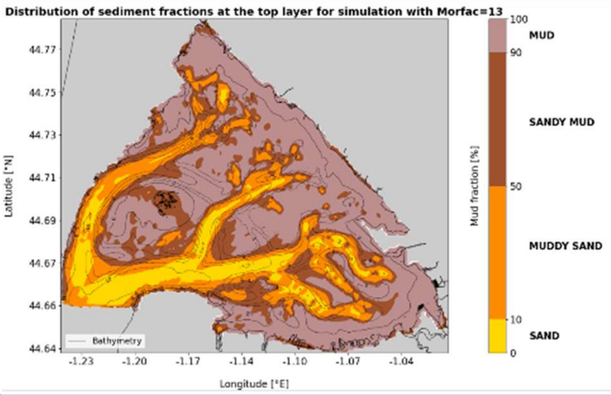
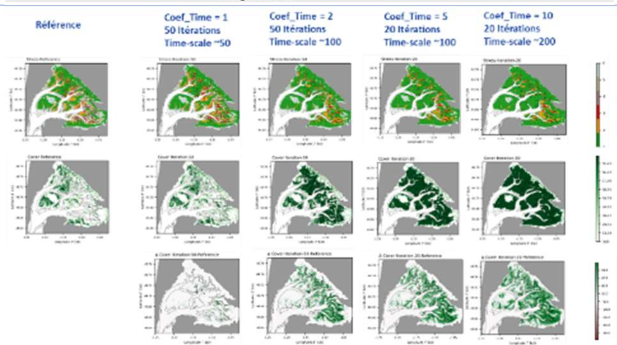
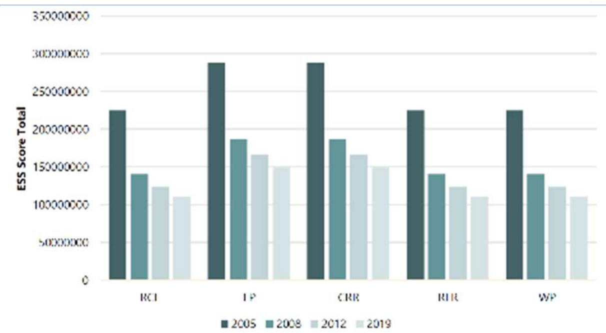
From our point of view, using maps to present the results of ecological restoration to local decision-makers psrovide a visual representation of spatial data, allowing decision-makers to quickly grasp the extent and location of restoration activities and their outcomes. This spatial context is essential for understanding the distribution of restored habitats, the connectivity between different ecosystem components, and the potential impacts on surrounding areas.

Additionally, maps can help highlight areas of priority for future restoration efforts, based on factors such as habitat loss, ecological significance, and vulnerability to environmental stressors. By overlaying multiple layers of spatial information, such as habitat distribution, land use, and environmental indicators, decision-makers can identify strategic locations for intervention and allocate resources more effectively.

Furthermore, maps facilitate communication and collaboration among stakeholders by providing a common visual language for discussing restoration goals, strategies, and outcomes. Decision-makers from different sectors, such as environmental management, urban planning, and infrastructure development, can use maps to coordinate their efforts, share information, and identify synergies or trade-offs between competing priorities.

Overall, the use of maps in presenting ecological restoration results to local decision-makers enhances spatial understanding, supports evidence-based decision-making, and fosters stakeholder engagement and collaboration. By visualizing the complex relationships between ecological processes and human activities, maps empower decision-makers to make informed choices that promote the long-term sustainability and resilience of ecosystems and communities.

As a consequence, we are relying on several tools developped in the frame of Rest-coast project in order to produce that kind of output to deliver clear messages illustrating the outputs of ecological restoration at large / basin scale, and to propose that kind of actions as inputs for future local strategies. We especially take advanatge of the following tools to propose these contents :

Tool	Output
Small scale numerical model, allowing to clearly explain the benefits of our approach in terms of hydrodynamics control, adn of effects on local flows and sediments	
Large scale hydro-morphological model, in order to share a gobal understanding of large scale perspective on hydrodynamics due to seagrass restoration. It helps in particular explaining outputs ion terms of erosion / submersion risks, but also in terms of dredging needs for instance.	
Large scale hydro-biological model, helping us with Ifremer expertise, to communicate on biodiversit output, ie. the expected success of large scale restoration action after local hydrodynamic control	
Quick scan tool, which has been developped by Deltares in the frame of REST-COAST, and that helps us understanding and forecating types and trends of ecosystem services value to be expected from large scale restoration actions	

The production of these cartographic results allows for a direct correlation between the expected outcomes of large-scale ecological restoration and:

- Concrete management challenges, such as optimizing dredging, rehabilitating oyster farming sites, or managing the basin in light of the various activities it hosts.
- Possible synergies between local governance actors with disjointed jurisdictions, but for whom ecological restoration provides a mutual solution, such as the combination of reducing submersion risk and improving biodiversity.

These maps are used as tools during working sessions, particularly during quarterly seagrass commissions, where we have the opportunity to share these elements with all local stakeholders, gather their reactions, and address questions associated with the restoration process.

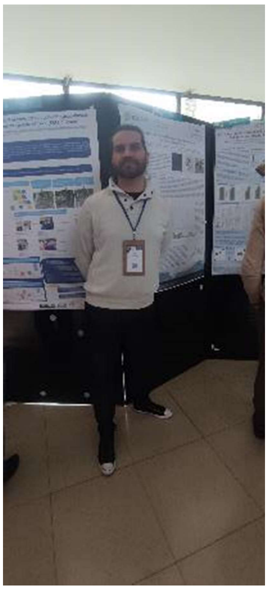
FIGURE 5. PHOTOGRAPHI OF PARTICIPANTS IN ZOSTERA COMISSION, LEAD BY LOCAL MPA MANAGER
Photographie prise lors de la comission zostère du 25 Novembre dernier – crédit photo PNMBA

3.3 Scientific communication

Communicating our results with rigorous scientific backing allows us to garner the support of the scientific and academic community for the project. This support is crucial in engaging in basin-scale restoration initiatives, as this scientific community plays a pivotal advisory role to the managers of the Arcachon Basin. Furthermore, with the perspective of replicating such actions on other sites in the future (out scaling), raising awareness within the scientific community about the approach employed, the results obtained, as well as the decision support tools implemented for local decision-makers, constitutes a significant lever for implementing local actions.

