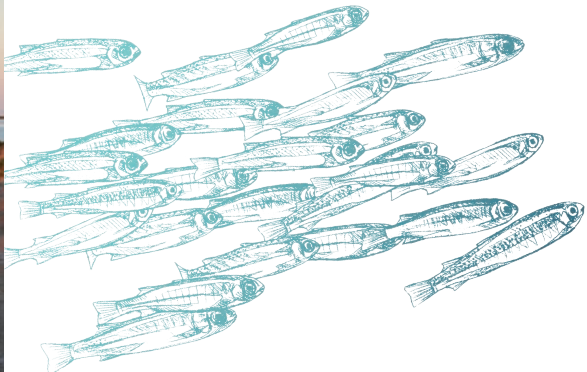
NATURE BASED SOLUTIONS
IN THE CAMARGUE'S FORMER SALTWORKS

SCIENCES & MANAGEMENT



Tour du Valat

Research institute for the conservation of Mediterranean wetlands

The Tour du Valat is a research institute for the conservation of Mediterranean wetlands created more than 60 years ago by Luc Hoffmann. It has since then developed its research activities for the conservation of Mediterranean wetlands with the constant desire to achieve: better understanding for better management.

Convinced that it will only be possible to preserve wetlands if human activities and the protection of the natural heritage can be reconciled, the Tour du Valat has for many years been developing programmes of research and integrated management that favour interchanges between wetland users and scientists, and promote wetlands benefits to decision makers.

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NATURE BASED SOLUTIONS

LESSONS LEARNED FROM THE RESTORATION OF THE FORMER SALTWORKS IN SOUTHERN FRANCE

INTRODUCTION

Climate change is causing extreme weather events such as droughts, flooding, heat waves and cyclones. These events are already affecting ecosystems and biodiversity, with impacts on human wellbeing, economic losses and threats to human lives [1, 2]. The Mediterranean region is especially threatened with an expected sea-level rise of 10 to 25 cm by 2050[3]. Adaptation and mitigation to climate change are thus a major priority.

WHAT ARE NATURE-BASED SOLUTIONS?

THE NATURE-BASED SOLUTION CONCEPT

The International Union for Conservation of Nature (IUCN) defines Nature-based Solutions as strategies designed to protect, sustainably manage and restore natural or modified ecosystems applied at a landscape scale. Nature-based solutions (NbS) use an adaptive management approach to tackle societal changes (climate change, food and water security, water pollution, human health or natural disasters) while simultaneously providing human well-being (ecosystem services) and biodiversity benefits [4] (figure 1).

NbS search for alternative techniques to work with ecosystems rather than relying only on conventional engineering solutions to counteract the forces of nature.

Figure 1.

Nature-based Solution diagram

©IUCN

STRENGTHS OF NBS: BENEFITS TO PEOPLE AND THE ENVIRONMENT

Concrete-based structures (so-called grey infrastructures) are not always able to adapt and compensate for changes, such as sea-level rise, and they require regular maintenance and adjustments. In addition, these artificial structures tend to cause unwanted erosion in other locations and add to the fragmentation of ecosystems, often resulting in sterile landscapes. The production of such structures is also indirectly associated with negative impacts related to mining activities for material extraction and the transportation of these materials[6] (figure 2).

NbS are thus an attractive alternative for natural hazard management and biodiversity protection. They allow for sustainable solutions that are able to respond to environmental changes and hazards in the long-term. NbS range from fully natural solutions, managed natural solutions, hybrid solutions to environmentally-friendly structural engineering[5]. They enlarge the discussions about biodiversity and nature conservation to include humans by integrating societal factors such as human well-being, socio-economic development and governance principles.

Scientific evidence shows that healthy and resilient wetlands, forests, coastal systems and other ecosystems can significantly decrease the effect of exposure to natural hazards by serving as protective barriers or buffers[2,6,7]. For example, by taking measurements across several marshes, researchers from the Netherlands have verified that vegetated wetlands — such as salt marshes, mangroves and reed beds — help reduce wave loads on coastal dikes by decreasing the strength and intensity of waves[8].

Figure 2.

Broken dike along the coast of the Camargue's former saltworks.

As a result of this research, scientists have concluded that the restoration of such ecosystems can complement conventional engineering methods to address societal requirements for flood protection, infrastructure and food production, simultaneously improving biodiversity and other ecosystem services (figure 3).

Figure 3.

Nature based solutions used in conjunction with infrastructure development.

INTERNATIONAL RECOGNITION OF THE NBS APPROACH

The NbS approach is highly accepted within global policy frameworks, including the Convention on Biological Diversity (2014), the United Nations Framework Convention on Climate Change (UNFCCC), the United Nations Office for Disaster Risk Reduction (UNISDR), the United Nations Educational, Scientific and Cultural Organization (UNESCO), the World Bank (WB), the Ecosystem Adaptation and Disaster Risk Reduction (PEDRR) and the UN-Habitat III new urban agenda.

The European Union's Framework Program for Research and Innovation Horizon 2020 has introduced NbS into its work plan and is working on defining, disseminating and implementing NbS to enhance the awareness and engagement of end-users and to steer supply and demand toward nature-based solutions.

There are many examples of how NbS provide positive results (both for the environment and for human societies) in a variety of different landscapes and ecosystems from around the world. A sample of case studies around Europe can be found in Box 1 below.

BOX 1. NATURE-BASED SOLUTIONS CASE STUDIES

Challenge for the society

Climate change mitigation in agricultural production

Example of Nature-based Solutions

Agroforestry: An alternative agriculture for the future (Montpellier, France) [10]

© Institut National de la Recherche Agronomique (INRA)

Agroforestry systems (i.e. walnut/wheat mix) are more resilient to the effects of climate change than conventional systems. They adapt better to changes in temperatures or droughts, water and biotic stresses and more extreme events.

© AMBER project

Challenge for the society

River flood risk

Example of Nature-based Solutions

Adaptive Management of Barriers in European Rivers [11] **(Poland, Italy, Germany, UK, Ireland, Netherlands, Spain, France, Switzerland, Denmark and Sweden)**

This European project applies adaptive management to the operation of dams and barriers in European rivers to achieve a more efficient restoration of stream connectivity and to reduce impacts caused by river fragmentation.

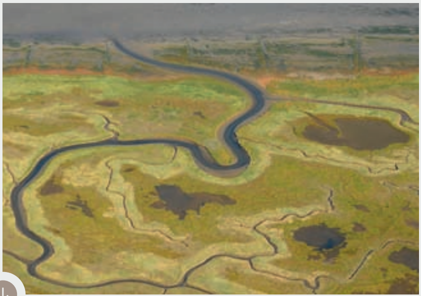
Challenge for the society

Coastal risks

Example of Nature-based Solutions

Dune management [13] **(Praia do Faro, Portugal)**

Dune fences help trap sand in the dune areas, reinforcing the dune system. Dunes protect the land from waves and flooding. The wooden path also played an important role in dune recovery.



