D6.8 Restoration Demo at Rhone Delta

29/03/2024

WP6

Lead beneficiary: TDV

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REST-COAST

Large Scale RESToration of COASTal Ecosystems through Rivers to Sea Connectivity

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Preface

The present report aims at providing an overview of the restoration activities undertaken within the Rhone Delta Fellow Pilot Site, one of the 9 pilot sites of the REST-COAST project, and one of the 2 Mediterranean Deltas among the sites. It includes a presentation of restoration activities carried out in the pilot and aims to show how that type of restoration actions can significantly contribute to enhancing biodiversity and mitigating the impacts of climate change on coastal ecosystems.

Summary

The document is structured to provide a comprehensive view of the efforts carried out at the Rhone Delta, with an introductory section that present the restoration project implemented on the pilot site.
The document then reports the demonstration activities carried out at the site, with the production of a restoration demo video, the creation of a web page dedicated to the project on the Tour du Valat website, the publication of news on the progress of the project, the use of spatial maps showing the ecological status of the habitats targeted by the project, several presentations to students, visits to the site by various groups, the transfer of the results to the CORE-PLAT, and presentations at international conferences.
The document then details the hands-on restoration actions undertaken. Finally, it evaluates the demonstration value of these activities and discusses how to identify areas where such an approach could be implemented, building on the other REST-COAST work packages.

1 Introduction to the Rhone Delta Fellow Pilot Site

The site of the Former Saltworks, located in the south-eastern part of the Rhone Delta (Figure 1), is an area of about 6500 ha which was acquired by the French State (Conservatoire du Littoral) between 2008 and 2012. Until 2008, and during about 50 years, this site was devoted to industrial salt production, operated by a private company.

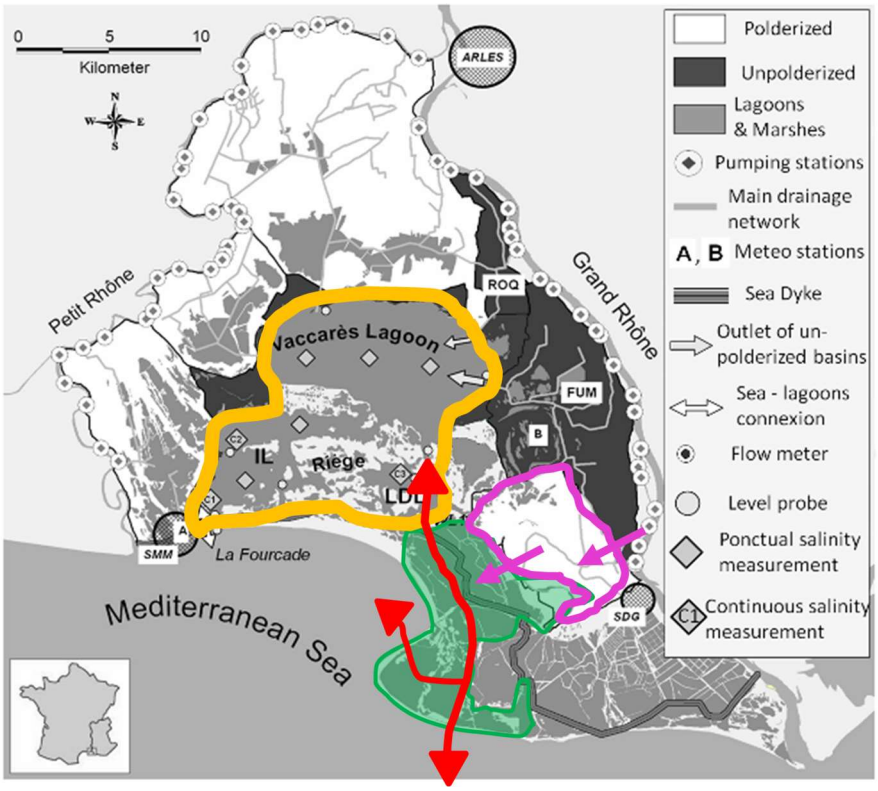

Figure 1: Location of the "Former Salt Works" (in green)

The acquisition of this site by the French Coastal Protection Agency involved changes in management, compared to that implemented in an industrial salt production model. Water management by means of hydraulic pumps, as well as continuous maintenance of the dikes of the former salt production site in the context of sea level rise, was in particular no longer economically sustainable without the financial benefits of salt production. In addition, with the existing dikes of the former salt production site, and without the use of hydraulic pumps to generate water flows, the Former Salt Works site would have been with no change in management a very confined site with long renewal times. Due to the high evaporation rates in Mediterranean areas, this site would have been exposed to very high salinity and an absence of water for several months of the year, which would have been problematic for several plant species, birds and fish. It was therefore decided since 2010 to implement a realignment strategy on the site (see Figure 2): the sea-dikes protection of the former salt production site is no longer maintained, and the protection effort is now focused on a government owned dike which is located about 7 km inland, resulting in a new 4600 ha "Climate change buffer area" between the former and the inland dikes. Several works have been carried out (opening of dikes, dredging works, etc.) to create connections between the various former salt production basins (North-South red arrow in Figure 1). Hydraulic works have reconnected the site to a nearby agricultural

catchment, itself irrigated from the Rhone river, allowing new fresh water flows in the site (purple arrows in Figure 1).

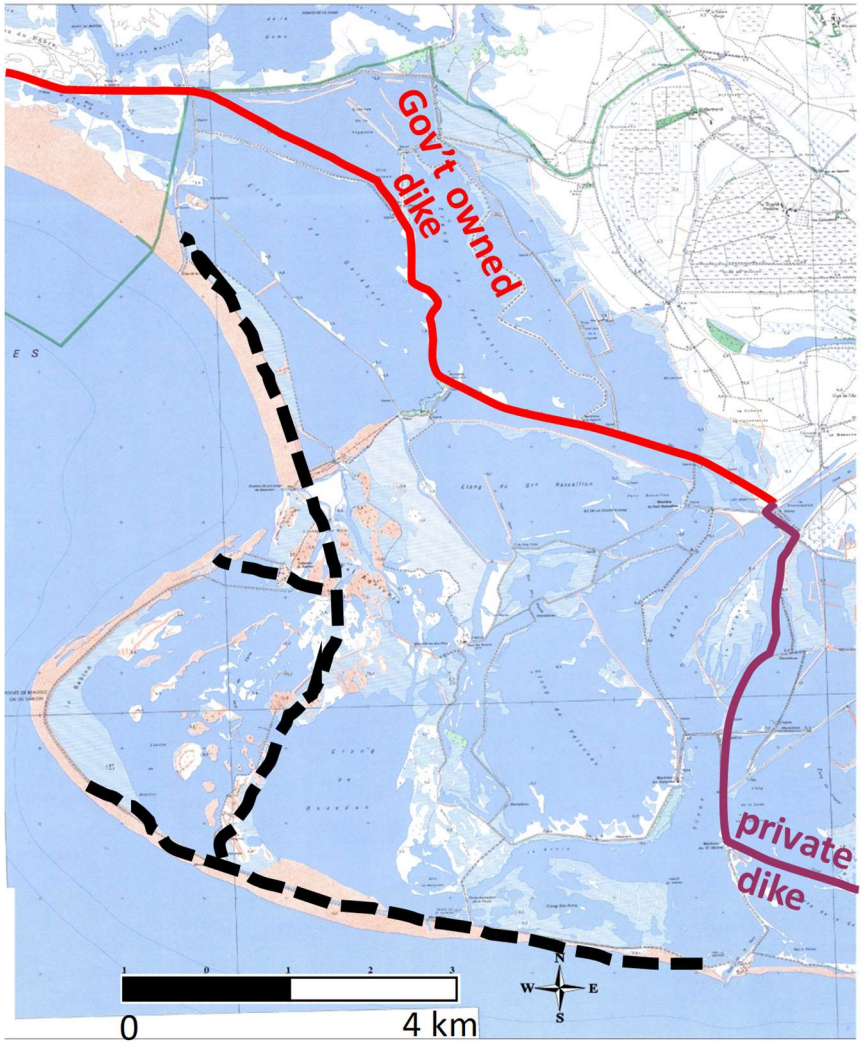

Figure 2: Location of the historic dikes that continue to be non-maintained during REST-COAST (black dotted line). In red is the dike on which protection efforts are now focused. Also shown in purple is the dike owned by the private salt production company which still produces salt to the east of the Pilot Site.

The restoration measures implemented as part of REST-COAST for the Rhone Delta pilot site aim to:

1/ Improve the connection of the site to the sea, and restore the natural coastal dynamics, by continuing not to maintain the historic sea walls of the site. (Passive restoration: elimination of the "historic" seawalls by their non-maintenance, see Figure 2).

2/ Implementing a new integrated water management:
- Fostering the restoration of targeted habitats within REST-COAST: Coastal lagoons (N 1150), Beach areas (N 1140), Mediterranean and thermo-Atlantic halophilous scrubs (N 1420), and Salicornia and other annuals colonising mud and sand (N 1310), see Figure 3.

- Enhancing the following Ecosystem Services targeted by REST-COAST: Water quality purification (hydro-saline regulation), Reduction of coastal flooding risk, Food (fish) provisioning, and Climate change regulation.