At this stage, several of our works on the Arcachon pilot project have been or are planned to be communicated scientifically. These include:

- A poster presented at the SoilCet congress by Olivier Taugourdeau (Egis) aims to detail our initial results on the analysis of the ecosystem service "climate regulation" supported by the seagrass beds of the basin.



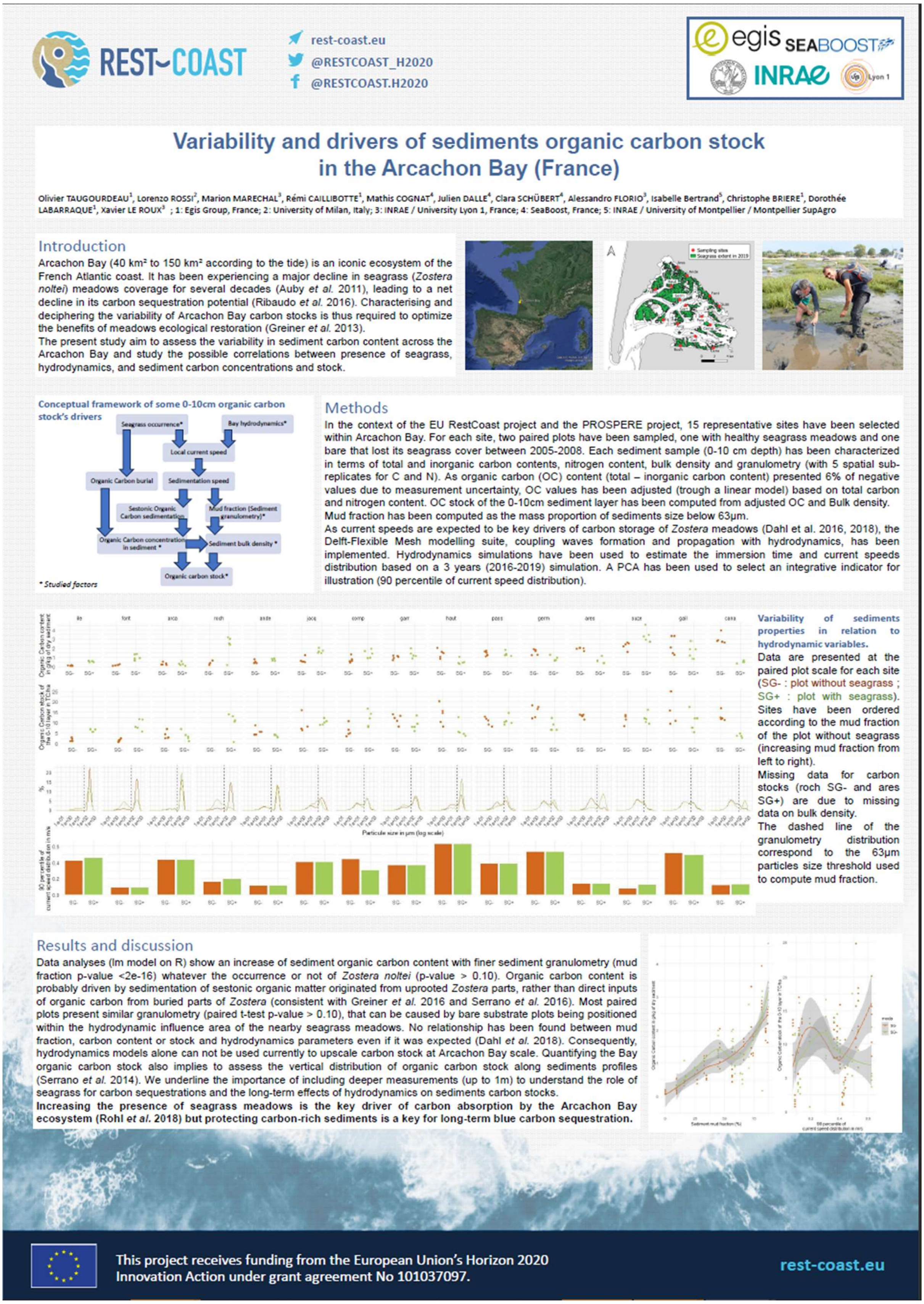


FIGURE 6. PHOTOGRAPHY OF THE POSTER PRESENTED IN SOILCET

- A presentation at the scientific days of the Arcachon Basin in May 2024 illustrates the significance of the method employed for large-scale restoration of seagrass beds in the basin, with a specific focus on biodiversity and the ecosystem service of climate regulation.

FIGURE 7. SCREENSHOT OF THE POSTER TO BE SHARED IN THE SCIENTIFIC DAYS OF ARCACHON BASIN

- An oral presentation and the delivery of a scientific communication at the National Civil Engineering and Coastal Engineering Days in June 2024 illustrate the benefits of ecological restoration of seagrass beds in terms of reducing sediment deposition in navigation channels and its importance for reducing dredging costs, for example.

Caractérisation des services écosystémiques rendus par les herbiers de zostères dans le Bassin d'Arcachon - Application d'un modèle couplé éco-morphodynamique

Rémi CAILLIBOTTE [1], Julien FORNASARI [1], Soazig MAHE [2], Alexis BEUDIN [3], Christophe BRIERE [2]

1. Egis Group, Equipe Littoral et Interface Terre/Océan, 889 rue de la vieille poste, 34000 Montpellier, France.
   remi.caillibotte@egis-group.com ; julien.fornasari@egis-group.com
2. Egis Group, Equipe Littoral et Interface Terre/Océan, 15 avenue du centre, 78280 Guyancourt, France.
   soazig.mahe@egis-group.com ; christophe.briere@egis-group.com
3. Egis Group, Equipe Littoral et Interface Terre/Océan, 208 Quai de Paludate, 33800 Bordeaux, France.
   alexis.beudin@egis-group.com

Résumé :
Dans le cadre du projet européen REST-COAST (Large scale RESToration of COASTal ecosystems through rivers to sea connectivity), une modélisation numérique basée sur la suite Delft-Flexible Mesh (D-FM) a été mise en œuvre pour analyser le rôle potentiel des herbiers de zostères sur l'aléa submersion, la qualité des eaux et la gestion des sédiments dans le Bassin d'Arcachon.
L'étude se focalise sur ce dernier point en présentant la démarche de modélisation couplée courants-végétation-sédiments (mix sablo-vaseux). Afin d'appréhender des évolutions morphologiques à l'échelle de plusieurs années, une représentation synthétique des forçages est nécessaire. Les réponses physiques qui résultent des scénarios de restauration des herbiers de zostères considérés sont présentées, ainsi que l'analyse des boucles de rétroactions associées.
Ce travail s'intègre dans un volet d'étude socio-économique servant à apporter un éclairage sur la planification de cet espace marin.