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Challenge for the society

Coastal risks

Example of Nature-based Solutions

Creation of a buffer zone and ecological restoration of wetlands [14] (Rhine river, The Netherlands)

Natural Climate Buffers:
Restoring natural areas to store water and prevent flooding of urban and farming areas. This strategy includes:

- moving dikes to open up free space for rivers flows.
- restoring coastal saltmarshes to revive their sediment dynamics, offset sea-level rise and re-establish hydrological connections for migratory fish.

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Challenge for the society

Flood risk mitigation

Example of Nature-based Solutions

Hydro-morphological restoration of watercourses (Province of Bolzano, Italy)

The Mareta River, in Northern Italy, was home to numerous structures and major sediment extraction for the construction of a motorway in the 1970s, dramatically altering its morphological structure. A major incision and narrowing of the river bed led to the disappearance of water retention zones, exposing the Vipiteno basin to more intense flooding.

© CIRF

Thirty years later, morphological restoration actions were carried out to enlarge and recreate the river bed and to reduce the lateral and longitudinal disconnections. These included the removal or the re-shaping of 17 weirs and gravel replenishment (130,000 m^3) along a 2 km long stretch.

WETLAND ECOSYSTEMS AS NATURAL CLIMATE BUFFERS

Healthy wetlands are essential in mitigating the adverse impacts of climate change by acting as natural climate buffers. Wetlands associated with seas, rivers and lakes provide areas to store and slow down the water flow during floods. These systems can help to steady flow rates, reduce flood peaks and lower the flood risks to towns and other important infrastructures [17] (see box 2 to learn more about their importance for marine floods). These natural climate buffers evolve with climate change and adapt to it while improving the quality of human life and hosting biodiversity at the same time.

Mangroves for example, are largely recognized as barriers that protect the coast from inundations. Countries around the world such as Costa Rica, the United States, Vietnam, Thailand, Mexico (figure 4) and the Philippines are investing resources in mangrove restoration in an effort to secure livelihoods, protect soil and fisheries, and to help in carbon sequestration [6, 15]. When wetlands have been damaged by excessive drainage, overgrazing and other pressures, they emit carbon and thus contribute to climate change. This is why conserving and managing wetlands properly not only stops the loss of carbon, but also helps to capture and store carbon thereby mitigating climate change [16].

Figure 4.

Mangroves in Celestun, Mexico

© E. Estevez Aguilar

BOX 2. **MARINE FLOODS IN EUROPE**

RESTORATION OF COASTAL ECOSYSTEMS CAN REDUCE THE COSTS OF FLOODS

The Intergovernmental Panel on Climate Change scenarios forecast an average 30 cm rise in the sea-level at the end of the century for European coasts. This could lead to the permanent displacement of over 10,000 people due to yearly flooding. If sea levels rise by more than 45 cm, nearly 440,000 Europeans would have to leave their homes permanently by the end of the century[17].

Flooding is the most frequent natural hazard, affecting more people and more countries than any other natural risk[18]. European Union countries expected to suffer the most economic damage by 2080 are the Netherlands (an average of 6 billion Euros of damage costs projected each year), followed by France, the United Kingdom and Germany (ranging from 3 to 4 billion Euros per country)[19] (figure 5).

According to the French Ministry of the Environment, Energy and the Sea (MEEM in French), the risk of marine flooding in France currently affects more than 860 municipalities potentially impacting 1.4 million inhabitants and 570,000 homes. All current climate models predict that average global sea levels will rise during the 21st century at a rate faster than what was observed between 1971 and 2010. Sea level has risen on average 20 cm since 1900, and it could continue to rise another 26 cm to 1 meter by the end of this century[19].

Figure 5.
Storm Kyrill hit northern Europe.
© Phillipe Hugen

There is an urgent need not only for emission reductions but also for the restoration of degraded coastal ecosystems. New or extended wetlands established in the Netherlands have already proven to function as reliable natural water retention measures for buffering inland flooding. Using the example set in the Netherlands, many countries could implement these alternative solutions in their National Action Strategies and replace gray infrastructure by green infrastructure to attenuate Climate Change effects when appropriate. These alternative solutions have benefits not only in terms of climate change adaptation, but they also provide effective conservation activities for biodiversity and offer new opportunities for nature-related recreation. Moreover, in many projects, natural solutions proved to be less expensive than traditional civil engineering methods[18].

OUR WETLAND: THE CAMARGUE'S FORMER SALTWORKS

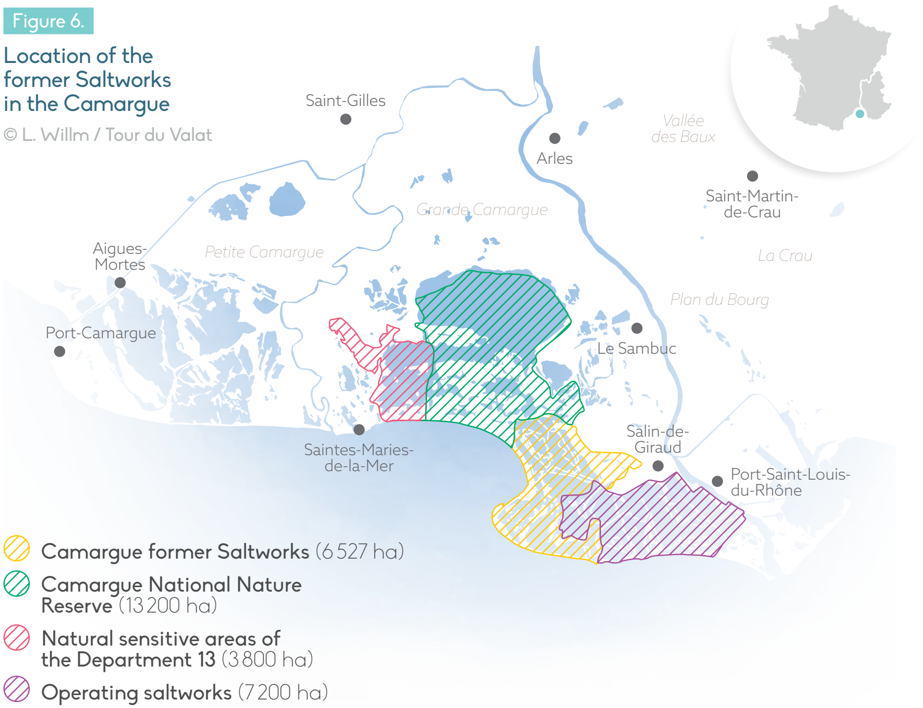
The Rhône river delta is also called the Camargue. It is located along the Mediterranean coast of southern France, west of Marseille. It covers 140,000 hectares, comprising agricultural lands and an outstanding diversity of wetlands and coastal ecosystems. Recent projections estimate that the Camargue will be more vulnerable to coastal erosion and marine submersion risks [19], with extreme sea-level rises forecasted between 1.6 and 1.8 m by 2100 [20].