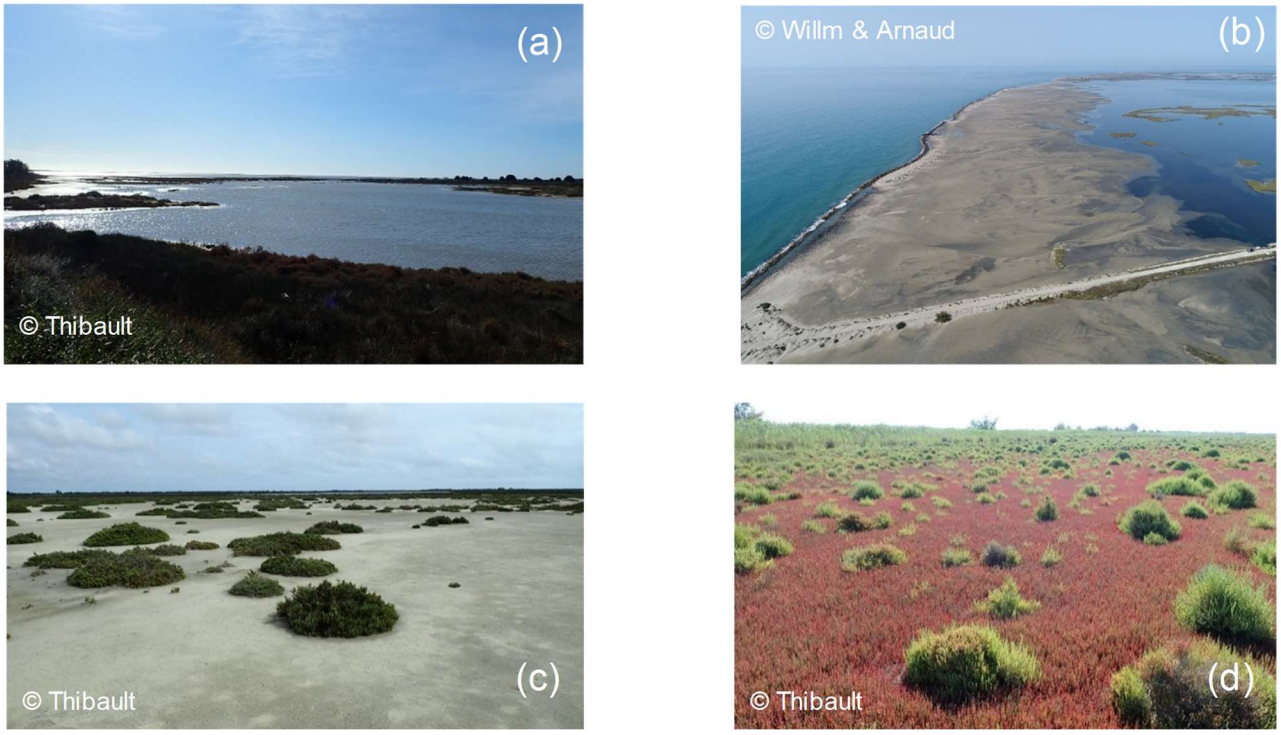

Figure 3 : Pictures of habitats targeted for restoration as part of the REST-COAST project. a) Coastal lagoons (N 1150); b) Beach areas (N 1140); c) Mediterranean and thermo-Atlantic halophilous scrubs (N 1420); and d) Salicornia and other annuals colonising mud and sand (N 1310).

The main challenge of the restoration project for the Rhone Delta Pilot Site is to determine whether it is possible to improve all the targeted ecosystem services at the same time, or whether feedback loops, causal chains and side effects exist in the system that would lead to the deterioration of one or the other services as a result of the improvement of one of the services (Figure 4).

One of the other challenges is to estimate the future of the restoration work carried out and the ecosystem services targeted in the context of climate change, in particular considering rising sea levels and changes in rainfall and temperature.

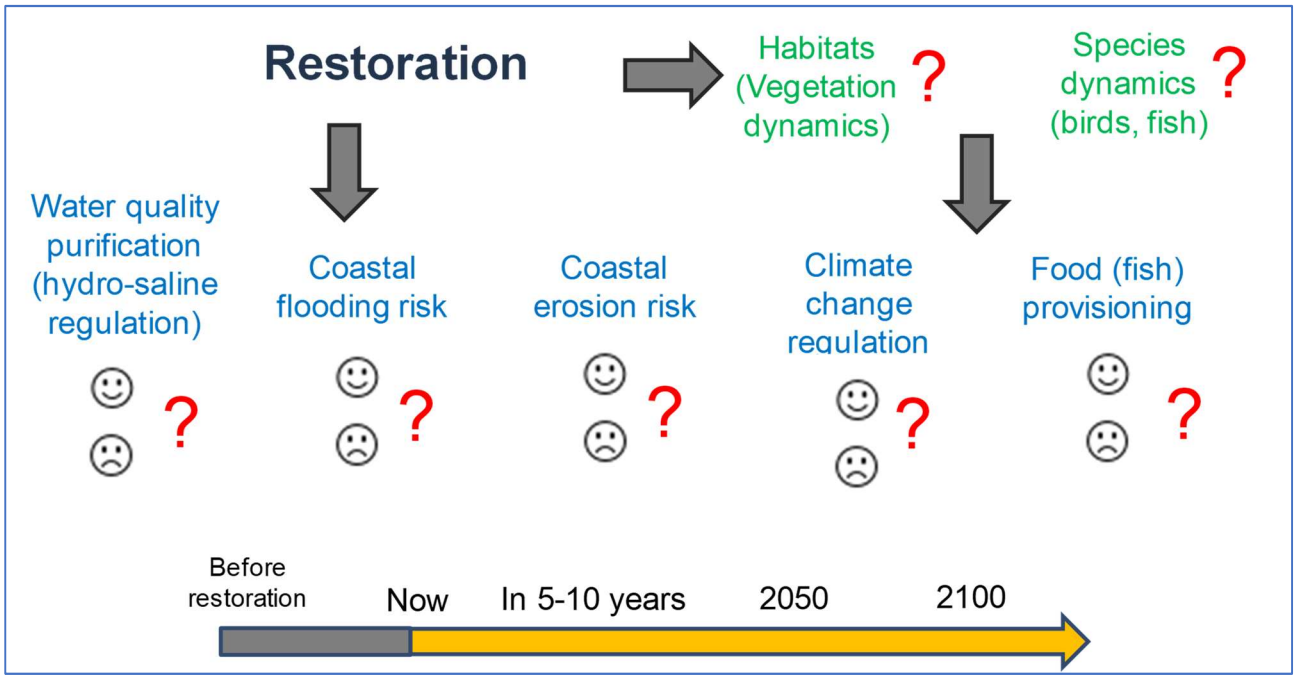

Figure 4 : Illustration of the stakes involved in the restoration project implemented for the Rhone Delta, aimed at simultaneously improving several habitats, species (fish) and ecosystem services that are sustainable over time, in relation to the rise in sea level and changes in rainfall and temperature.

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

Since the implementation of the restoration project, a number of benefits are already being perceived and achieved, as described in Table 1.

Table 1: Status of the benefits of the restoration project

Description	perceived	achieved	expected	not achievable
Restoration of coastal lagoons		**X** A quantitative estimate of the areas restored will be carried out on the basis of the results of field monitoring carried out during REST-COAST, which ends in the summer of 2024.		
Restoration of Mediterranean halophilous scrubs/Salicornia		**X** A quantitative estimate of the areas restored		

and other annuals colonising restored mud/sand		will be carried out on the basis of the results of field monitoring carried out during REST-COAST, which ends in the summer of 2024.	
Creation of new beach areas (through overwash processes)		**X** A quantitative estimate of the areas restored will be carried out on the basis of the results of field monitoring carried out during REST-COAST, which ends in the summer of 2024.	
ESS Hydro-saline regulation		**X** The hydrosaline dynamics of the site follow variations more in line with the Mediterranean climate	
ESS Reduction of coastal flooding risk	**X** The dyke located 7 km inland, on which protection efforts are now focused, is subject to less significant swells and flows than the historical protection dykes.		
ESS Reduction of coastal erosion risk			**X** Restoration of coastal dynamics and connectivity: Analysis of the field data will make it possible to define the project's influence on

		erosion, in comparison with the period when the historical dykes were maintained.	
ESS Food (fish) provisioning	X Analysis of existing data from another project shows that the new connections with the sea resulting from the restoration strategy has led to new fish migration.		
ESS Climate change regulation		X The influence of the project on the emission of GHG will be assessed on the basis of the results of field monitoring carried out during REST-COAST, which ends in April 2024	
Using the project as a demonstrator to underscore the importance of ecosystem-based solutions in enhancing coastal resilience and sustaining biodiversity Global commitment with all stakeholders local population about the	X International presentation of the project, organisation of site visits, ...		X Although the CORE-PLAT brings together the majority of stakeholders and

restoration strategy	users' and inhabitants' associations, the restoration project is not unanimously supported, in particular because of the fear perceived locally with regard to the fact that the site's historic dykes are no longer being maintained, and the possible consequences for the risks of flooding and salinization.

For the Rhone Delta Pilot Site, although tangible results have been achieved in terms of restoring biodiversity and several ecosystem services, there is a priority need to convince more local stakeholders and inhabitants or users of the benefits of the restoration implemented. For some of them, the project is mainly perceived as a project to "leave the area to the sea", and not as a project with ecosystem-based solutions to enhance coastal resilience.

3 Demonstrative strategy of restoration benefits

The restoration work carried out on the Rhone Delta pilot site is intended to be a demonstration site of how ecosystem-based solutions can be implemented in enhancing coastal resilience and sustaining biodiversity, while involving civil society, policy makers, stakeholders and education community.

The benefits of this restoration is demonstrated through:

- the production of a demonstration video,
- the creation of a web page dedicated to the project on the Tour du Valat website,
- the publication on the Tour du Valat website, and on the REST-COAST website, of news on the progress of the restoration of the Rhone Delta site,
- the use of spatial maps showing the ecological status of the habitats targeted by the project,
- presentations to students,
- visits to the site by various groups,
- making the results of the REST-COAST project available for the CORE-PLAT,
- presentations at international conferences.

3.1 Production of a video

A video (duration: 4 minutes 44 seconds) was produced both in French and English to describe the restoration project implemented on the pilot site, its philosophy, the issues to which the project aims to respond, and

the methodologies implemented. This video presents a number of images and video sequences illustrating the restoration project itself, the evolution of the habitats of the site, and the field measurements and modelling tools used and developed within REST-COAST. It is available on the REST-COAST project website (https://www.rest-coast.eu/news/rest-coast-demo-video-collection-rhone-Delta-pilot-site) and on the Tour du Valat website (https://tourduvalat.org/en/actions/rest-coast-restauration-a-grande-echelle-des-ecosystemes-cotiers-grace-a-la-connectivite-des-rivieres-avec-la-mer/).

A number of images taken from the video are shown in Figure 5.