FIGURE 8. SCREENSHOT OF THE ABSTRACT FOR THE PRESENTATION TO BE PERFORMED IN JNGCGC 2024

- An upcoming oral presentation at the ASTEE (Association Scientifique et Technique pour l'Eau et l'Environnement) congress in June 2024 highlights the importance of restoration in increasing our resilience to coastal risks, within the context of climate change.

- A presentation at the 2024 World Seagrass Conference & 15th International Seagrass Biology Workshop aims to present the initial results of our large-scale restoration approach in terms of hydrodynamic control levels and restoration prospects, primarily focusing on biodiversity and climate regulation aspects.

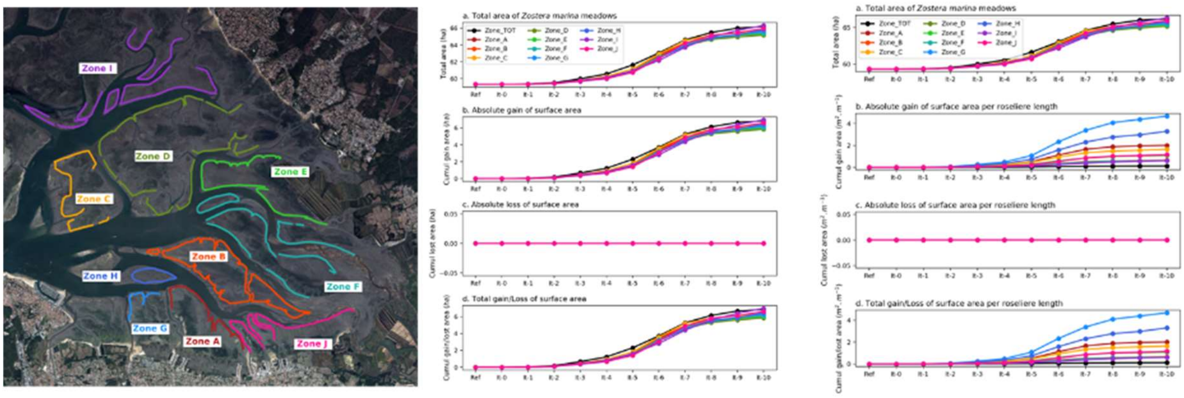
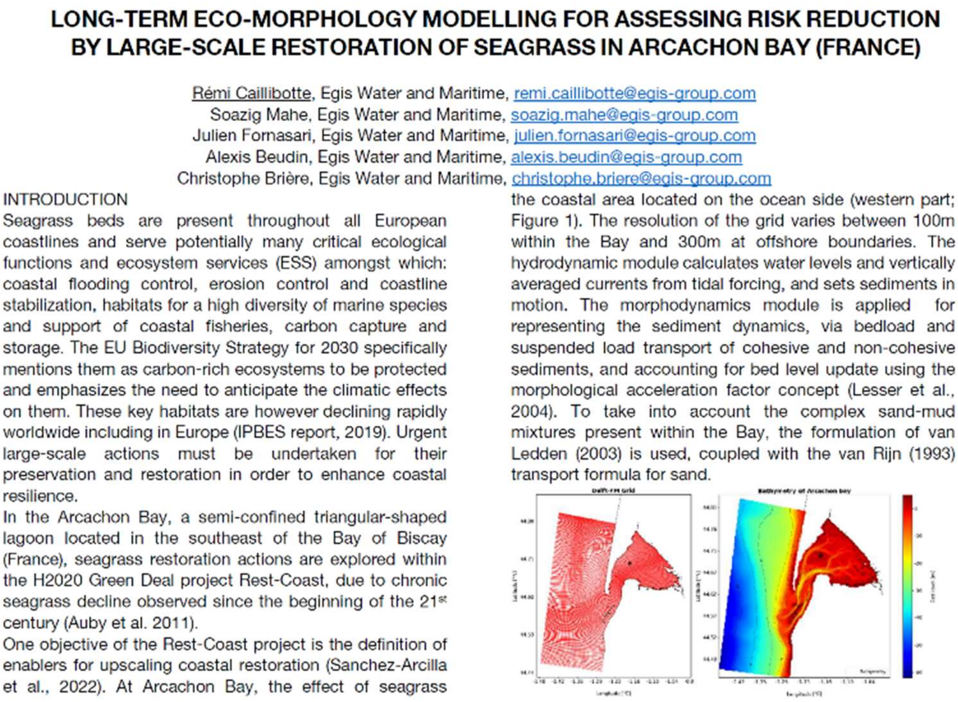


FIGURE 9. EXTRACTION OF THE RESULTS TO BE SHARED IN WORLD SEAGRASS CONGRESS 2024 SHOWING THE PERSPECTIVE OF RESTORATION SUCCESS ACCORDING TO THE PRIORITIZATION OF THE AREAS IN THE ARCACHON BASIN

- An oral presentation at the ICCE (International Conference on Coastal Engineering) in September 2024 showcases the significance, as demonstrated by numerical modeling, of seagrass restoration in reducing dredging needs and improving water quality.