The former saltworks are located in the southeast of the Rhône delta, in the Camargue Regional Natural Park and the UNESCO's Man and Biosphere Reserve. This site represents a vast coastal area of over 6,500 ha in the municipalities of Arles and Saintes-Maries-de-la-Mer (figure 6).

Figure 6.

Location of the former Saltworks in the Camargue

© L. Willm / Tour du Valat



HISTORICAL CONTEXT: SALT PRODUCTION IN A DYNAMIC DELTA

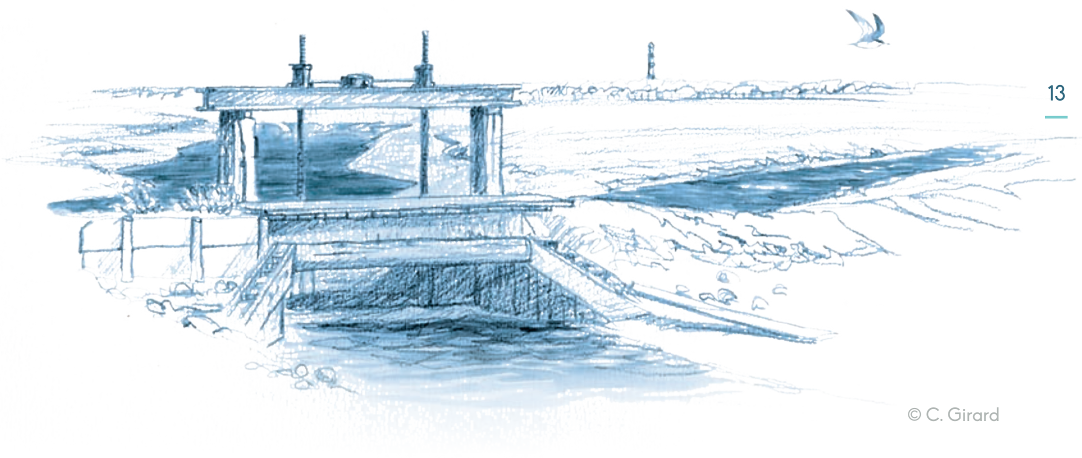
The Salin-de-Giraud saltworks were created in 1855 and gradually expanded during the 19th and 20th centuries. The area currently known as the former saltworks of Camargue remained undeveloped until the 1950's. Between 1950 and 1970, the land was transformed and developed for industrial salt production.

During the period of industrial salt production, the Salins du Midi Company undertook major infrastructure works (leveling, embankments, creation of hydraulic works, electrification, etc.) aimed at transforming the Mediterranean halophilous scrubs, mudflats and lagoons into salt concentration evaporation ponds. Water dynamics and ecological conditions like water levels and salinity, were largely transformed during the 50 years of salt production. The water bodies were disconnected from the surrounding sub-watersheds and seawater was pumped during the spring and summer into the evaporation ponds. Dikes along the sea allowed for total control of the sea water surges. These mechanisms caused high water levels during summer and low levels during winter, which is the opposite of natural dynamics in a Mediterranean climate.

The site faced economic difficulties beginning in the 1990's and in 2007, the Salins du Midi decided to sell part of the saltworks.

In 2011, the site was purchased by the Conservatoire du Littoral. Its main vocation then shifted from salt production to wetland conservation. A restoration process through adaptive management was put into place by the Regional Natural Park of the Camargue (coordinating manager) working in partnership with the Tour du Valat Research Institute and the National Society for Nature Protection (co-managers) under the aegis of the Conservatoire du Littoral (landowner).

The main objectives were to restore the natural hydrological processes by reconnecting the lagoons within the site and with the surrounding aquatic ecosystems and the sea.



© C. Girard

This site hosts important biodiversity and acts as a buffer against sea floods. While one of the main ambitions of the restoration project is to enhance biodiversity, the site provides space set aside to mitigate the effects of sea-level rise. This corresponds to recent scientific research recommending that "accommodation space" should be expanded by using "natural and nature-based features"[19].

IMPORTANT ECOSYSTEMS LOCATED IN THE TERRITORY

The former saltworks are included in the "Camargue" Ramsar site and contain coastal lagoons, Mediterranean salt steppes, coastal dunes and wooded dunes (Stone pine- *Pinus pinea* (figure 7) and Maritime pine- *Pinus pinaster)*. It is part of the Natura 2000 network and includes 17 habitats targeted by the European Habitats Directive. It hosts 315 plant species (including 25 protected species), 268 bird species and is an important breeding site for the Greater Flamingo *(Phoenicopterus roseus)*. The area is also an important place for human activities such as tourism, sea sports and recreational hunting.

Figure 7.

Coastal dune with Stone Pines (Pinus pinea) and a temporary pond.

© M. Thibault / Tour du Valat

The sea-water pumping in the summer months during the salt production era increased water levels and caused the loss of large surfaces of local halophytes *Salicornia and Arthrocnemum* - Glasswort scrubs (figure 8).

Large numbers of marine fish were sucked into the pumping station, some managed to survive in the lagoons located at the beginning of the water circulation route where salinity was low enough for some fish species to survive (i.e. European Eel, Sand Smelt, Mullets), but most could not manage to escape back to the sea. Furthermore, along the water circulation route, the high salinity levels (up to 150 g / l of salt in water) were also an impediment to fish populations and to the survival of most aquatic species. Other non-aquatic populations that were clearly affected included most of the wintering duck species (with the exception of shelducks).

On the other hand, a variety of water birds, including the Pied Avocet, Slender-billed Gull, Mediterranean Gull and various Tern species experienced a dramatic population increase at the beginning of the saltworks era. This was due to high water levels being artificially maintained during the breeding period, which prevented terrestrial predators from reaching the breeding islets located in the lagoons. However, the stabilized and predictable water regime that was created also favored an accelerated population growth of the larger Yellow-legged gull, which eventually out-competed other, smaller colonial species, causing an important decline in the colonial water bird populations.

Nevertheless, the salt production era was very favorable to the breeding of the Greater Flamingo. After centuries of periodic breeding in the Camargue, the construction of a breeding island in the saltworks created ideal conditions and allowed the Greater Flamingo to successfully reproduce on a yearly basis from 1977.

When the Conservatoire du Littoral purchased the site, the opportunity arose to restore the ecosystem, recover its ecosystem functionality and associated ecosystem services including species habitats, fish migration corridors, buffering zone against sea floods and aesthetic areas for recreational activities.

Figure 8.

Mediterranean halophilous scrubs with Glasswort (Salicornia) scrubs.