Sites pilote du projet REST-COAST / Delta du Rhône: les Etangs et Marais des Salins de Cam...
À regarder ...
Partager
mer
digue à la mer
se porte maintenant sur une autre digue
appelée Digue à la Mer,
0:50 / 4:44
YouTube


Sites pilote du projet REST-COAST / Delta du Rhône: les Etangs et Marais des Salins de Cam...
À regarder ...
Partager
sur le site, véritable
piliers de son état écologique.
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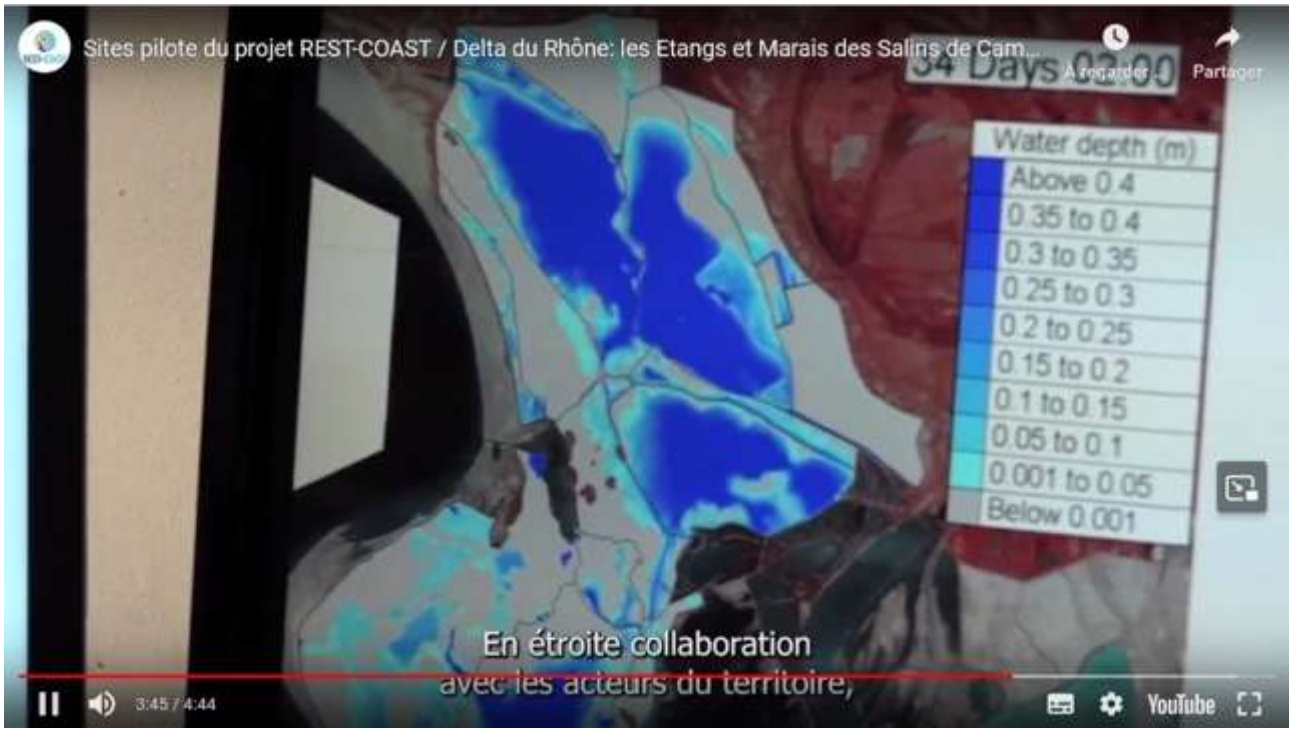

Figure 5 : number of images taken from the French version of the video produced as part of REST-COAST to present the restoration project at the Rhone Delta pilot site.

This video is a powerful tool for presenting the restoration project to a wide audience, with two versions available in English and French to target different audiences.

3.2 Creation of a web page dedicated to the project on the Tour du Valat website, with various project news items posted online

As part of the REST-COAST project, a web page on the Tour du Valat site has been specially designed (Figure 6)

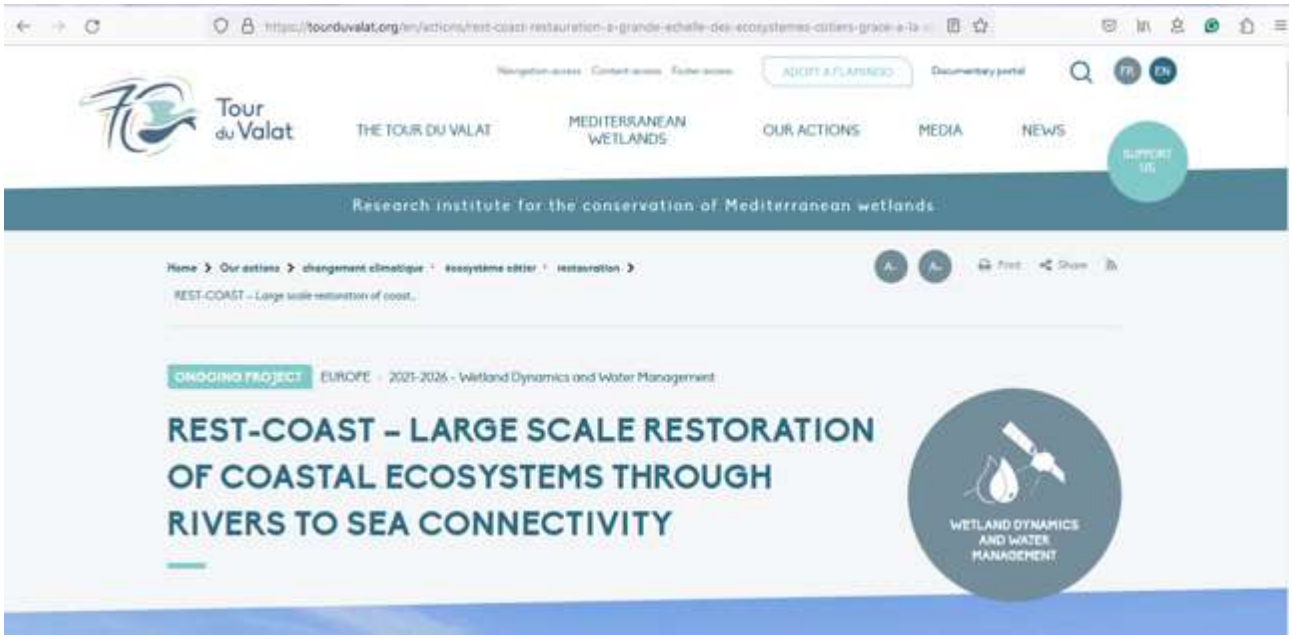

Figure 6 : Web page specially created on the Tour du Valat website for the REST-COAST project.

This page is available at:

https://tourduvalat.org/en/actions/rest-coast-restauration-a-grande-echelle-des-ecosystemes-cotiers-grace-a-la-connectivite-des-rivieres-avec-la-mer/

A French version and an English version are available. For both versions, various information is given, such as the objectives of the project (Figure 7), the actions and methodologies employed, illustrations of the results (Figure 8), the funder, the Tour du Valat staff and the REST-COAST partners involved.

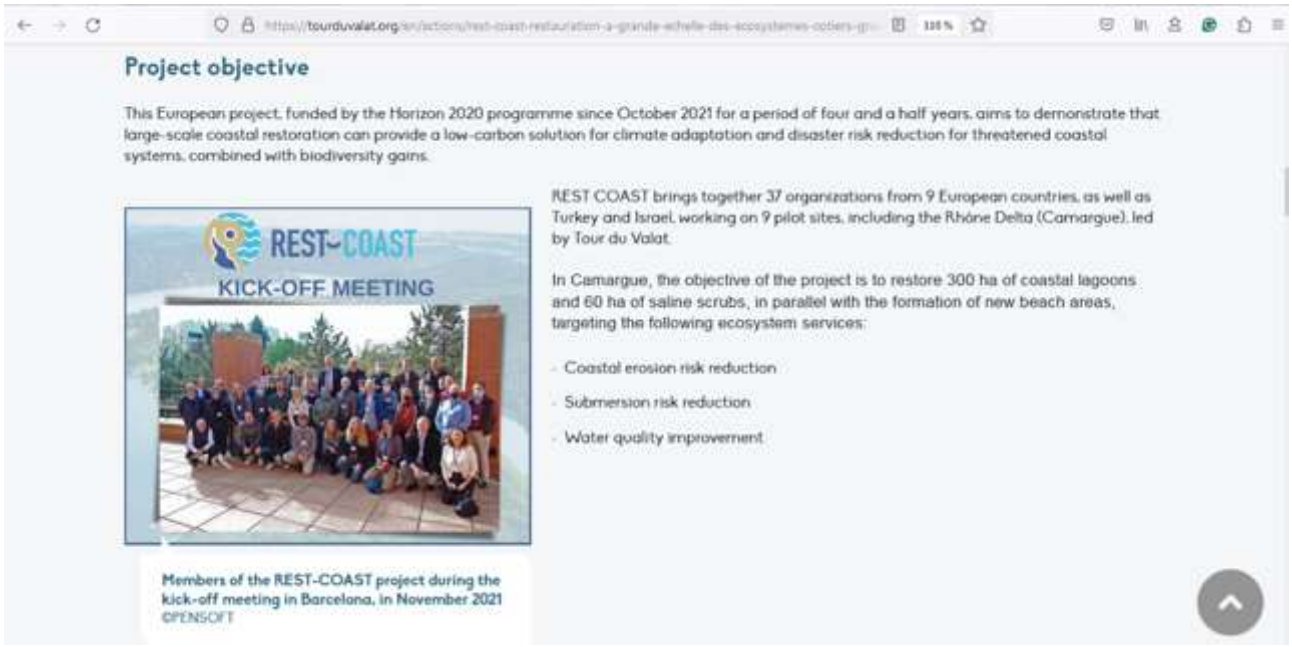

Figure 7 : Information on the Tour du Valat website about the project's objectives