LONG-TERM ECO-MORPHOLOGY MODELLING FOR ASSESSING RISK REDUCTION BY LARGE-SCALE RESTORATION OF SEAGRASS IN ARCACHON BAY (FRANCE)

Rémi Caillibotte, Egis Water and Maritime, remi.caillibotte@egis-group.com
Soazig Mahe, Egis Water and Maritime, soazig.mahe@egis-group.com
Julien Fornasari, Egis Water and Maritime, julien.fornasari@egis-group.com
Alexis Beudin, Egis Water and Maritime, alexis.beudin@egis-group.com
Christophe Brière, Egis Water and Maritime, christophe.briere@egis-group.com

INTRODUCTION
Seagrass beds are present throughout all European coastlines and serve potentially many critical ecological functions and ecosystem services (ESS) amongst which: coastal flooding control, erosion control and coastline stabilization, habitats for a high diversity of marine species and support of coastal fisheries, carbon capture and storage. The EU Biodiversity Strategy for 2030 specifically mentions them as carbon-rich ecosystems to be protected and emphasizes the need to anticipate the climatic effects on them. These key habitats are however declining rapidly worldwide including in Europe (IPBES report, 2019). Urgent large-scale actions must be undertaken for their preservation and restoration in order to enhance coastal resilience.
In the Arcachon Bay, a semi-confined triangular-shaped lagoon located in the southeast of the Bay of Biscay (France), seagrass restoration actions are explored within the H2020 Green Deal project Rest-Coast, due to chronic seagrass decline observed since the beginning of the 21st century (Auby et al. 2011).
One objective of the Rest-Coast project is the definition of enablers for upscaling coastal restoration (Sanchez-Arcilla et al., 2022). At Arcachon Bay, the effect of seagrass

the coastal area located on the ocean side (western part; Figure 1). The resolution of the grid varies between 100m within the Bay and 300m at offshore boundaries. The hydrodynamic module calculates water levels and vertically averaged currents from tidal forcing, and sets sediments in motion. The morphodynamics module is applied for representing the sediment dynamics, via bedload and suspended load transport of cohesive and non-cohesive sediments, and accounting for bed level update using the morphological acceleration factor concept (Lesser et al., 2004). To take into account the complex sand-mud mixtures present within the Bay, the formulation of van Ledden (2003) is used, coupled with the van Rijn (1993) transport formula for sand.

FIGURE 10. EXTRACTION OF THE OREL PRESENTATION THAT WILL BE SHARED DURING ICCE 2024

4 Demonstration activities

4.1 Hands-on restoration actions

4.1.1 Field surveys

Carbon storage potential of the Arcachon basin

The role of Seaboost in the Arcachon basin is to restore regressed seagrass beds by installing current slowing artificial seagrass, called Roselière. In order to estimate the carbon storage potential of the basin, a carbon storage estimation study was performed in September 2022 together with INRAE, soil.is and eco&soil. A total of 15 sites (Figure 1) were assessed, measuring the stored carbon in bare (Figure 3) and colonized plots (Figure 2), because carbon is known to fluctuate strongly among different sediment types (muddy/sandy), current speeds, immersion times and other abiotic factors. Additionally, the seagrass cover was estimated and included as the main biotic factor influencing carbon storage. By using an isotope dating method, the age of sediment within 5 sites was estimated in order to understand the age and history of the upper sediment layer. This data can be used to investigate if there was predominantly accumulation (new sediment on top) or erosion (old sediment on top) in the last 100 years and the accumulation rate can be calculated. The dating of the sediment helps to understand the predominant processes in the 15 locations and if seagrass helps to retain sediments within those locations.

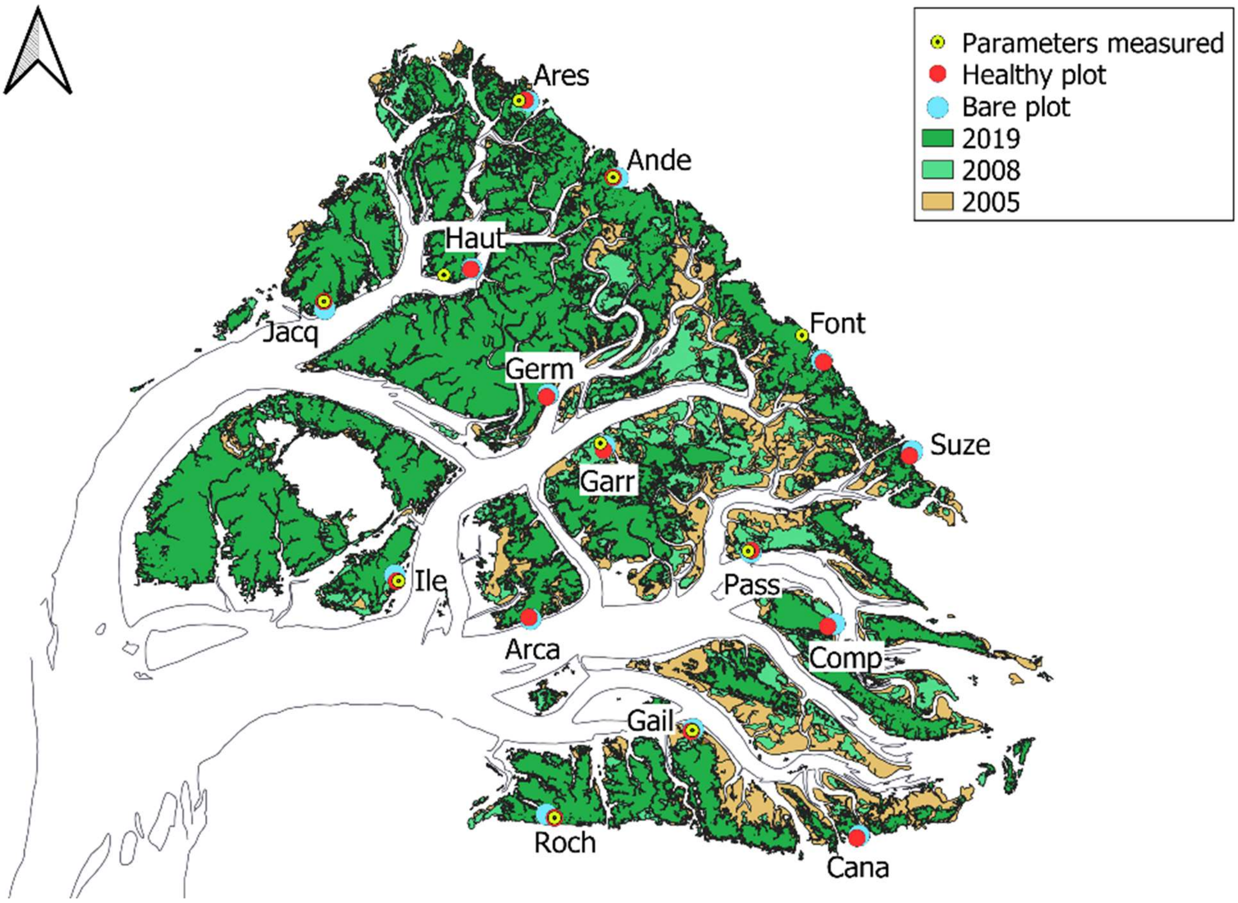


Figure 11 Sampling locations in the Arcachon Basin.