© M. Thibault / Tour du Valat

NBS APPROACHES APPLIED IN THE FORMER SALTWORKS OF THE CAMARGUE

The former saltworks restoration project incorporates many NbS approaches, but especially focuses on ecosystem-based adaptation and ecosystem-based disaster risk reduction.

Ecosystem-based Adaptation (EbA)

The IUCN presents EbA as Nature-based Solutions that harness biodiversity and ecosystem services to reduce vulnerability and build resilience to climate change. EbA emphasizes that healthy ecosystems hold more resilience capacity and climate adaptation responses. Research has demonstrated that the future of coastal wetlands and their ecological value depend on their capacity to adapt to the interacting effects of human impacts and sea-level rise[21].

The former saltworks restoration project aims to recover the functionality of the site through adaptive restoration [22] (figure 9). The reconnection of water bodies leads to the eventual reshaping of water paths in a natural way (e.g. after storms). Newly emerged soils and restored waterways produce " new " homes for vegetation, fish, birds and other wildlife populations. This coastal ecosystem becomes more resilient to better face the impacts of climate change.

Figure 9.

Colonization by various Salicornia species is facilitated by the restoration of natural water cycles.

Figure 10.

The water reservoir capacity of the former saltworks.

© M. Thibault / Tour du Valat

Ecosystem-based Disaster Risk Reduction (ecoDRR)

"Ecosystem-based disaster risk reduction (Eco-DRR) is the sustainable management, conservation, and restoration of ecosystems to provide services that reduce disaster risk by mitigating hazards and by increasing livelihood resilience"[6]. Ecosystem properties can therefore be used to reduce damage caused by natural hazards.

Coastal ecosystems are particularly vulnerable to sea-level rise due to their location in low lying areas. Many studies have predicted the submergence of 20-78 % of worldwide coastal wetlands by the end of the 21st century[23, 24].

Healthy and functional coastal wetlands have a high capacity to fight against sea-level rise[25]. Restored wetlands in the former saltworks are resilient to sea storms and associated sea floods. Using the wetlands' capacity to temporarily store sea water during flooding events is an efficient strategy to prevent the occurrence of sea disaster events further inland in the Rhône delta[26]. In addition, *Salicornia* vegetation and other marshland ecosystems can evolve and gradually rise as they retain more sediment and their vegetation decomposes and grows back. The restoration of marshland in the Camargue's former saltworks consists in a strategy to mitigate the expected acceleration in sea-level rise by the middle of the century, reducing the risk of inundations, while supporting the current inland protection dike (figure 10).

NEW LIFE TO THE FORMER SALTWORKS LAND

NEW ADMINISTRATION AND OBJECTIVES:

Since the former saltworks were purchased by Conservatoire du Littoral, a new management organization took over with new objectives, applying adaptive management to sea level rise in an effort to enhance habitats for biodiversity. The new strategy includes abandoning the dikes along the coastline and adapting and reinforcing the second-row dikes further inland.

The Conservatoire du Littoral set the following management objectives for the former saltworks of the Camargue:

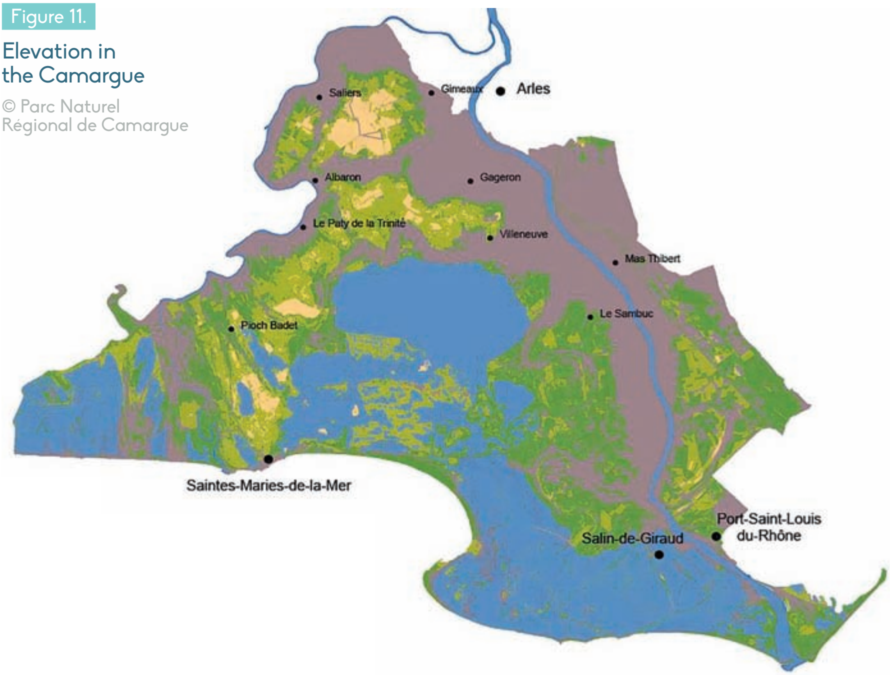
1. **Restore a more natural hydrological functioning** that reconnects the surrounding hydrosystems (including the lagoons located further inland, the Mediterranean Sea and the Rhône River).
2. **Restore the natural ecosystems characteristic** of coastal lagoons and sandy coastlines, including dunes, salt steppes and saltmarshes.
3. **Maintain or increase the carrying capacity** for breeding colonial water birds.
4. **Implement adaptive management to sea-level rise,** including controlled coastal retreat in areas affected by erosion.
5. **Contribute to sustainable developments,** including facilitating the development of green tourism and recreational activities.

NEW CHALLENGES: COASTAL DYNAMICS AND SEA LEVEL RISE

As 70% of the Camargue delta is located at an altitude of less than 1 m, the territory is susceptible to flooding when sea level rises (figure 11). For centuries, the strategy to prevent floods was to build dikes along the Rhone River and the Mediterranean Sea. The delta was almost completely polderized* by 1860's. The lack of sediment inputs from the Rhône River as a result of its containment has had important impacts on dune formation, erosion and water distribution. All this, combined with the acceleration of sea-level rise due to climate change has put the territory in a vulnerable situation.

Figure 11.