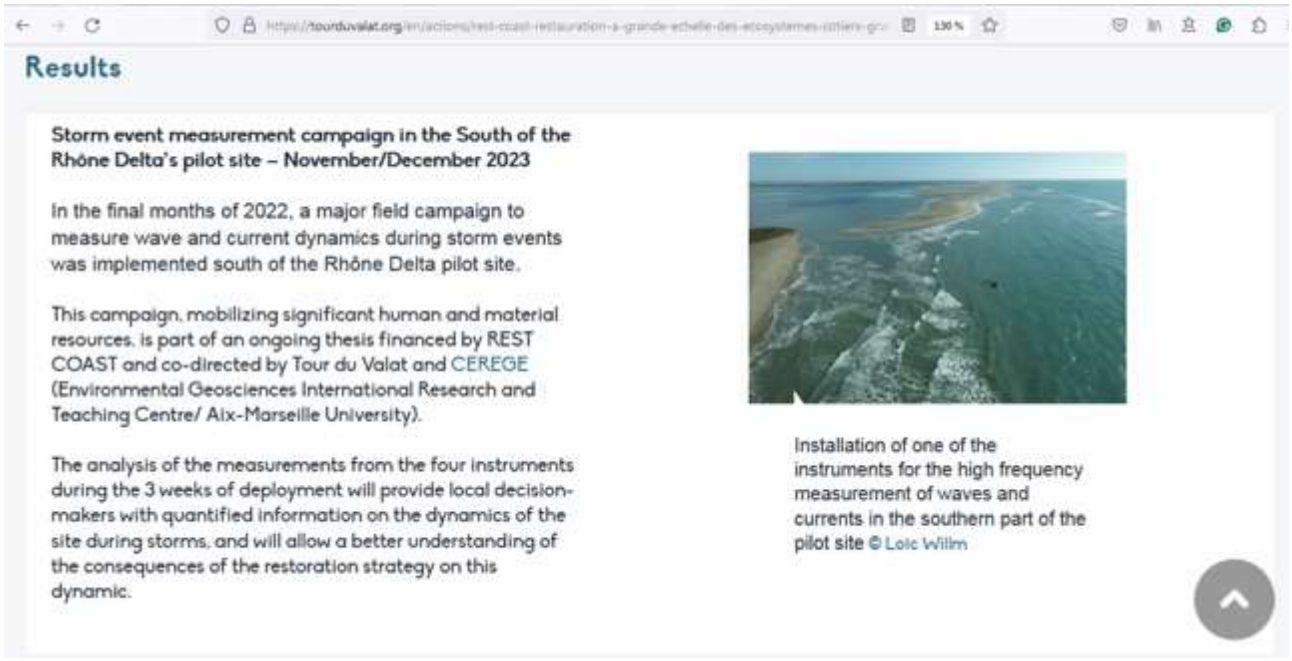

Figure 8: Illustration of an example of the results shown on the Tour du Valat web page dedicated to the REST-COAST project.

3.3 publication on the Tour du Valat website, and on the REST-COAST website, of news on the progress of the restoration of the Rhone Delta pilot site,

To increase the visibility of the project, in addition to the dedicated web page on the Tour du Valat website, news of the progress of the site restoration is posted on the home page of the general Tour du Valat website, increasing its visibility. An example of one of these news items is shown in Figure 9.

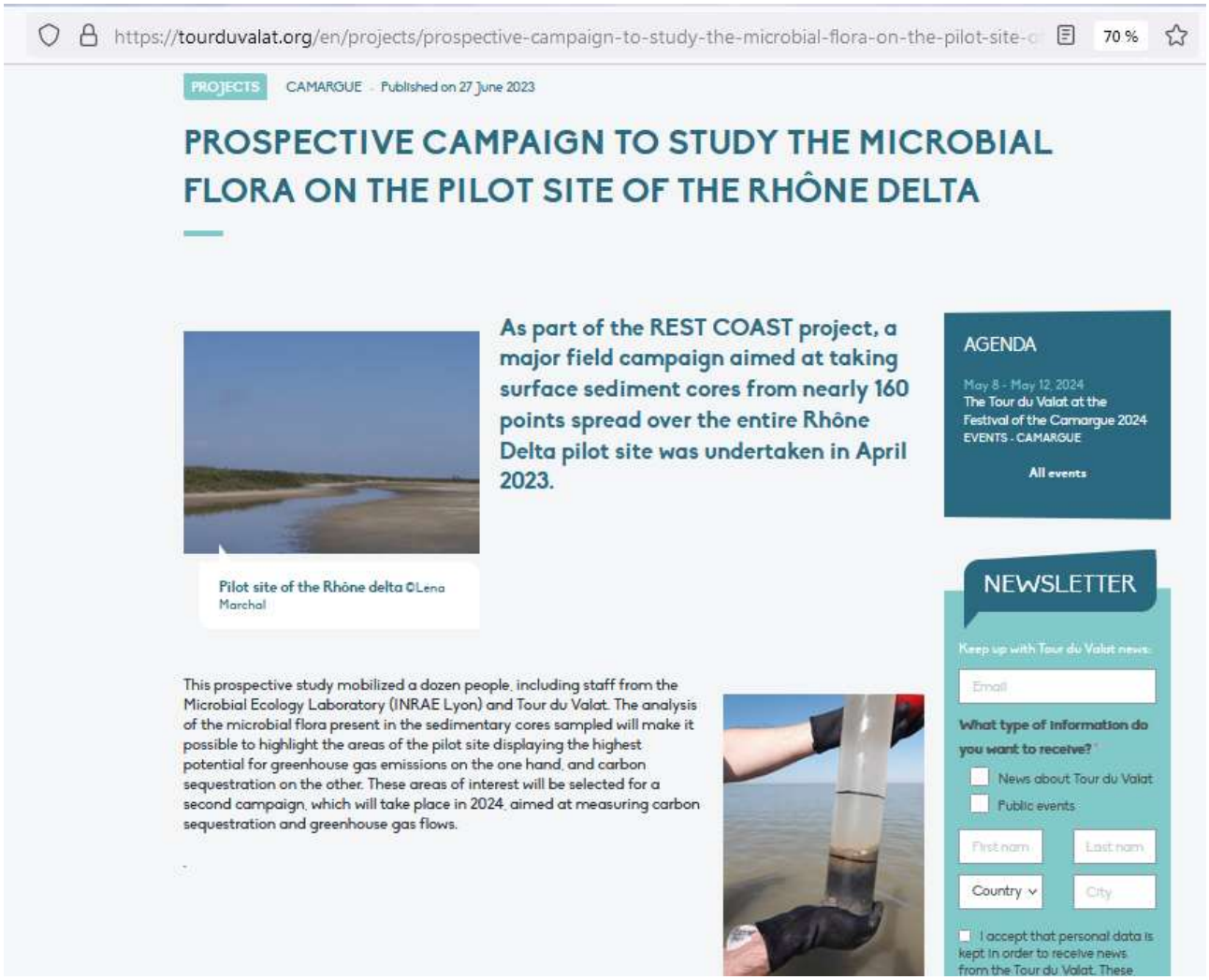

Figure 9: Example of a news of the progress of the site restoration posted on the home page of the general Tour du Valat website. Available at: https://tourduvalat.org/en/projects/prospective-campaign-to-study-the-microbial-flora-on-the-pilot-site-of-the-rhone-Delta/

3.4 Use of spatial maps showing the ecological status or the restored surface area of the habitats targeted by the project

To help illustrate the restoration of the ecological status of the habitats targeted by REST-COAST, spatial maps are being drawn up. They have been presented to various audiences, including two presentations to the CORE-PLAT technical and management committees, and presentations to students from various training courses who visited the site. Three illustrations are given for the ecological status of waters (Figure 10), of the benthic compartment (Figure 11), and for the area of Mediterranean halophilous scrubs (N1420) and Salicornia and other annuals colonising mud and sand (N 1310) (Figure 12), two of the habitats targeted by the restoration project. These maps are generated from field monitoring carried out as part of REST-COAST.

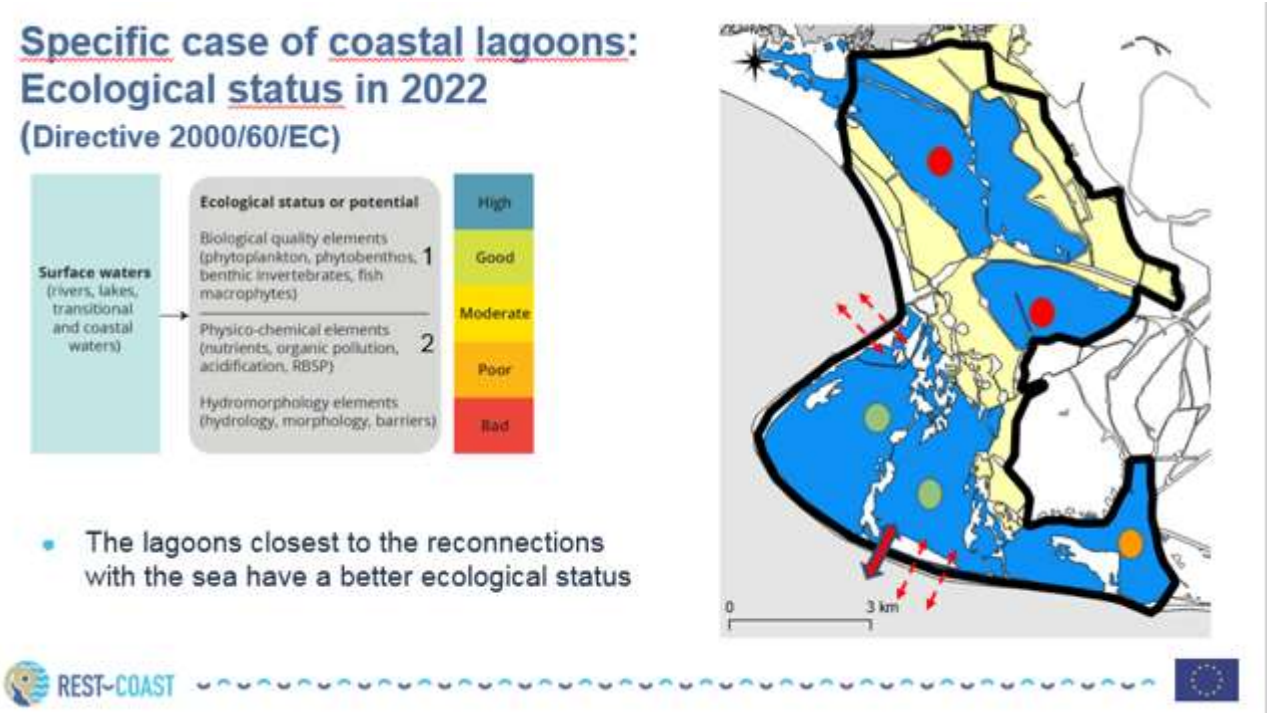

Figure 10: Illustration of the ecological status of the site's lagoon waters, one of the habitats targeted by the restoration project.