By knowing the difference in stored carbon between bare and colonized plots, it can be estimated how much carbon could be stored in the basin if the bare areas would be restored to colonized areas. It is crucial to assess the carbon sequestration potential (the storage of carbon from the atmosphere within plants) and the carbon capture potential (due to the accumulation of sediment) of seagrass meadows to implement nature-based solutions and mitigate the increase of carbon in our atmosphere.

Figure 12 Sampling of bare Sediment Core. Core is pushed into the sediment, then retrieved by digging a hole next to the core and stored in a plastic bag.

Hydrodynamics measures and field calibration of restoration method

In order to characterize the in-situ current climates and to dimension the biomimetic reed beds of the seagrass (leaf density, leaf length, surface density, etc.), in-situ hydrodynamic monitoring works have been conducted. These works have allowed for the calibration and validation of the reed beds used, and for sizing the necessary anchorages to ensure the long-term stability of the deployed systems.

FIGURE 13. LOCATION AND SHCEMATIC PROTOCOL FOR HYDRODYNAMIC SURVEYS TO CALBRATE ROSELIÈRE DEVICE

The measurement campaign took place from May 9 to May 27, 2022. Two important constraints of the study are the evolution of the tidal range, which determines the duration of access to the site at each low tide, and the intensity of the wind, which determines the navigability of the water body. Figure 3 represents the tidal coefficient over the 3 weeks of deployment, Figure 4 represents the wind intensity over the same period (Météo-France station at Cap-Ferret), and Figure 5 represents the variation in atmospheric pressure over time (Météo France station at Cazaux). The encountered conditions cover a cycle of spring tides/neap tides and fairly moderate wind conditions.

SEABOOST deployed two lines of prototypes named Device A and Device B on the field. We then instrumented two perpendicular profiles (Profile A and Profile B) visible in Figure 8. Our analysis focuses on the ebb current, which is stronger and has less impact than the flood current. A SIG0 current profiler is placed about thirty meters before the structures, allowing for pressure and upstream current profiling (at ebb). For each instrument line, a pressure sensor was placed about fifty centimeters before the device (P1A and P1B). A current profiler was placed one meter after the structure (SIGA and SIGB). Pressure sensors were placed respectively at 2 m and 3 m after the structures (P2A, P2B, P3A, and P3B). An additional pressure sensor was placed on Profile A about 5 meters after the structure (P5A). Finally, a pressure sensor is placed about ten meters after the structure for each of the two profiles (P6A and P6B). The instruments were set up on Wednesday, May 11, 2022, and three pressure sensors (P1B, P2B, and P6B) were removed on Sunday, May 22, 2022. The rest of the instruments were removed on Tuesday, May 24, 2022, due to weather reasons.

Using GNSS, we acquired fixed points (reference points and instruments) using a known-height pole. The instrument points were acquired at the top of the angle iron for the pressure sensors (Figure 6) and at a marker on the current meter structures (Figure 7). Table 3 gathers the horizontal positions of the instruments in the LAMBERT93 coordinate system. We also performed automatic points over an area of approximately 100 m long and 50 m wide. The acquisition was done with a sampling frequency of 1 Hz. The antenna was mounted on a backpack, and the height between the ground and the receiver base was measured daily.

FIGURE 14. REFERENCE POINT TO CALIBRATE VERTICALLY PRESSURE SENSOR AND ADCP. AND

FIGURE 15. FIELD PICTURES OF THE SENSORS AND DEVICE ONCE SETTLED

FIGURE 16. ILLUSTRATION OF THE DUNE / SCOURING PIT SETTLED AFTER ROSELIÈRE SOLUTION UNDER FLOW INFLUENCE

The observations conducted in the field have highlighted (Figure 13) the development of a trench-dune system, typical of erosion processes, in the immediate wake of the seagrass beds, downstream of the ebb current (stronger and more perpendicular than the flood current). These morphological structures gradually develop during the early days of deployment, in response to the combined effects of intensified tidal currents and the establishment of larger seagrass beds. For the trench, the maximum depth reached is about 20cm with an extension of approximately 1.5 to 2m. For the dune, the maximum height is about 15cm above the upstream level, with an extension of about 4m. Comparison of displaced volumes and photographic observations confirms the local effect of erosion: the sediment (sandy here) is set in motion immediately downstream of the structure by the intensification of turbulent stress and then redeposited immediately behind when the hydrodynamic conditions fall below transport thresholds.

The first significant observation is that the free configuration (free in Figure 15) without seagrass beds studied at the end of deployment has drag coefficients (Cd) on the order of 0.02, which is an order of magnitude higher than observations made on smooth bottoms. The observed pressure drop is attributed to the presence of the trench-dune erosion system, which alone disturbs the flow sufficiently to increase turbulent dissipation by form drag. Part of the differences observed between seagrass beds may therefore be due to the variability of pressure drop induced by morphology. It is impossible to discriminate the respective contributions of the seagrass bed and its erosion system from the field data collected here. Furthermore, field observations have highlighted a progressive tilt of the seagrass bed system, particularly pronounced (around 30°) for strong currents and the largest seagrass beds. The inclination of the seagrass bed inevitably induces a modification of the projected surface in the flow and the turbulent structure of the wake, which is difficult to assess here. Keeping these limitations in mind, the following observations can be listed:

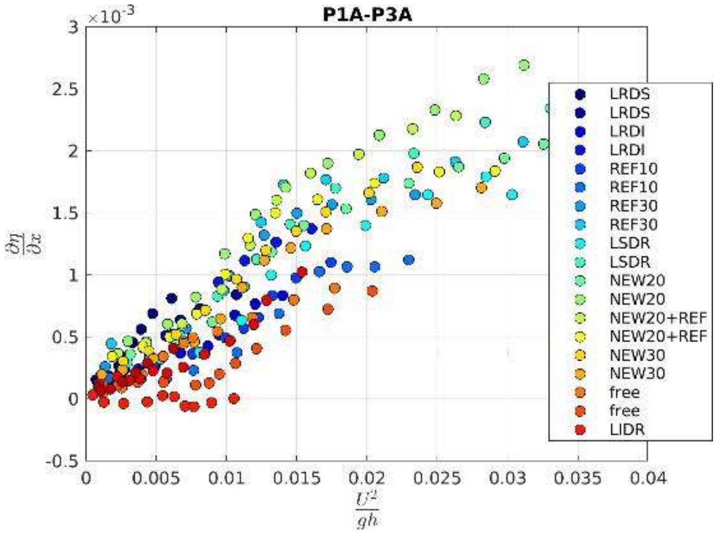


FIGURE 17. ILLUSTRATION OF THE RESULTS OF THE MEASURE ACCORDING TO THE TYPE OF ROSELIÈRE, IN TERMS OF BULK DRAG COEFFICIENT