Elevation in the Camargue



Elevation	Surface	% of territory
Below 0 m	2 600 ha	2,6
≥ 0 m and ≤ 0,5 m	13 800 ha	13,8
≥ 0,5 m and ≤ 1 m	22 200 ha	22,2
≥ 1 m	30 500 ha	30,5
Water surface	30 900 ha	30,9

**polderization: consist of isolating a space covered by the sea with dikes.*

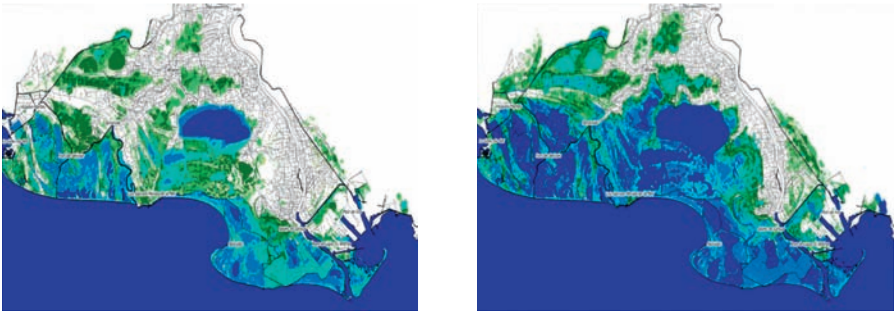
The managers of the former saltworks site are therefore tasked with the difficult job of designing strategies to minimize the vulnerability of the area to sea-level change. Models of marine water submersion related to extreme events are carried out by the Geological and Mining Research Bureau (BRGM) (figure 12).

The forecasted water levels in the delta are calculated using LIDAR images. These models take into account the Rhône River water regime and the forecasted elevation of the sea level. The models serve to guide the actions related to sea disaster risk reduction.

Figure 12.

Current extreme sea level (left) and sea level rise forecast for 2100 (right)

© BRGM



Maximum water levels reached for a current average sea-level rise

- 0 - 0,2 m
- 0,2 - 0,5 m
- 0,5 - 1 m
- 1 - 1,5 m
- 1,5 - 2 m
- Sup. 2 m

Maximum water levels to be reached in 2100

- 0 - 0,2 m
- 0,2 - 0,5 m
- 0,5 - 1 m
- 1 - 1,5 m
- 1,5 - 2 m
- Sup. 2 m

NEW STRATEGY: TURNING THE FORMER SALTWORKS INTO A BUFFER ZONE TO MITIGATE SEALEVEL RISE EFFECTS

As the dikes and hydraulic structures inherited from the salt-mining activity were no longer adapted to the new objectives defined for the site, several actions were implemented to reconnect the water bodies. The principle activities included channel dredging, construction of water gates, rehabilitation of water gates and dike levelling (figure 13).

Figure 13.

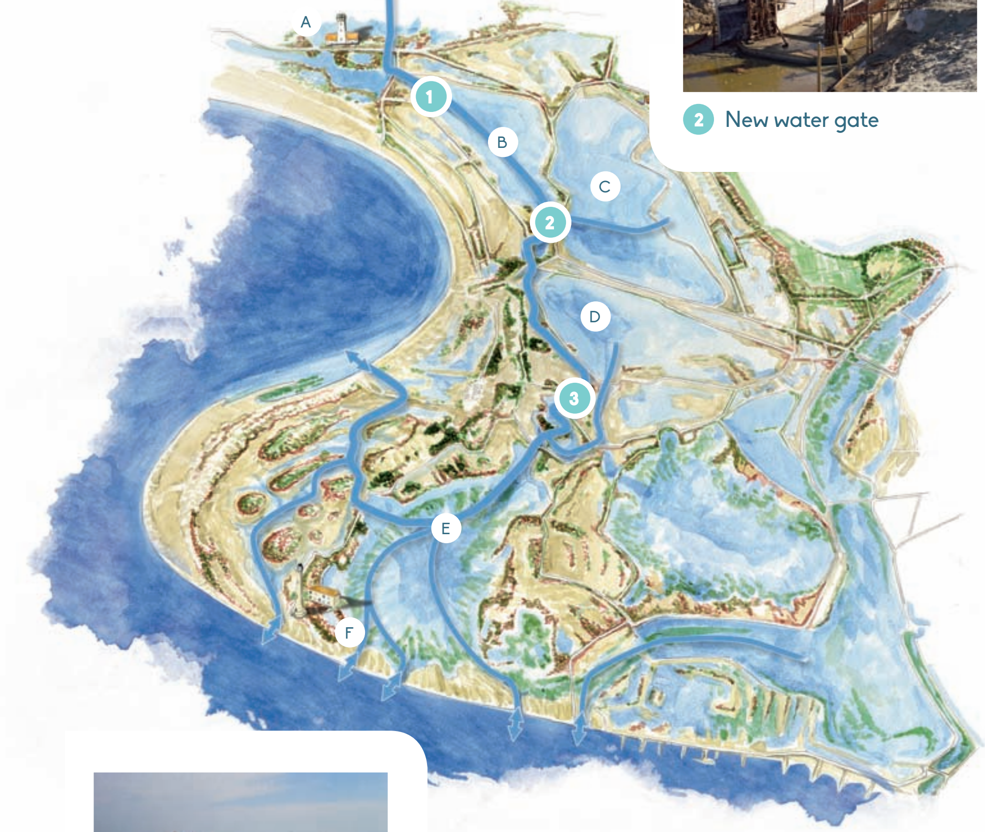
Restored hydraulic axis and location of the hydraulic works in the former saltworks.

Figure © C. Girard and photos © Parc naturel régional de Camargue

A. Phare de la Gacholle
B. Étang du Galabert
C. Étang du Fangassier
D. Étang du Grand Rascaillan
E. Étang de Beauduc
F. Phare de Beauduc

1 Rehabilitated water gate

2 New water gate



3 Channel dredging

The former saltworks hydrosystem was reconnected to the lagoons located in the nearby Camargue Nature Reserve, lagoons located within the former saltworks were reconnected to each other, and coastal defenses (dikes) were abandoned, allowing the water to move more freely between the former saltworks and the Mediterranean Sea, at least seasonnally (figure 14). Large parts of the former saltworks are now depolderized and water flows have become strictly gravitational.

As the site is adjacent to the National Nature Reserve of Camargue, this restoration project has set important management objectives related to connectivity. In particular, restoration is based on unobstructed natural water flows and spontaneous colonization by wildlife.

Figure 14.

Restoration of the coastal dynamic along the former saltworks induces many changes, with coastal retreat in some areas (photos above), while coastal progression occurs elsewhere.

© Jean E. Roché

Evaluation of the NbS

To evaluate the effectiveness of NbS in the former saltworks restoration project, we identified the challenges, actions and impacts based on the EU guideline EKLIPSE for Nature-based Solutions. We thus assessed the environmental, economic and social aspects of the project (Figure 15).