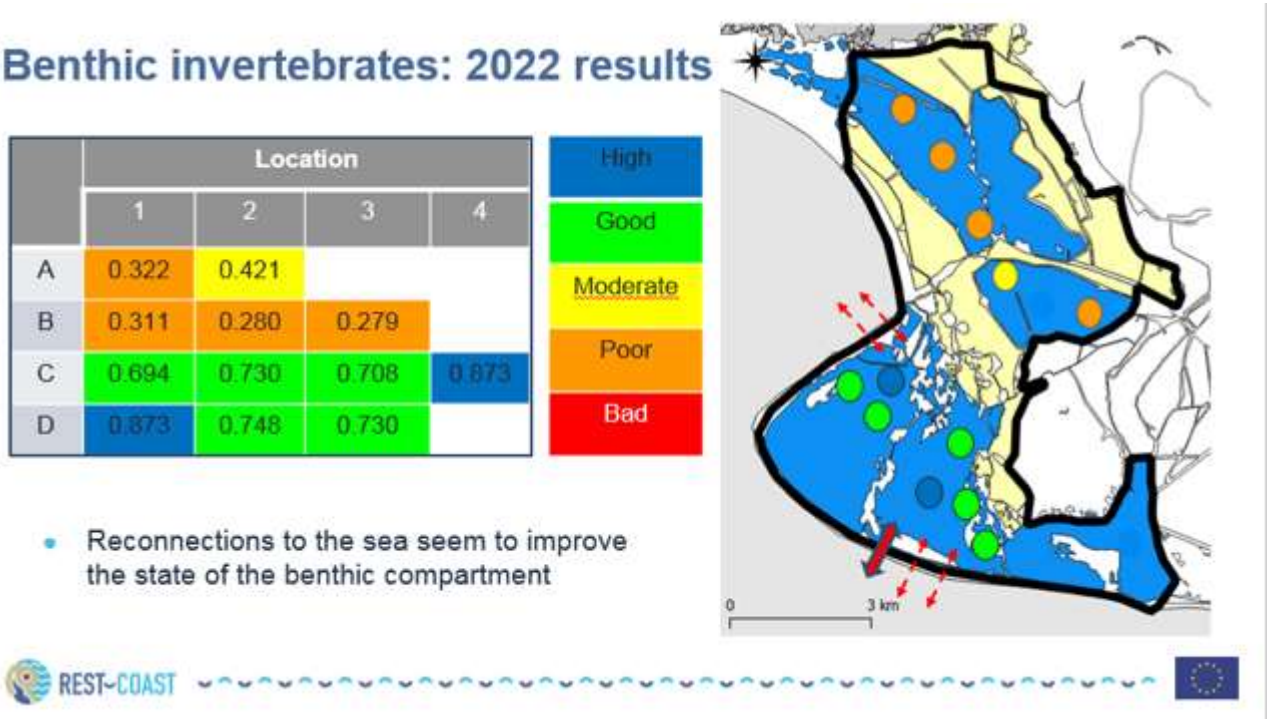

Figure 11: Illustration of the ecological status of benthic invertebrates of the lagoons, one of the habitats targeted by the restoration project.

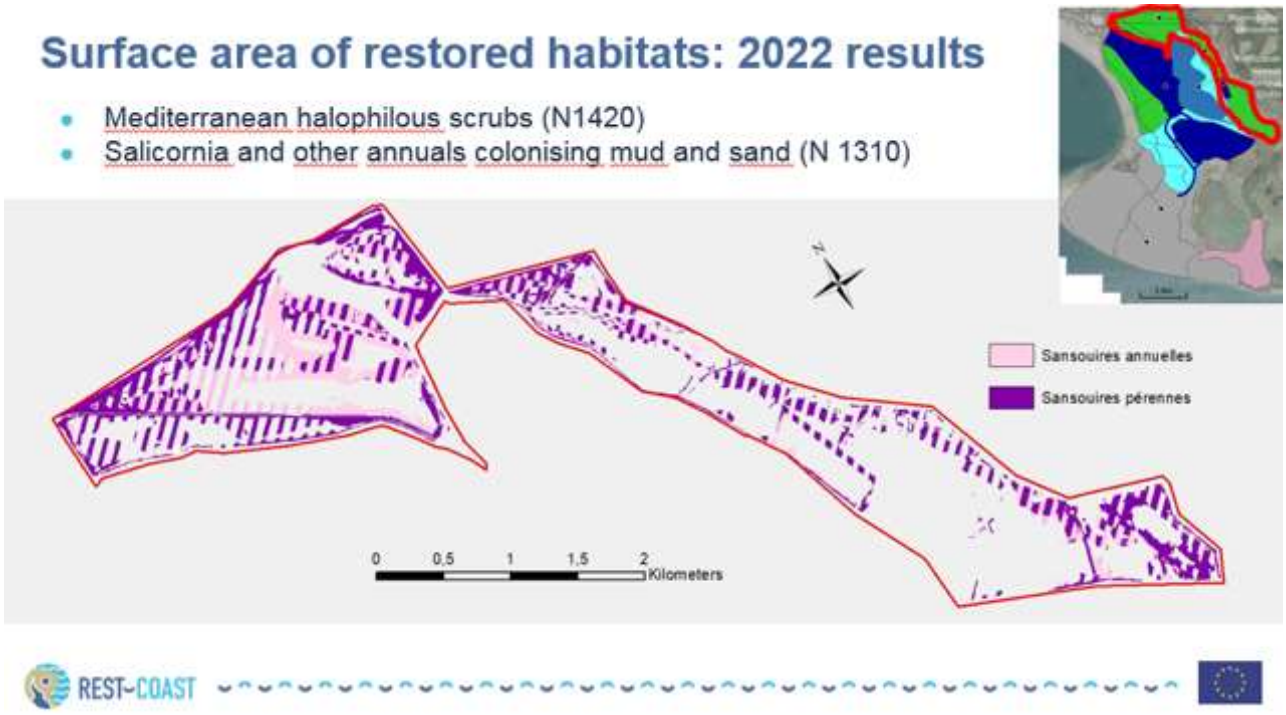

Figure 12: Illustration of the surface area monitored in 2022 of Mediterranean halophilous scrubs (N1420) and Salicornia and other annuals colonising mud and sand (N 1310), two of the habitats targeted by the restoration project.

3.5 Presentations to students / visits to the site by various groups

To facilitate the transfer of the ESS/Biodiversity messages to next generations, we have communicated about the REST-COAST project with secondary school and university students. This communication took the form of oral presentations, as well as the organisation of field visits.

- Presentation was given to secondary school students:

In October 2022, a presentation was given to secondary school students, as shown in Figure 13.

AU LYCÉE L'EMPÉRI

D'anciens élèves devenus scientifiques vantent la science

Autour du "cabinet de curiosités" rassemblées au CDI, des médecins et des chercheurs se sont succédé cette semaine au lycée de l'Emperi pour faire découvrir aux élèves leur thématique de travail. Arnaud Leroc, professeur de SVT, et son équipe ont organisé ces mini-conférences autour de thématiques variées.

La semaine a commencé par une proposition pour développer son esprit critique, notamment grâce à la science. Les élèves ont pu s'inscrire à des conférences sur des thématiques médicales comme l'évolution des connaissances sur les cellules souches embryonnaires, la transmission des virus et le lien au changement climatique ou encore la prévention des maladies comme Alzheimer par l'amélioration de l'IRM.

C'est aussi un lien de proximité puisque certains des intervenants sont des Salonais comme le Dr De Montgolfier, gynécologue au centre hospitalier de Salon, ayant "*certainement accouché une partie des élèves présents*" ou encore le Dr Bruny, du laboratoire salonais, qui est un ancien élève du lycée.

Présentation et petites expériences par Cécile Puigserver /PHOTO M.B.

Le vendredi matin, les élèves ont eu l'occasion de rencontrer 4 doctorants du Cerege (Centre de Recherche et d'Enseignement de Géosciences de l'Environnement) d'Aix venus présenter leurs travaux de recherche. L'explication simplifiée de leurs travaux est un challenge pour eux mais est aussi un moyen de "*partager la passion de la recherche. Plus tôt on en parle et plus tôt on développe l'appétence pour ce métier*" assure Vincent Rinterknecht, chargé de recherche sur l'époque glaciaire.

C'est aussi l'occasion pour ces chercheurs de partager sur leur parcours, parfois atypique comme Cécile Puigserver, doctorante sur l'évolution des littoraux, qui s'est plusieurs fois réorientée au cours de ses années de formation pour découvrir le "*sujet passionnant de l'océanographie*". M.B.

Figure 13: presentation given to secondary school students. Figure reproduced from an article in the French newspaper "La Provence" (www.laprovence.com) dated 16 October 2022.

- Site visit for architecture students

In January 2023, we welcomed a group of around 40 architecture students from 4 schools of architecture in France, Belgium, Italy and Morocco. During an indoor presentation, followed by a field trip (Figure 14), we presented the restoration project on the Rhone Delta pilot site, and the importance of ecosystem-based solutions in enhancing coastal resilience and sustaining biodiversity.

Figure 14: Site visit for architecture students, 30 January 2023

- Site visit for students on the Roche Continent programme

In summers 2022 and 2023, we welcomed around sixty international students each time, selected as part of the Roche continent programme (https://www.roche.com/about/philanthropy/arts-and-culture/roche-

continents). This programme brings together young, talented students from Europe's top universities for a week-long programme where the worlds of arts, science, and innovation converge for a more sustainable future. These students, the future decision-makers of tomorrow, were presented with the restoration project on the site, and the importance of nature-based solutions.

- Visit of a delegation from Paul da Gouxa reservation area (Portugal), involved in REWET European project

In November 2023, together with the staff of Tour du Valat involved in the the European project RESTORE-4CS, we received a visit of a delegation from Paul da Gouxa reserve area (Portugal), involved in REWET European project (Figure 15). This delegation was composed by scientists as stakeholders and PhD students. The objective of this exchange was to present good practice of the natural reserve area managed by Tour du Valat or other organizations in Rhone Delta. We conducted a visit of the REST-COAST pilot site, to present the restoration project. The conclusion of the visit was to explore the possibility of an Interreg Med project to support cooperation from Paul da Gouxa reserve with Tour du Valat for natural reserve management and Luma foundation (https://www.luma.org/fr/arles.html) to benefit their experience on regional strategies for bio-economy.

Figure 15: Field trip with Tour du Valat teams involved in the REST-COAST and RESTORE-4CS European projects, with a delegation from Paul da Gouxa reserve area (Portugal), involved in REWET European project.

- Collaboration with a Master 2 university course

In 2022, a collaboration was also established with the Master 2 "Coastal Engineering and Sustainable Coastal Development" from Montpellier in France, whose students carried out a 5-month tutored project on the pilot site, aimed at measuring flows and waves on the site, as part of their training in morphodynamic measurement techniques. During this collaboration, the students, future coastal planners, were made

sensitive to the importance of ecosystem-based solutions in enhancing coastal resilience in a context of climate change.