- Modifying the height of the seagrass bed (REF10 and REF30) does not produce a significant effect on Cd.
- Decreasing density (LRDI) does not produce a significant effect on Cd.
- Increasing density (LRDS) tends to increase Cd (around +15%) but remains very close to the natural variability range observed in the reference configuration.
- Modifying the blade length tends to produce effects, by modifying Cd by 10 to 20% (increase for longer blades, decrease for shorter blades), but once again, we remain very close to the natural variability range observed in the reference configuration.
- Implementing double (NEW20, NEW30) and triple (NEW20+REF) configurations induces an increase in Cd, up to almost +45% for the triple configuration.

The data we gathered in the frame of this survey allowed us to define the most appropriate roselière configuration to reach a suitable hydrodynamics control effect for seagrass rehabilitation, and to define the dimension of the anchor we were going to use to settle the large-scale demonstration.

4.1.2 Field deployment

As explained earlier, our large-scale demonstration protocol relies on field survey results and dedicated numerical model, in order to define the most suitable settlement pattern ion a technical, economic and environmental trade-off. To get the best possible effects on local hydrodynamics and optimize the ratio between the deployment cost and the covered area, we proceeded to numerical 2DH-model (SWASH) in order to find, through a deterministic approach, the best settlement pattern allowing both easy scalability and replicability in different situations. We finally converged towards a triangular fractal pattern.

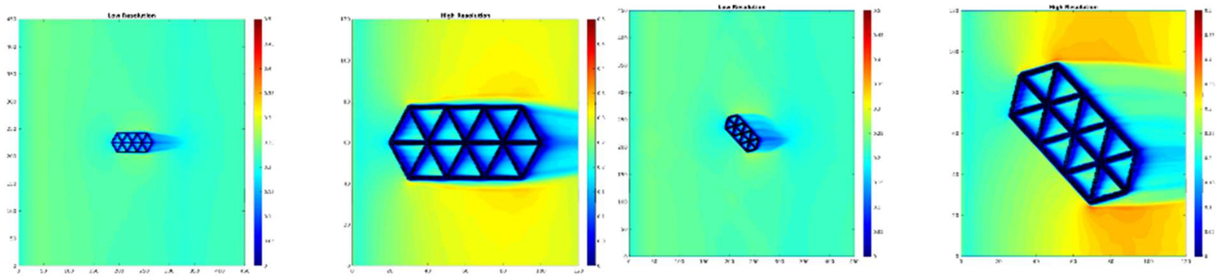


FIGURE 18. ILLUSTRATIONS OF RESULTS OF NUMERICAL MODEL TO ASSESS THE EFFECTIVENESS OF A SETTLEMENT PATTERN TO REDUCE FLOW VELOCITY, AND THE ASSOCIATED WAKE

The main observations at the present stage of the study can be summarized as follows:

- The present modelling approach appears to conveniently reproduce the observations performed on the field.
- The external flow field is characterized by (i) a slightly slowing flow area upstream the Roselière system, for which sediment deposition may be enhanced, (ii) deflection-accelerated flow on the lateral sides of the system, likely associated probably erosion trench and (iii) a sheltered wake area, nearly as wide as the exposed section of the Roselière and about 50 to 80m long, again with potential sediment deposition depending on the level of available flux after crossing the Roselière system.

Inside the Roselière system, we can observe:

- A heterogeneous near-bed velocity field inside the Roselière cell, with a strongly sheltered zone extending 4-7m behind the Roselière line and a progressive downstream increase of velocity.
- A straightforward cumulative effect, the downstream cell being more protected than the upstream ones.

A heterogeneous near-bed velocity between the cells of the Roselière system, depending on the incidence angle of the upstream line, more incidence leading to stronger sheltering.

Filed deployment was launched in October 2023, involving 8 people from Seaboost 6 people from local area manager team, oyster farmers and volunteers. That global involvement was made possible thanks to our communication efforts and our strong relationship with local MPA manager.

FIGURE 19. FIELD PICTURE OF DEPLOYMENT OPERATION INVOLVING MPA, VOLUNTEERS AND OYSTERFARMERS

More than 1ha was equipped with in order to perform a large-scale restoration, to be monitored along years in order to assess its short- and long-term performance. We hope that we will reduce flow velocity, then bottom shearing stress inside the equipped areas, but also in the wake of attenuation of each deployment pattern, and then trigger a positive retro control loop benefiting from restored seagrass to support the same kind of flow attenuation for nearby areas.

FIGURE 20. AERIAL VIEW OF THE FIELD DEPLOYMENT ACCORDING TO OUR NUMERICAL MODEL OPTIPMIZATION

According to our projections, based on Ifremer hydro-biological model (which can propose trends regarding seagrass restoration / progression according to local abiotic conditions, band which has been calibrated and validated on field for several years now), all scenarios of ecological restoration should lead to an increase in seagrass cover, then biodiversity and associated ecosystem services.

