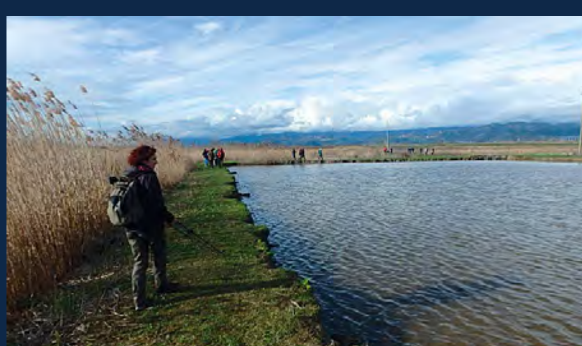
Best Practices in Evaluation and Restoration of Degraded Mediterranean Environments

Monografías do IBADER - Serie Territorio

Agustín Merino
Serena Doni
Niki Evelpidou
Teresa Ferreira
Ana I. García-Arias
Grazia Masciandaro
Patricia M. Rodríguez-González
(Editors)




LANDCARE

USC UNIVERSIDADE DE SANTIAGO DE COMPOSTELA
IBADER
Instituto de Biodiversidade Agraria e Desenvolvemento Rural

Contents

3. Study cases

3.1. Study case 1: Restoration of Pobra do Caramiñal saltmarsh (NW Iberian península)

Xosé Lois Otero[1,2], Augusto Pérez-Alberti[2,3]

[1] Departamento de Edafoloxia e Química Agrícola, Facultade de Bioloxía, Universidade de Santiago de Compostela (Spain), e-mail: xl.otero@usc.es, https://orcid.org/0000-0001-5447-1842

[2] Cross-Research in Environmental Technologies (CRETUS Institute). Universidade de Santiago de Compostela, 15782 Santiago de Compostela, Spain

[3] Departamento de Xeografía, Facultade de Historia e Xeografía, Universidade de Santiago de Compostela

1. Background

The saltmarsh of Pobra do Caramiñal is located in the Ria de Arousa, on the SW coast of the province of A Coruña (Galicia, NW Iberian Peninsula). It is a small saltmarsh complex with a total area of 14 ha, located in an increasingly touristic area. In 2000, the Spanish Ministry of Environment launched a nationwide program to restore degraded and irregularly occupied coastal areas. Within this context, a plan to restore the salt marshes of Pobra do Caramiñal started to develop in 2000 and was finally executed 14 years later.

Alterations were first assessed by photographic interpretation of a 1954 flight in which the saltmarsh showed an acceptable conservation status. Subsequent aerial photographs (years 1968, 1976, etc.) showed that a significant portion of the area was already occupied, both for the construction of public infrastructures (roads and a water treatment plant) and for privately owned filled areas under irregular concessions. Occupied areas represented more than 50% of the saltmarsh complex in 1999, mostly corresponding to a private filled area (Figure 1).

Additionally, wastewater discharges, presence of invasive species (*Acacia melanoxylon, Arundo donax, Cortaderia selloana),* riparian forest degradation, and strong alterations of the hydrologic system are also worth mentioning (Figure 2).

The project carried out a detailed analysis of water, soil, and sediment quality; a description of the animal and plant biocenosis of the saltmarsh and its environment; a detailed study of the occupation of the saltmarsh complex by continued filling activities during the 1956-99 period, and an inventory of habitats of community interest as defined by Directive 92/43/CEE (Habitats Directive). This project was made by Eurcoin, CIISA, Tragsa companies in collaboration with Santiago de Compostela University. Finally, a number of interventions aimed at recovering the main habitats and improving water, soil, and sediment quality were proposed.

Figure 1. Aerial view of the Pobra do Caramiñal saltmarsh in 2014 (A), before the start of the interventions, and in 2017 (B), after the interventions. In the 2014 aerial photograph, sections (1), (2), and (3) indicate areas where fillings occupying more than 50% of the saltmarsh area were removed. Section (4) corresponds to the area where invasive species were removed and channels and riparian forests were restored. In the 2017 aerial photograph, sections (1), (2), and (3) correspond to newly restored saltmarsh areas.