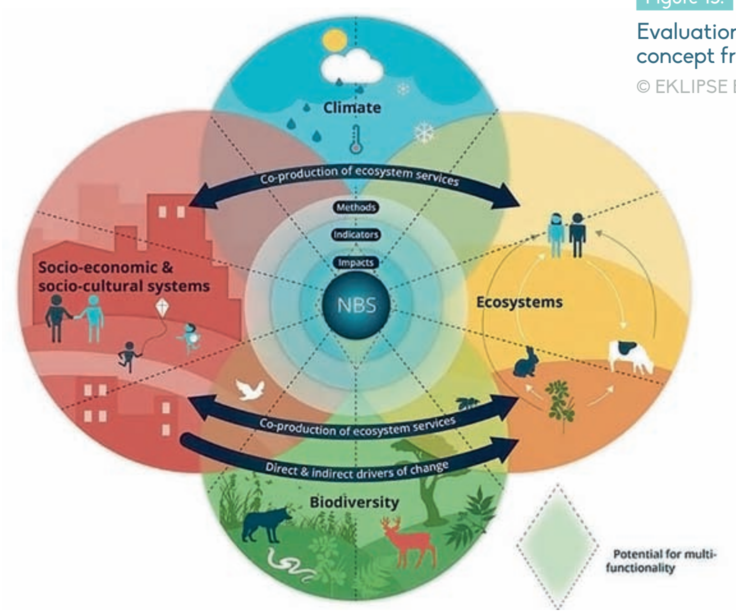


Figure 15.

Evaluation scheme concept from EKLIPSE.

ENVIRONMENTAL ASSESSMENT

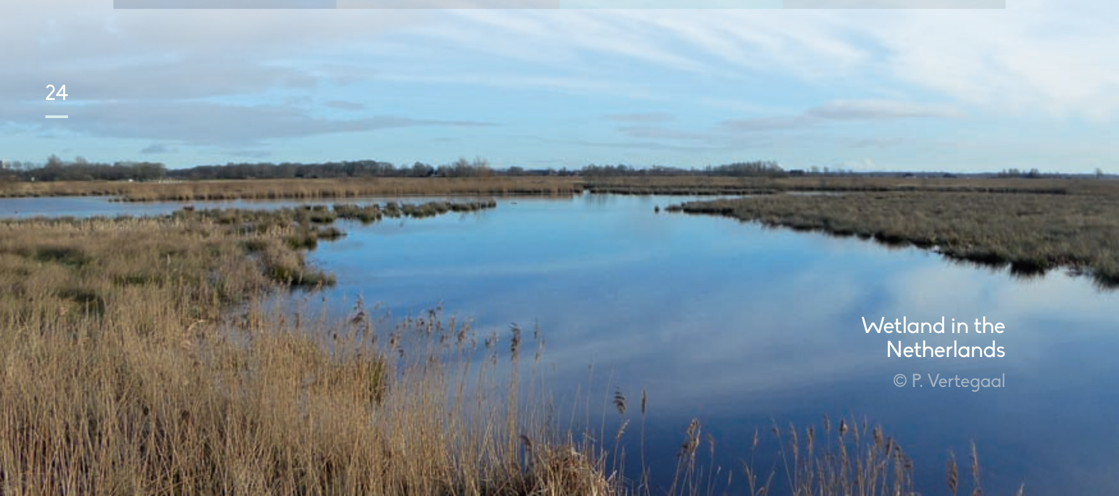
Biological monitoring of the site is being implemented. Biologists and specialists on wetlands management, hydrology and ecological restoration have been working in the area of the former saltworks and have developed a solid understanding of population dynamics and the ecological status of the site (Table 1).

The ecological evaluation of the former saltworks NbS indicate improved functioning of the restored costal lagoons and salt marsh ecosystems.

This was assessed through biological indicators such as the successful salt-marsh vegetation succession, the evolution of benthic invertebrate community structure and submerged macrophytes cover in the lagoons, and the fish species composition.

TABLE 1. **ENVIRONMENTAL EVALUATION**

CHALLENGE	ACTION	IMPACT	INDICATORS
1. Coastal erosion and loss of beach ecosystems	No longer maintaining and restoring the dikes along the coastline	Restoration of a sandy coastline behind the abandoned dikes	Beach topography
2. Sea level rise	Decompartmentalization of lagoons within the former saltworks	Improved water flows and spreading	Evolution of water levels in lagoons Coastline monitoring
3.Oversalinization of the lagoons **Disruption of the life cycle of aquatic species**	Reconnection with surrounding brackish and freshwater ecosystems	The salinity of some of the lagoons has decreased Migratory fish movements and fish nursery function are partially restored	Water salinity Composition of aquatic flora and fauna in coastal lagoons Composition of fish communities
4. Loss of Salicornia scrubs and other salt marshes	Restoration of natural cycles (winter submersion, summer drying) favorable to salt marsh vegetation Implementation of an adapted hydraulic management system	Restoration of salt marsh habitats, including habitats targeted by the European Habitats Directive. Restoration of habitats for wildlife including water birds and bird species associated with salt steppes.	Habitat surface Bird community composition



Wetland in the Netherlands
© P. Vertegaal

IN THE WATER

Aquatic vegetation

The monitoring from 2011 to 2018 shows an increase in aquatic plant cover. Widgeon grass - *Ruppia cirrhosa* (figure 16) surfaces are growing, there is a new colonization of Dwarf Eelgrass - *Zostera noltei* (figure 17) and an increase in Rhodophyta algae in the lagoons located close to the sea, suggesting an improved ecological status of these lagoons. There were also stations of Widgeon grass found starting in 2015 onwards in some of the temporary lagoons located further inland. These are positive indicators as *Ruppia* species are associated with recovering ecosystems.

Figure 16.
Ruppia cirrhosa.
© C. Girard

In contrast, the Rascaillan lagoon, in which no hydraulic reconnections have yet taken place, does not show a significant change in the composition and cover of its aquatic vegetation, whose development remains very limited, in particular, because of high salinities. This result indicates a need for additional hydraulic restoration works in the future.

Figure 17.
Zostera noltei.
© C. Girard

Macrobenthic fauna

Benthic macroinvertebrates are small aquatic animals that live on or in the bottom of water bodies. In the Mediterranean coastal lagoons, they are most frequently composed of a number of organisms such as molluscs (i.e. cockles, clams, tellins), snails, sea worms and diptera larvae. Given that benthic macroinvertebrates community structure is a robust indicator of water and sediment quality because these organisms have specific ecological requirements, the presence of certain species provides relevant information on environmental conditions.

Figure 18.

Microdeutopus gryllotalpa.

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The benthic macroinvertebrate monitoring found the presence of *Microdeutopus gryllotalpa* (figure 18), indicating good water quality in the coastal lagoons. Moreover, the presence of the sea snails *Akura bullata* (figure 19) and *Glycera tridactyla* (figure 20) found in 2018 in different lagoons where hydraulic works have been carried out demonstrated improvement in water flows and connectivity.

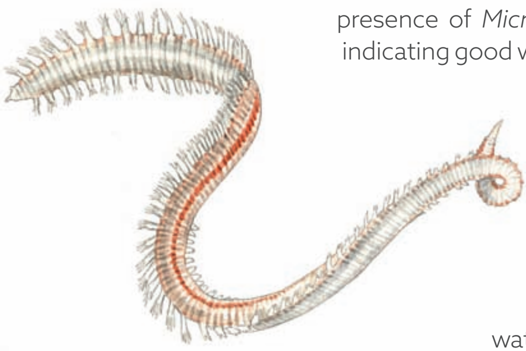

Figure 19.