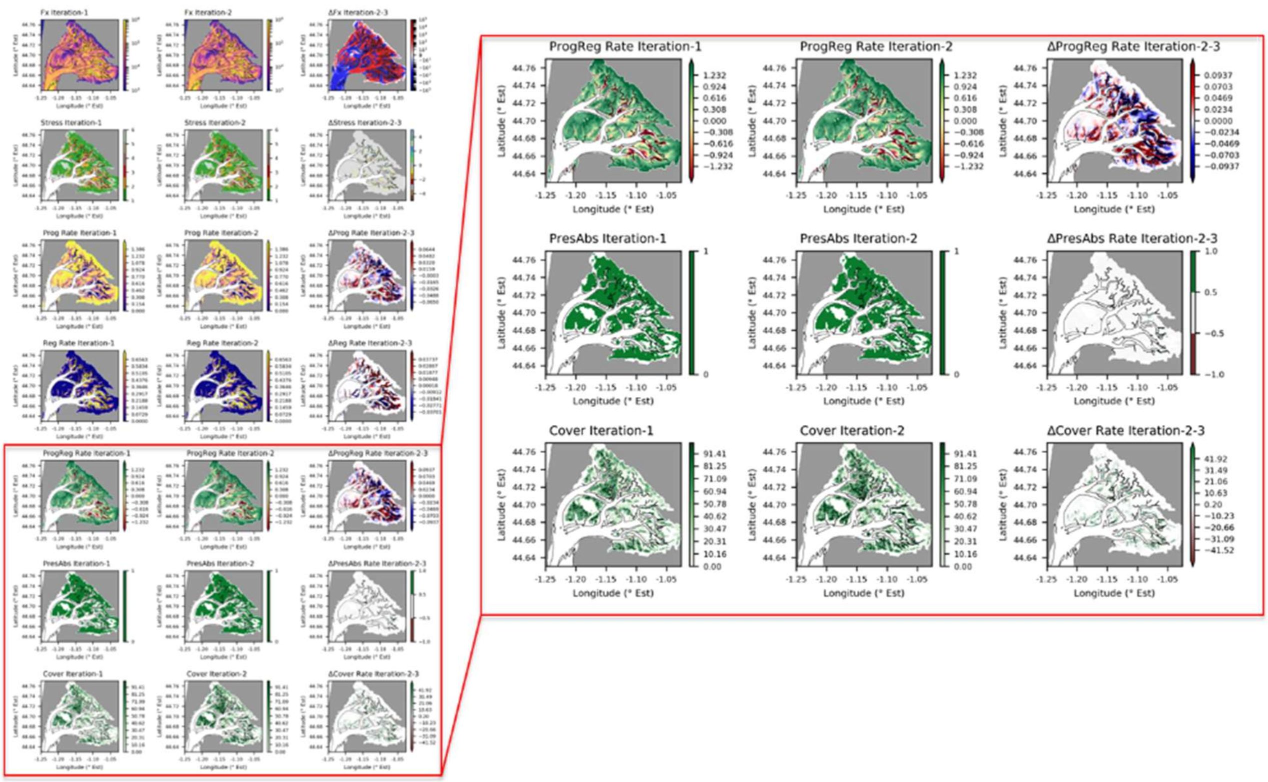
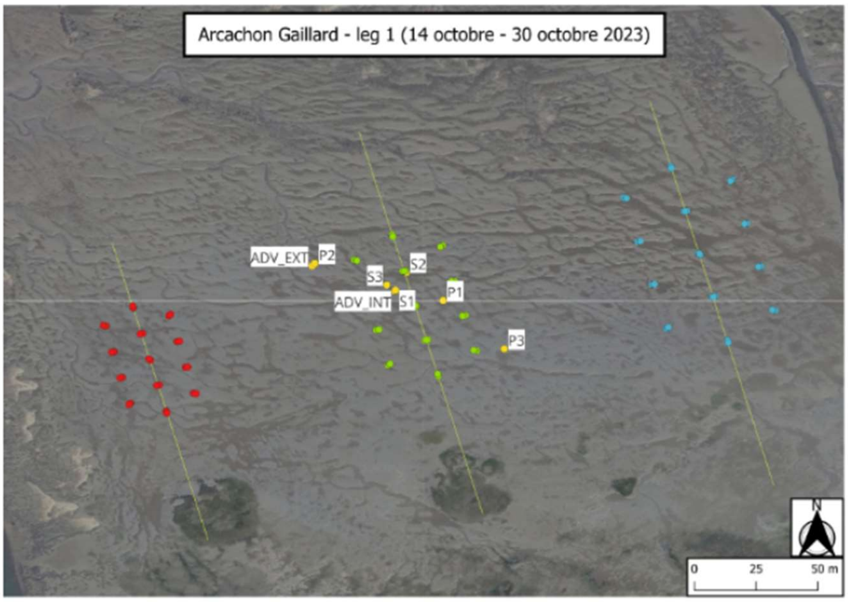


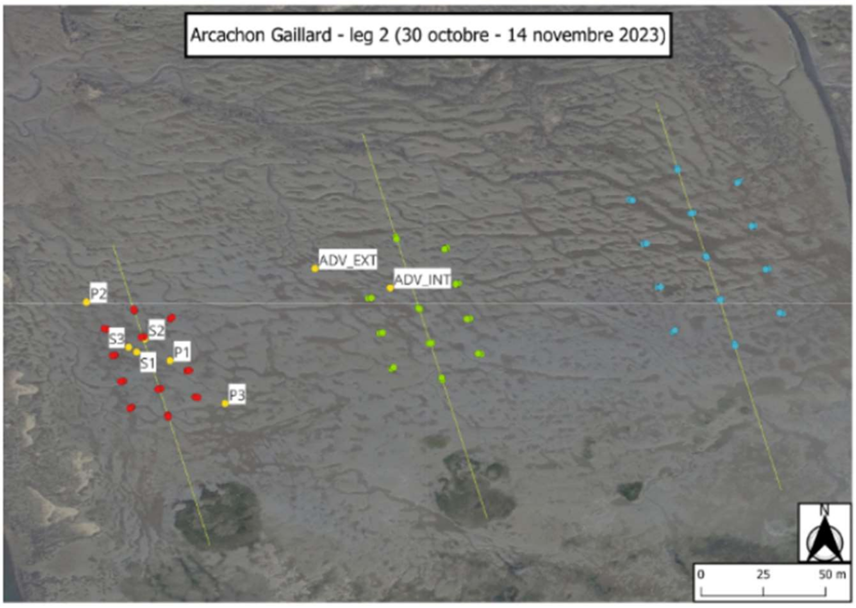
FIGURE 21. EXTRACTION FROM OUR HYDRO-BIOLOGICAL MODEL ALLOWING US TO GET AN INSIGHT OF THE PROGRESSION OF SEAGRASS REHABILITATION AFTER SEVERAL ITERATO, ACCORDING TO THE AREA THAT WAS PRIORITIZED FOR THE INITIAL INTERVENTION

The objective now is to confirm the relevance of the modeling results through field monitoring via 3 different types of campaigns:

- Instrumented monitoring campaigns, allowing validation of the orders of magnitude of hydrodynamic control exerted by the deployed solutions, and ensuring their consistency with the data input into the seagrass progression/regression model.

⇨ Data acquisition carried out over 3 periods in November 2023 allows determination of the most relevant deployment patterns in terms of mesh size and defines an optimum in terms of hydrodynamics.