3.6 making the results of the REST-COAST project available for the site management and governance

As part of REST-COAST, we have taken particular care to ensure that the results generated are useful to all the people involved in the CORE-PLAT, and that they can feed into the definition of site management.

3.6.1 Presentation of the results of the first 18 months of REST-COAST to the CORE-PLAT technical committee

On 2 March 2023, the detailed results of the first 18 months were in particular presented (Figure 16) at a meeting of the CORE-PLAT technical committee, which brings together the site owner and the three co-managers (around 10-15 people depending on the meeting).

Figure 16: Presentation of the detailed results of the first 18 months of REST-COAST to the CORE-PLAT technical committee.

3.6.2 Presentation of the results of the first 2 years of REST-COAST to the CORE-PLAT management committee

On 10 November 2023, several results from the first 2 years of the REST-COAST project were presented at the annual meeting of the Management Committee of the CORE-PLAT, whose members are listed in Table 2.

Table 2: Composition of the CORE-PLAT management committee

Stakeholder name	Stakeholder type	Role in the pilot
French Coastal Protection Agency (Owner)	Government	Owner of the Former Saltworks
Tour du Valat	Private foundation	One of the three co-managers of the site
Camargue Regional Nature Park	Government	One of the three co-managers of the site
Company under agreement: Salt production company	Industry	The company continues to produce salt in the area east of the Pilot. The two areas have common dikes, maintained either by the French state or by the salt production company. In addition, the French state has granted the salt company the right to pump water from an area to the south east of the pilot site.
Partner under agreement: Communauté d'Agglomération Arles Crau Camargue (ACCM)	Government	
Users under agreement : Fishermen	Private partner	Access allowed for a given number of fishermen on the site
Users under agreement : Hunting Office	Private partner	Access allowed for a given number of hunters on the site
Users under agreement : nature guides	Private partner	Official authorisation given to a guide office to conduct tours of the site.
Users under agreement : bull breeding	Private partner	Official permission given to a bull breeder to use part of the land on the site.
Elected representatives of the city of Arles	Government	
Elected representatives of the city of Saintes-Maries-de-la-Mer	Government	
Financial partners: French Water Agency	Government	Funds restoration and management projects on the site.
Financial partners: “Provence Alpes Cote d’Azur” (PACA) region (a French region)	Government	Funds restoration and management projects on the site.
Financial partners: department of Bouches du Rhône (a French department)	Government	Funds restoration and management projects on the site.
French state services: the Sub-Prefecture of Arles	Government	Prefect's representative for the site.
French state services: The departmental directorate for the territories and the sea (DDTM - department of Bouches du Rhône)	Government	Ensures compliance with the legal texts for the site.
French state services: the Regional Directorate for the Environment, Planning and Housing (DREAL - PACA Region)	Government	Ensures compliance with the legal texts for the site.

French state services: the French Biodiversity Office (OFB)	Government	
French state services: the police force	Government	Ensures compliance with the law for the site.
French state services: the architects of the buildings of France (ABF)	Government	Ensures compliance with the law on historic buildings on the site.
French state services: Symadrem	Government	Structure in charge of managing and maintaining the dykes of the Rhone Delta.
The Agricultural Watershed Management Association in connection with the pilot site.	Private partner	Manage the hydraulic structures in the agricultural catchment area of which the pilot site is the outlet. The management of the structures in this catchment area drives the volumes of non-saline water that enter the site.
Tourist Office	Private partner	
User associations: the association for the protection of the Camargue Salt Works	Private partner	
User associations: the association of the "cabaniers du Sablon"	Private partner	
User associations: the Beauduc boaters' association	Private partner	
User associations: the association for the defence of Beauduc's heritage	Private partner	
Kite surfing schools	Private partner	The south-western part of the site is a well-known kite-surfing area in Europe.

3.6.3 Use of REST-COAST results for reports to the CORE-PLAT

The results of the project are used each year to draw up the site's annual activity report (approximately 70 pages), which is distributed to the entire CORE-PLAT members.

Examples of figures from the 2022 report are shown below (Figures 17, 18 and 19). The 2023 report is currently being finalised, and will also use the results of the REST-COAST project.

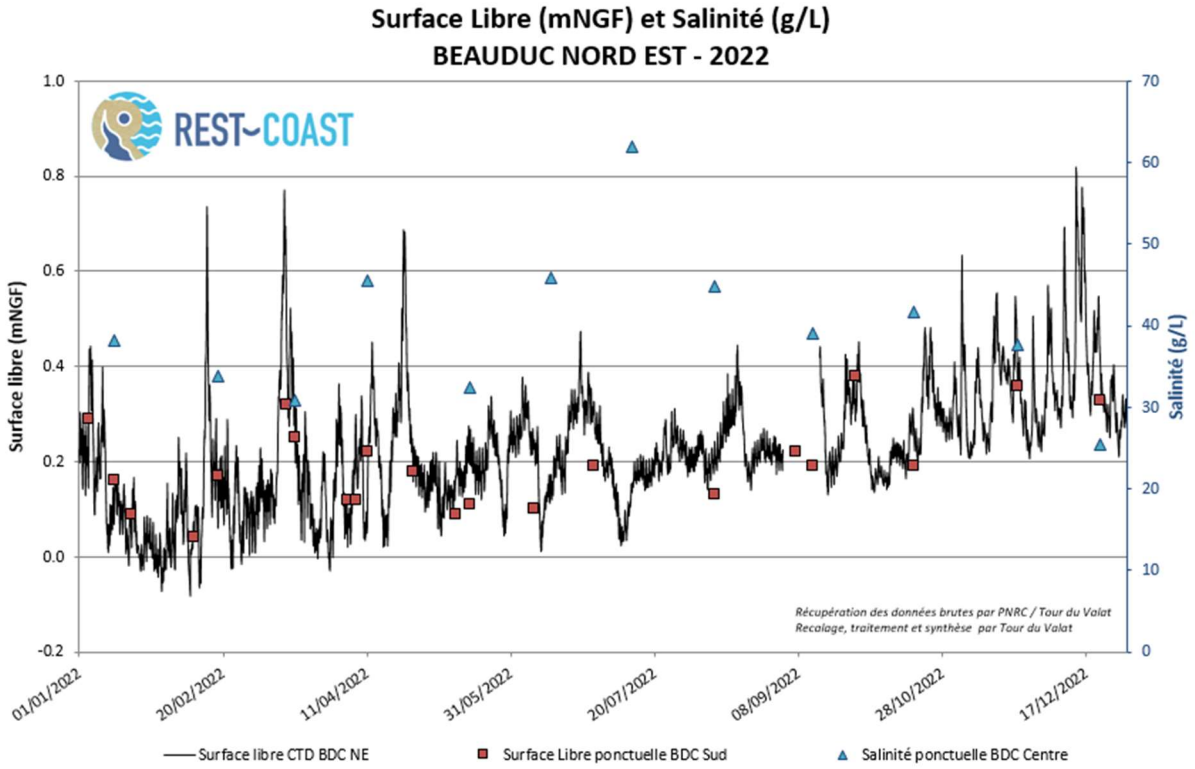

Figure 17: Changes in water levels and salinity at the Etang de Beauduc monitoring point - January to December 2022. Figure extracted from page 22 of the pilot site activity report.

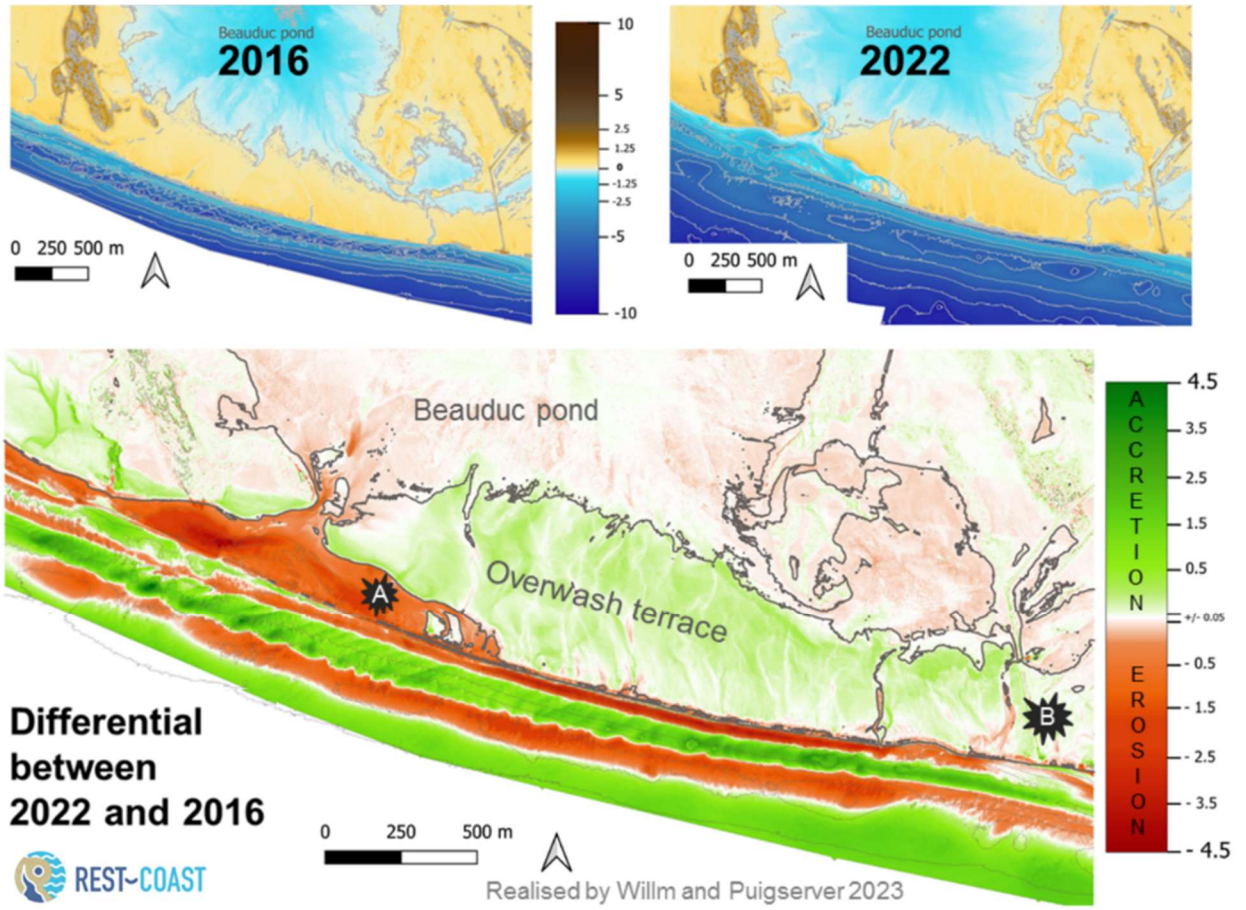

Figure 18: Changes to the topo-bathymetry to the south of the site. Figure extracted from page 65 of the pilot site activity report.