Akura bullata.

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Figure 20.

Glycera tridactyla.

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Fish and crustaceans

An intensive monitoring survey was implemented from 2016 in order to assess the degree of hydrobiological connectivity between the sea and the northern lagoons in the former saltworks. Emphasis was placed on species (fish and crustaceans) migrating between the sea and the lagoons to complete their life cycle. Numerous marine migratory species, such as the common sole *(Solea solea)* or the gilt-head bream *(Sparus aurata)*, spawn at sea and migrate to shallow coastal nurseries to grow during their first life stages. The massive arrival of juvenile sole was detected in early spring each year, indicating a potentially strong nursery role of the former saltworks. This nursery function is essential for the renewal of fish stocks at sea (figure 21).

Figure 21.

Above left Juvenile Eel (Anguilla Anguilla) catches Above right Common Goby (Potamochistus microps) Lower left Juvenile Common Sole (Solea solea) Lower right Juvenile Grey Shrimp (Crangon crangon)

The former saltworks also represent a new migratory path and territory for diadromous migratory species such as the endangered European Eel *(Anguilla anguilla)*. Monitoring will be maintained for an additional 2 to 3 years to assess the effectiveness of the new hydraulic works planned in the near future.

Birds

Wintering duck numbers and diversity have increased compared to the era of industrial salt production. Most notably, the monitoring indicated increases in species such as the Northern Shoveler *(Spatula clypeata)* and the Northern Pintail *(Anas acuta)* since the beginning of the restoration phase.

When the site was used for salt production, it had a major importance for wintering shorebirds. Recent studies have shown that the wintering wader populations (all species included) have remained stable and that the Dunlin *(Calidris alpina)* in particular, which is a core species, has increased. Shorebird species richness during spring and autumn migrations has also increased (figure 22).

Figure 22.

Flock of dunlins (Calidris alpina) and sanderlings (Calidris alba) on the sandflats in the former saltworks.

INLAND

Terrestrial vegetation

The vegetation showed an impressive development since the beginning of the restoration process, especially in the northern parts of the site, where the vegetation cover was estimated at more than 240 ha at the end of 2016 compared to only 15 ha in 2011[26]. The recolonization by halophilous vegetation began with annual plants such as *Salicornia* and *Suaeda* species and then by a slower expansion of the perennial scrubs including *Arthrocnemum* and *Sarcocornia* species (figure 23).

Coastal vegetation can help increase sediment and organic matter trapping[2, 27], reducing flood risks. But most importantly, the site provides space set aside to mitigate responses to sea-level rise. This corresponds to recent scientific research recommending that " accommodation space " should be expanded by using " natural and nature-based features "[19].

Figure 23.

Evolution of the vegetation cover in dunes.

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SOCIAL ASSESSMENT (HUMAN WELLBEING)

The restoration of the former saltworks generates social benefits such as protection against climate change, the production of scientific knowledge, recreation and tourism opportunities and inspiration for art and design (table 2).

TABLE 2. **SOCIAL EVALUATION**

CHALLENGE	ACTION	IMPACT	INDICATORS
1. Protection of people and properties in surrounding areas	Establishment of a buffer zone to mitigated disaster risk between the sea and the inner protection dike	The project addresses the issue of protecting people and properties	Insurance values
2. Accessibility to the site	Free access to parts of the site for pedestrians and cyclists. Motor vehicle access is severely restricted	Increase in pedestrian and cyclist traffic	Number of visitors
3. Exploitation of natural resources (hunting and fishing)	Restoration of a migration corridor and nursery area for fish Recreational hunting continues to be allowed on part of the site	Expected positive impact on fish stocks in the surrounding areas 110 hunters have access to the site	Fishermen's testimonies Fish monitoring Results of hunting bags
4. Support from the local population and stakeholders engagement	Public meetings, workshops, production of information panels, brochures, videos Scholar visits Guided tours	Awareness of climate change issues (environmental education) Understanding of management choices	Public support for the project (social survey)

BOX 3. THE ARTISTIC INSPIRATION OF THE FORMER SALTWORKS

TESTIMONY OF A PHOTOGRAPHER:

The Camargue inspires photographic opportunities for many reasons. First of all, there is the interaction of land and water, a source of sublime graphics on the beaches that great photographers such as Lucien Clergue, Hans Sylvester and Yann Arthus-Bertrand have portrayed in their own way. The high salinity of the environment is also fascinating because salt crystallizes in some places, producing real art works in miniature. Additionally, the aquatic species are remarkably graphic, especially the microalga *Dunaliella salina*, creating a peculiar pink color in the landscape. Pink is very rare in nature, but it is present in the Camargue with sea lavender *Limonium spp* (“saladelles”), flamingoes and artemia outbreaks in the saltworks and ancient saltworks.

Figure 24.
Tête d'Aigle. © Jean E. Roché

The former saltworks are a remarkable area because, apart from the presence of the lighthouse, there are very few signs of human presence on the horizon. The wild nature of the site is quite breathtaking although it is just 45 kilometers away from the most developed industrial and shipping area in France (Fos-sur-mer)! An interesting but perhaps crazy project would be to follow the evolution of the shoreline from the top of the Beauduc lighthouse using thousands of serial shots over several years and then, in accelerated projection, visualize the retreat of the coastline as the American photographer James Balog did to visualize the retreat of the glaciers.

A great challenge for the photographer in the Camargue is that the coastline is constantly changing. The images depend strongly on the time and place. I remember the image of my eagle on the sand, no one believed me. It had just been shaped by a flamingo, by water and by the wind that day at that place and only appeared with these exact conditions. Another great challenge is the generally very flat landscape. For me, as a landscape photographer, space is constantly scratched by the horizon. Only special weather conditions or a strong framing bias can erase it.

The light of the wild Camargue has inspired other artists such as the painters, Van Gogh of course, but also less well-known ones (Pranishnikoff, Ziem...). Writers have been sensitive to the strength of the natural elements, particularly the Rhône, and some works are deeply marked by them in Giono, Bosco, Mistral, D'Arbaud, Clavel... For me, putting the landscapes of the Camargue into images is a bit like painting and writing at the same time, just writing with light and telling stories without pigment or ink, just with photos.

Jean Emmanuel Roché

Opportunities for recreation

The area provides opportunities for the local population and tourists, contributing to the aesthetic and ecological values of the Rhône delta. Landscape changes and increased wilderness induced by ecosystem restoration create natural and scenic views of coastal and marine seascapes. Cyclist groups and pedestrians frequently visit the site during nice weather conditions (Figure 25).