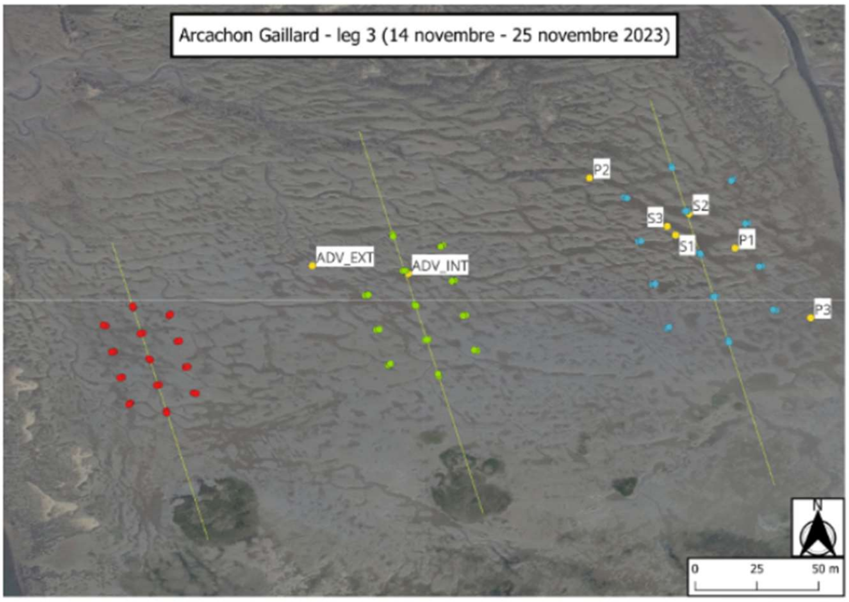


FIGURE 22. PICTURE SHOWING THE POSITION OF THE SENSORS ACCORDING TO THE PERIOD, TO BE ABLE TO COMPARE DIFFERENT LARGE-SCALE CONFIGURATION AND TO ASSESS THEIR PERFORMANCES

FIGURE 23. PICTURE SHOWING THE SENSORS IN SITU

- Biological monitoring campaigns involving field monitoring by MPA actors and drone flyovers to measure topo-bathymetric changes and the evolution of seagrass coverage within and near equipped areas.

- Participatory monitoring, involving the dissemination of certain biological materials in specific areas, to assess whether this type of seeding enhances the success of restoration compared to an approach solely relying on spontaneous regeneration.

FIGURE 24. PICTURE FROM THE OPERATION OF ZOSTERE SEEDLINGS DISSEMINATION IN THE FRAME OF PROSPERE PROJECT.

4.1.3 Demonstration value and replication

Through REST-COAST, this demonstration approach aims to provide evidence, on the Arcachon Basin pilot, of the relevance of ecological restoration and Nature-based Solutions to address climate change adaptation challenges. In this regard, this action should be considered through several levels of interpretation:

1. Through field monitoring actions and the sizing of hydrodynamic control devices, it is technically demonstrated that nature-inspired solutions can be deployed to address the challenges of mitigating stressors in current-dominated environments. Through this demonstration, it is thus conceivable to deploy this type of flexible, lightweight, manually portable solution in environments where current stresses are predominant, to raise the flow boundary layer and reduce sediment mobility. Lagoon environments dominated by tidal currents, estuarine areas, or rivers are all environments where deploying this type of approach would:
    a. Ensure effective and easy-to-deploy bank protection.
    b. Be eco-designed to shelter organisms associated with seagrass beds, algal beds, or root networks.
    c. Be transparent, and therefore less impactful on adjacent areas.

    In addition to the in-situ demonstration of the hydro-sedimentary performance of this approach, these results also constitute a lever for replication on other sites, in different contexts, where flow represents a strong constraint.

2. Within the framework of large-scale deployment action, the feasibility of an intervention of this type on a scale of several hectares has been demonstrated. This deployment also marks a key step in the acceptance of future large-scale restoration projects, as, in addition to integrating these solutions into the landscape of the basin, it has mobilized various local bodies and stakeholders around a common ecological restoration operation.

3. Hydro-morphological and hydro-biological modeling actions, coupled with the use of the Quick Scan Tool, allow for tailor-made scenarios to be developed and adjusted/modified in co-construction workshops with local stakeholders. The objective is clear: to share the results and perspectives of this type of restoration action to contribute to feeding into a strategy for restoring seagrass beds on the scale of the Arcachon Basin, with objectives in terms of restored area and timeframe.

From an institutional point of view, the Arcachon Basin demonstrator has also facilitated close collaboration with the local marine protected area manager, which has helped to overcome several barriers to large-scale ecological restoration of seagrass beds:

- The barrier related to demonstrating the replicable nature of the technical approach, as the PROSPERE project, conducted jointly, relies on the same type of approach to demonstrate the benefits of active intervention through the introduction of genetic material, thus showing the local capacity to take charge and deploy this type of approach.
- The barrier related to sharing results and perspectives with local decision-making bodies, to influence decision-making on the regulatory and strategic aspects of ecological restoration. Here again, the collaboration allows the marine protected area to disseminate this information and to propose scenarios and strategies for ecological restoration on a basin scale in the near future. This would not have been possible without REST-COAST, as we were never able to integrate into local governance committees.
- The barrier related to projecting results, as the coupling between hydro-morphological modeling, hydro-biological modeling, and the Quick Scan Tool provides a tool to project with some confidence towards results in terms of biodiversity and ecosystem services, based on choices made today and climate change scenarios.
- The barrier of local acceptance, although there is still work to be done on this front. Nevertheless, the involvement of volunteers in the field, the participation of oyster farmers in transportation and deployment operations, demonstrate the growing interest in the approach, and above all, an awareness of the complementary, rather than antagonistic, nature of ecological restoration with local socio-economic activities.

Following this project and demonstration, several perspectives emerge, such as, of course, the implementation of a restoration scheme on the scale of a foreshore on the Arcachon Basin, following the definition of an associated strategy, but also the restoration of seagrass beds in the Gulf of Fos, next to Marseille (France), currently under discussion, among others. On another hand, the demonstration of the effects of seagrass-inspired solutions on hydrodynamics lead to a project which has now been launched in order to master erosion issues along underwater cables, to support both erosion control and habitat functions and decreasing at the same time the environmental footprint of that kind of infrastructures.