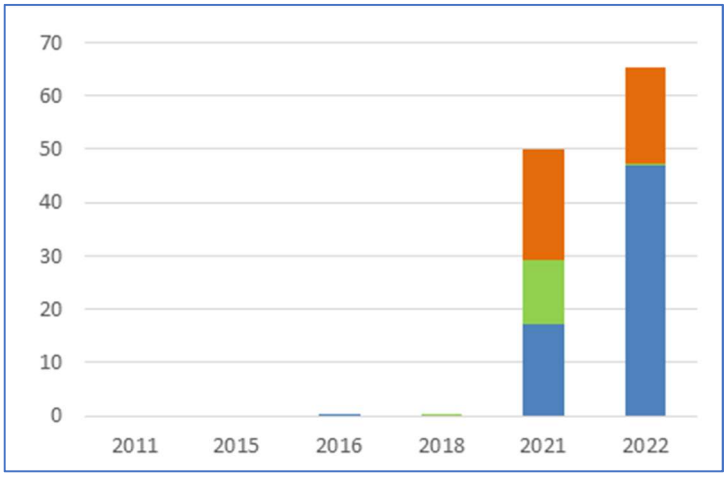

Figure 19 : Recovery rate (%) of different macrophyte species in the coastal lagoon ”Sablons”. In blue: "*Ruppia cirrhosa*". In green: "chlorophytic algae". Orange: "Rhodophytic algae". Figure extracted from page 29 of the pilot site activity report.

3.7 Presentations at international conferences

- The geomorphological evolution of the southern part of the site, induced by the restoration project, was presented in 2023 at the conference ”Coastal Sediments 2023”, with an oral presentation (Figure 20) and a published proceedings article (Puigserver et al., 2023).

Figure 20: First slide of the oral presentation given at the conference ”Coastal Sediments 2023”

- An oral presentation will also be given at the 38th international conference on coastal engineering, from 8 to 14 September 2024 at Rome.

4 Demonstrative material of restoration benefits

4.1 Hands-on restoration actions

4.1.1 Field surveys

Since the start of the project, numerous field surveys have been carried out to assess the restoration success of the targeted habitats, as well as the impact of restoration on the ecosystem services targeted by REST-COAST.

4.1.1.1 Monitoring the restoration dynamics of coastal lagoons

To monitor the restoration of the coastal lagoons targeted by the project, a number of monitoring programmes have been carried out for 2022 and 2023, to be continued in 2024. This monitoring involves measuring the ecological quality of surface water, the benthic macrofauna and the composition of aquatic vegetation.

Regarding the ecological quality of surface water, the protocol used is that recommended for the Mediterranean lagoon monitoring programme implemented in application of the Water Framework Directive (WFD 2000/60/EC of 23 October 2000, transposed into French law by law no. 2004-338 of 21 April 2004), which provides for 3 sampling campaigns to be carried out in June, July and August. In addition, a fourth campaign was carried out at the beginning of May in order to integrate the analysis results into the benthic macrofauna study.

For each campaign, water samples were taken from 5 stations (Figure 21), all located in the centre of the main lagoons of the Site (Figure 10).
The parameters analysed were as follows:

- NOx (nitrites + nitrates),
- Ammonia, Orthophosphates, Total P, Total N,
- Chlorophyll + Phaeophytin,
- Total Suspended Solids,
- Mineral Suspended Solids,
- Phytoplankton abundance (pico and nanoplankton),
- Water height, conductivity, salinity, water temperature, pH, turbidity, (chlorophyll a fluorescence), dissolved oxygen, secchi disk depth.

Figure 21: Physico-chemical monitoring of the water in the lagoons

Monitoring of the benthic macrofauna in the lagoons was carried out in 2022 in 12 locations (see Figures 11), and will be repeated in 2024. The method is similar to the protocol for monitoring lagoon environments in application of the Water Framework Directive (WFD). At each station, three substations spaced 10 metres apart were sampled, with each substation taking 4 samples a few metres apart. Unlike the DCE protocol, the benthic invertebrates were not collected using a grab sampler, but rather a PVC corer, by taking sediment cores 15 cm deep and 10 cm in diameter, over a total surface area corresponding to 940 cm2 per station. Sorting was carried out by sieving using 5 mm, 1 mm and 0.5 mm mesh sieves. Water height, temperature, turbidity and conductivity were also recorded at each station (Figure 22).

Figure 22: Monitoring of the benthic macrofauna in the lagoons

For most of the macroinvertebrates sampled, identification was carried out down to species level. In other cases, identification was limited to class, subclass, family or genus. To describe community structure, abundance, species richness, the Shannon-Weaver diversity index (H') and the Piélou equitability index (J) were calculated. The AMBI and M-AMBI indices were used to describe the quality of water bodies in permanent lagoons.

Monitoring of the site's aquatic vegetation was carried out in 2022 and 2023, and will be repeated in 2024. This monitoring is carried out at 88 locations on the site (see Figure 23). For each location, species composition, abundance, soil characteristics, bathymetry, water level, temperature and salinity are monitored. Aquatic plants are determined at the specific level for phanerogams and charophytes, and at the generic or specific level for macro-algae.

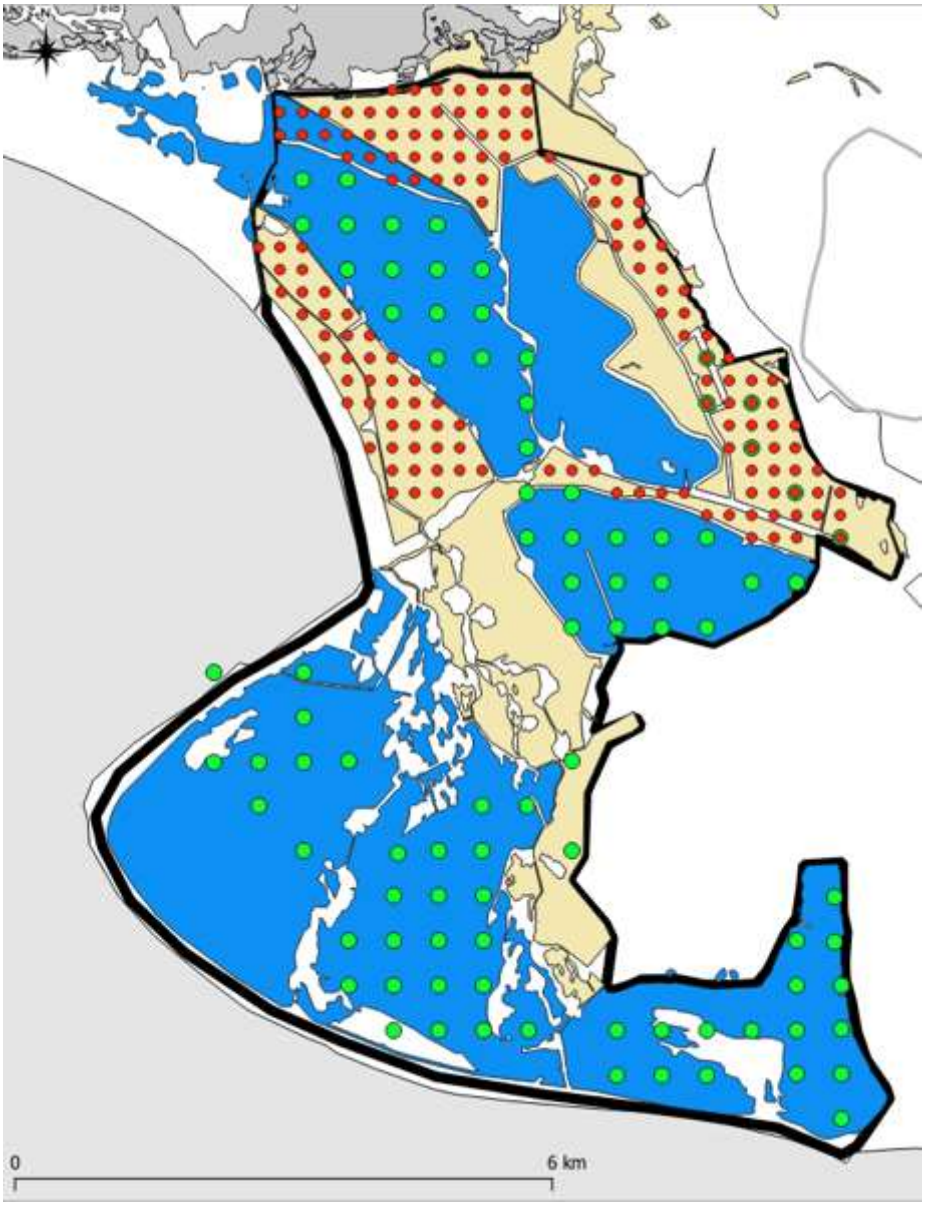

Figure 23: Measurement sites for aquatic (green) and terrestrial (red) vegetation for the years 2022, 2023 and 2024.

Figure 24: Illustration of aquatic vegetation monitoring

Example of the results of this monitoring are shown in Figure 19 for one lagoon.

4.1.1.2 Monitoring the restoration dynamics of Mediterranean and thermo-Atlantic halophilous scrubs, and Salicornia and other annuals colonising mud and sand

To assess the restoration dynamics of habitats ”Mediterranean and thermo-Atlantic halophilous scrubs (N 1420)”, and ”Salicornia and other annuals colonising mud and sand (N 1310)”, monitoring of the site's terrestrial vegetation was carried out in 2022 and 2023, and will be repeated in 2024. This monitoring is carried out at 136 locations on the site (see Figures 23 and 25). For each location, the parameters measured are species composition, abundance, soil characteristics, bathymetry, water level, temperature, and salinity (Figure 26). Illustration of results are shown in Figure 12).