Access to the beach is regulated but accessible, which was not the case when it was a private property. Regulation of visitors to the area helps control anthropogenic disturbances and establish long term conservation goals.

ECONOMIC ASSESSMENT

Restoring and maintaining the seafront dike (including breakwaters and numerous groins) would be much more expensive than maintaining the dike constructed further inland in order to prevent flood disaster (figure 26).

The restoration process also saves on the environmental costs of the mining activities like the stone extraction and transportation of materials to build the dikes (Table 3 on next pages). Thus accepting coastal erosion but adopting a new strategy to manage flood risk is assessed as the least expensive and most reasonable option.

Figure 25.

Nature observation excursions.

The economic benefits of the ecological restoration include not only an important reduction in the use of public funds for the protection against flood risks, but also the multiple ecosystem services provided by restored wetlands.

Some of these services include:

1. **Nutrient regulation/cycling (water purification)** through the recolonization of microorganisms
2. **Increased food provision** through the restoration of fish migration and the fish nursery function
3. **Pollination**
4. **Habitat and refuge for wildlife**
5. **Genetic resources**
6. **Aesthetic values**
7. **Inspiration for culture,** art and design
8. **Information and cognitive development** with intensive research that supports science conducted in the area
9. **Environmental education,** through school excursions and information board
10. **Recreation** (beach access, bike and trekking access, recreational fishing)
11. **Soil protection** through increased terrestrial vegetation cover.

An estimated global value of coastal wetlands can reach up to €160,000 per hectare per year [28] when considering carbon storage, coastal protection, fisheries and water quality improvements. Therefore, ecosystem services and biodiversity conservation are additional assets to NbS that should be considered by decision-makers and investors.

Figure 26.

Sea disaster risk protection system in the Camargue's former saltworks area.

- Current second-row protection dike (public management)
- New second-row protection dike (private management)
- Second-row protection dike extension (project)
- Abandoned seafront dike

TABLE 3. **ECONOMIC EVALUATION**

CHALLENGE	ACTION	BENEFITS	INDICATORS
1. Coastal erosion	Defense infrastructures located along the seafront are no longer maintained (9 km)	Savings in public funds: €13 to 17 million investment for the reconstruction of dikes, €7 to 24 million for the construction of groins, at least €800,000 in annual maintenance	Savings due to the absence of maintenance work on seafront dikes
2. Management of sea flooding risk	Investments only on the inner protection dike (linear: 16 km)	Investment of 7 to 13 million euros, plus 80 K€ to 140 K€ for annual maintenance Salt production is maintained on the nearby private property of the Salins group	Cost for maintaining and adapting the inner protection dike
3. Hydraulic management of the former saltworks	Investments for hydraulic reconnections Maintenance of most of the dikes surrounding the lagoons stopped Gravitational water management	3 investment phases: < €1.5 million Savings related to maintenance of the dikes surrounding the lagoons Savings related from no longer using pumping stations: € 30 to 60,000 / year	Costs of hydraulic works. Cost of natural water management compared to artificial water management

Of course not everything is perfect…

There are still challenges to be met. Freshwater that is entering the site as a result of the depolderization process is polluted by agricultural activities and actions must be taken upstream to improve the water quality. New, sometimes unexpected wildlife is colonizing the former saltworks, including large predators such as the Eurasian Eagle Owl *Bubo bubo,* which jeopardizes the natural breeding of the Greater Flamingo colony. The re-naturalisation of the site means that not everything is under human control and there could be tradeoffs regarding biodiversity.

It has not been easy for the local population to accept that the seafront dike was abandoned. There is a need of improve the communication and collaboration with the nearby community to increase acceptance.

Figure 27.

Working in the former Saltworks.

©L. Segura

FUTURE PERSPECTIVES

The Conservatoire du littoral and the site managers are considering the following actions in the future:

- **Adaptation of the inland protection dike** to sea level rise (to be implemented by local authorities)
- **Creation of cycling routes** (figure 28) (in cooperation with local authorities) and test of shuttles buses to improve access to the site
- **Continuation of hydraulic restoration works,** including upstream
- **Definition of prospective models / scenarios** on the effects of sea level rise
- **Continuation of the dialogue** with local actors and inhabitants of the nearby village of Salin de Giraud
- **Assessment of hydrological and climate buffer functions** of restored ecosystems

Currently, assessments of sea-level rise impact on wetlands are uncertain due to limited understanding of hydrodynamic and geomorphological interactions in areas with high anthropogenic intervention. Thus, there is a need to incorporate vegetation dynamics processes and hydrodynamic effects to achieve more realistic predictions of wetland response to sea-level rise in different coastal ecosystems and design effective management actions [29, 30].

Figure 28.

New cycle routes are planned.

© J. Champagnon

NATURE BASED SOLUTIONS

LESSONS LEARNED FROM THE RESTORATION OF FORMER SALTWORKS IN SOUTHERN FRANCE

CONCLUSIONS

The former saltworks restoration project is an example of how humans can help to reverse a disturbance using NbS and adaptive restoration until nature recovers its functionality and resilience. In this case, reconnecting water bodies leads to the eventual reshaping of water paths in a natural way. Newly emerged soils and restored waterways produce "new" homes for vegetation, fish, birds and other wildlife populations. This coastal ecosystem becomes more resilient to work as a buffer and to mitigate the impacts of climate change.

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THE SITE MANAGERS

Three institutions manage the former saltworks area: Parc naturel régional de Camargue (coordinating manager), Tour du Valat and Société Nationale de Protection de la Nature (co-managers). These are under the authority of Conservatoire du littoral (owner).

Parc naturel regional de Camargue (The Camargue Regional Nature Park)

Created in 1970, it is a public organization carrying out missions of general interest in the Camargue delta: protection and management of natural and cultural heritage, spatial planning, economic and social development, reception, education, information and experimentation.

Tour du Valat

Research centre dedicated to the conservation and sustainable use of Mediterranean wetlands. It was created in 1954 by Luc Hoffmann, owner and manager of a 1800-ha regional nature reserve of the same name. Over the last 6 years, Tour du Valat has contributed to the restoration of the former saltworks through hydrological modeling, habitat management, species monitoring and fund raising.

Société Nationale de Protection de la Nature (SNPN) (National society of Nature Protection)

Founded in 1854, is the oldest nature conservation NGO in France. Since 1927, SNPN has managed the Camargue Natural National Reserve, adjacent to the former saltworks site.

THE OWNER OF THE SITE

Conservatoire du Littoral

The Coastal protection agency (whose official name is Conservatoire de l'espace littoral et des rivages lacustres) is a French public organisation created in 1975 to ensure the protection of outstanding natural areas on the coast, banks of lakes and stretches of water of 10 square kilometres or more. The Conservatoire is a member of the World Conservation Union.

Tour du Valat

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