Figure 25: Illustration of field monitoring of terrestrial vegetation.

4.1.1.3 Monitoring the restoration dynamics of beaches, and ESS coastal erosion reduction

To assess the restoration dynamics of beaches, several measurement campaigns (Figure 26) were carried out with:

- An airborne bathymetric LIDAR Campaign in 2022
- Several photogrammetric campaigns by drone in 2021, 2023 and 2024)

- Regular measurements on several areas of the topo-bathymetry with a differential GPS in 2021, 2022, 2023 and 2024.

Figure 26: illustration of topo-bathymetry measurements of beach areas, and of the natural channels connecting the site to the sea.

These measurements make it possible to estimate the width, area, and volume of the beaches, to assess their restoration dynamics. They are also used to study changes in the Evolutionary dynamics of connections with the sea (natural channels), in relation to the hydro-salines dynamics of the site, the risks of erosion and coastal flooding, and the migration of fish (ecosystem services studied in REST-COAST).

4.1.1.4 ESS Climate change regulation: monitoring of greenhouse gas emissions

The restoration work carried out on the site has an influence on the microbial diversity of the soil, sediments and vegetation, which in turn influences the emissions and sequestration of GHGs on the site. We are therefore working with the INRAE and EURECAT REST-COAST teams to estimate GHG emissions on the site, and to study their links with soil composition (granulometry, carbon, nitrogen and phosphorus contents), bacterial diversity, vegetation and the hydro-saline dynamics. The final objective is to link these emissions to the degree of connection to the sea (southern part) and to water management choices, in relation with the strategy of restoration.

An initial measurement campaign was carried out in April 2023 at 161 locations on the site, at the same sites as those where aquatic and terrestrial vegetation is monitored (Figures 23).

For each of the 161 sites, three soil/sediments samples were taken (Figure 27), mixed and analysed by the INRAE team. The results provide information on:

- The abundances of the microbial functional groups involved in CO2, CH4& N2O production/consumption
- Potential for CO2, CH4& N2O production/consumption by sediments/soils

Figure 27: sediment/soil sampling for analysis of the microbial functional groups involved in CO2, CH4& N2O production/consumption (X. Leroux on the left, M. Maréchal and X. Leroux on the right)

Based on the results obtained at these 161 sites, a second field campaign is planned for April 2024, during which we will use instrumental chambers to measure the fluxes of CO2, CH4& N2O emitted at 84 of these 161 locations.

4.1.1.5 ESS hydro-saline regulation and reduction of coastal flooding risk

To assess the impact of the restoration project on the ESS hydro-saline regulation and reduction of coastal flooding risk, additional probes were installed (Figure 28) in addition to the existing measurement network to monitor the variations in water level and salinity (CTD probes). An example of the results from one of the monitoring sites is shown in Figure 17.

Figure 28: Installation of sensors for continuous measurement of water level, temperature and salinity. Installation carried out in collaboration with the Camargue Regional Nature Park.

A three-week high frequency measurement campaign of a marine surge event was carried out in November 2022, with, in particular, the installation of 4 sensors (ADCPs) in the southern part of the site to measure currents and waves (Figure 29).

Figure 29: Installation of 4 ADCPs in the southern part of the site to monitor a marine surge event

In addition to these sensors, a hydrodynamic model is developed to simulate the hydro-saline dynamics of the site at different times of the year, including storm periods.

An example of the results of this model for water depths is shown in Figure 30.

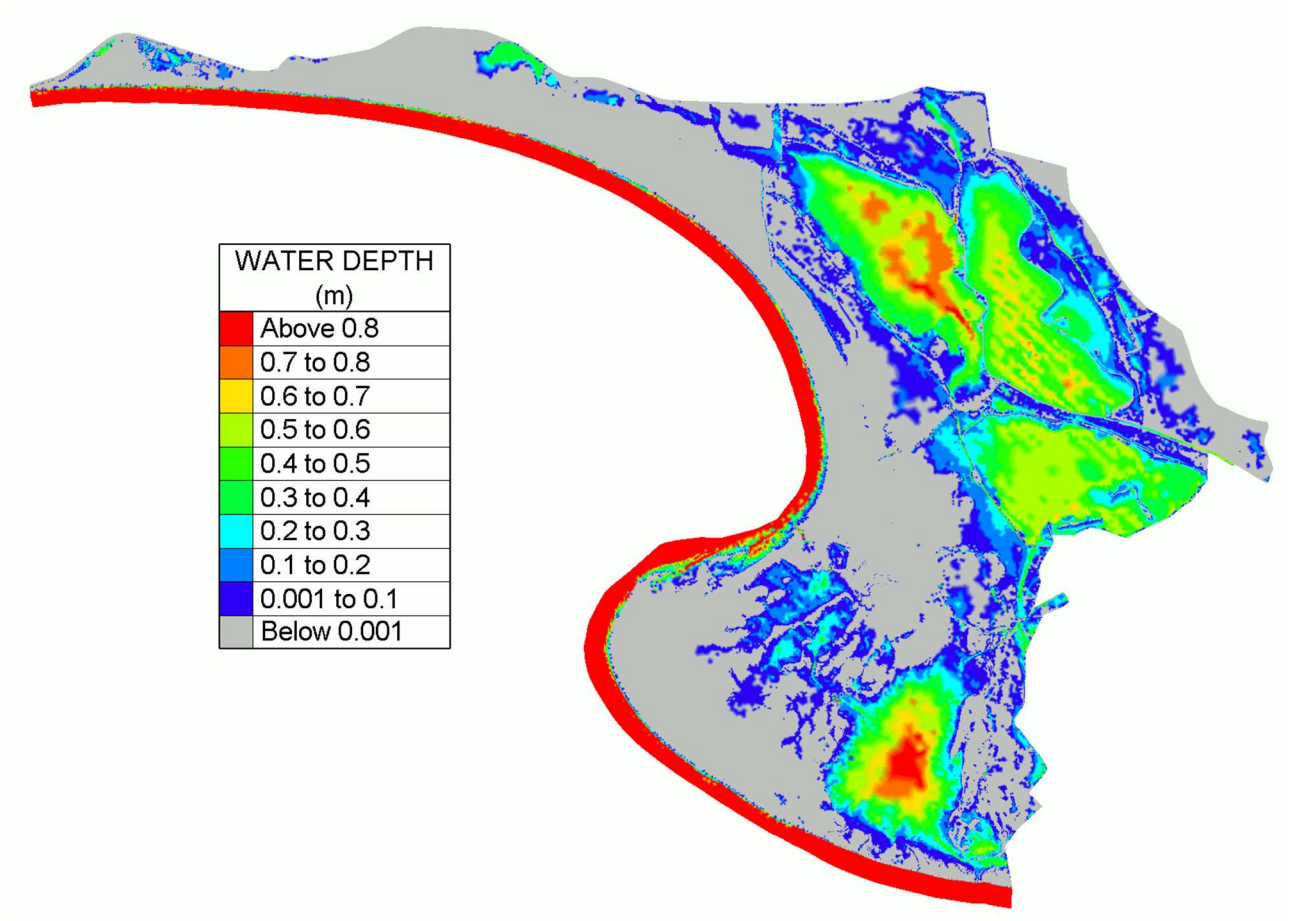

Figure 30: Example of the results of the modelling tool in terms of water levels

All of these measures, together with the modelling tools, make it possible to estimate the impact of the restoration project on ESS hydro-saline regulation and reduction of coastal flooding risk.

4.2 Demonstration value and replication

The Rhone Delta pilot site is a site with a high demonstrative value, underscoring the importance of ecosystem-based solutions in enhancing coastal resilience and sustaining biodiversity. To our knowledge, there is no other site of this size in the Mediterranean for which a strategic retreat has been implemented, with more than 10 km of historic dykes not being maintained, and the restoration of ecological processes over an area of 6,000 hectares to create a buffer zone to adapt to the effects of climate change.

The results of the large-scale modelling carried out in Task T2.4 of REST-COAST, as well as the results of WP4, should make it possible to target European coastal areas where such a project could be applied. In particular, Task T4.2 will make it possible to estimate the consequences of large-scale strategic retreats on coastal adaptation to rising sea levels. An article, led by the University of Lincoln (leader of task T2.4), has been submitted on this point, highlighting the positive impact of the available inland migration space on the response of coastal marshes to rising sea levels.

For the Rhone Delta Pilot Site, although tangible results have been achieved in terms of restoring biodiversity and several ecosystem services, there is a priority need to convince more local stakeholders and inhabitants or users of the benefits of the restoration implemented. For some of them, the project is mainly perceived as a project to “leave the area to the sea”, and not as a project with ecosystem-based solutions to enhance coastal resilience. The Rhone Delta pilot site is a good example of how a strategic retreat, with the abandonment of dykes, generates local fear of the risk of flooding. It clearly highlights the need for stakeholders, as well as local inhabitants, to be fully involved in the project, in order to benefit from local support, which will determine its success.

The main challenge of the restoration project for the Rhone Delta Pilote Site is to determine whether it is possible to improve all the targeted ecosystem services at the same time, or whether feedback loops, side effects and causal chains exist in the system that would lead to the deterioration of one of the other services as a result of the improvement of one of the services. Disseminating the experience gained on these points is therefore of major importance in supporting future managers, decision-makers and residents to design strategic retreat projects on other sites. By welcoming visitors from different backgrounds (scientists, managers, inhabitants) and presenting the project, and by sharing the experience gained from its implementation on the Rhone Delta, we believe that this type of project could soon be implemented on other sites.

As part of REST-COAST, albeit on a smaller scale, a similar project exists for the Ebro Delta, with the reopening of a dyke to reconnect a lagoon with the sea. Comparisons between the two pilot sites will provide interesting insights into the application of this type of approach for two deltaic systems.

Thanks to the experience acquired on the Rhone Delta pilot site, Tour du Valat has been invited to join a consortium which has submitted a project, ADAPTO+, that will explore solutions to the impacts of climate change on the coast by advocating adaptive coastal management, based on several pilot sites in France (the REST-COAST pilot site is not one of these pilot sites). This project will benefit from the lessons learned from the Rhone Delta pilot site during REST-COAST.

5 References

Puigserver, C., Sabatier, F., Larroude, P., Boutron, O., 2023. Realignment Strategy in the Rhone Delta: Consequences for Geomorphological Dynamics in a Context of Climate Change, in: Coastal Sediments 2023. World Scientific, pp. 2293–2306. https://doi.org/10.1142/9789811275135_0211