Figure 2. Summary of activities carried out for the restoration of the environmental quality of the Pobra do Caramiñal saltmarsh. A) Overview of the old wastewater treatment plant built in the saltmarsh (filled area 3; Figure 1). This plant was removed and part of the saltmarsh was restored (Figure 1 B); B) Removal of filled area 2 (Figure 1); C) Dredging of polluted sediment; D) Protection barriers for containing suspended materials during sediment dredging; E) Hydrological restoration. Recovery of secondary channels within the saltmarsh; F) Removal of urban solid waste; G) Removal of invasive plant species and restoration of the riparian forest.

2. Previous study

A study on the quality of the system was carried out, focusing particularly on the concentration of toxic (Pb, Cu, Ni, Zn,…) and eutrophicating (P, N) elements and on the conservation status of its habitats.

Water, soil, and sediment quality

Water quality in the saltmarsh showed severe impacts in the vicinity of wastewater discharge points, where high concentrations of ammonium (1.5-14 mg L^{-1}), nitrite (0.1-0.7 mg L^{1}), orthophosphate (0.2-11 mg l^{-1}), and DBO5 (50-200 mg O_2 L^{-1}) were reached. Likewise, surface enrichment of certain toxic elements such as Pb (0.25-0.5 mg L^{-1}), Co (0.15-0.22 mg L^{-1}), Ni (0.20-0.32 mg L^{1}), and Cu (0.03-0.04 mg L^{-1}) was also detected. The situation improved substantially at high tide due to the diluting effect of the tidal flow.

Soils and sediments showed high surface concentrations of organic matter, nitrogen, and phosphorus. Concentrations of toxic metals were not high, consistently with the urban origin of waste and with the lack of intense industrial activities in the area. Nevertheless, enrichment in metals such as Pb, Zn, Cu, and Ni was clearly demonstrated in areas close to sewage discharge.

Highly reduced (redox potential <100 mV), black soils with a strong smell of hydrogen sulfide (H_2S) were also associated with sewage discharge areas. These are indicators of oxidation-reduction conditions characteristic of sulfate-reducing environments, where microorganisms oxidize organic matter using marine sulfate and generating H_2S, which is highly toxic for plants and fauna.

Environmental value of habitats

The habitats of community interest that are present in the area, according to Directive 92/43/CEE, are: riparian forest (residual alluvial forests of *Alnion glutinoso-incanae 91E0**), salt meadows (*Glauco-Puccinelietalis 1330*), and estuaries (code 1130). The first one is an arboreal strip around rivers and wetlands, which in the past may have completely occupied the saltmarsh and river banks. However, nowadays it constitutes a residual formation, present only in the back of the saltmarsh, while in the rest of banks it is highly degraded and has been replaced by replanted eucalyptus and acacias (Figure 1, 2).

The second of the habitats (*Glauco-Puccinelietalis* salt meadows) includes coastal saltmarsh vegetation. This habitat includes several vegetal associations whose distribution along the saltmarsh is determined by salinity and degree of soil reduction (see Sánchez *et al.*, 1998, Sánchez, 2010, among others), which in turn are largely determined by the physiography of the saltmarsh itself (Sánchez *et al.*, 1996).

Intertidal areas show marked gradients in terms of salinity and degree of flooding. Knowledge of the geochemical processes characterizing these environments is an essential aspect for restoration activities. For Galician saltmarshes, a clear relationship has been established between salinity and hydromorphic intensity of each plant community, which is determined by their redox potential (Eh). Higher or lower degrees of flooding of the saltmarsh determine the degree of soil aeration; therefore, coastal saltmarsh soils can show important variations in salinity, primarily depending on the relationship between tidal influence and freshwater input, mainly from rivers, as well as variations in oxidation-reduction conditions (redox processes). Prolonged flooding leads to soil reduction. Depending on the intensity of reduction, soils can show suboxic or anoxic conditions. Suboxic conditions entail the dissolution of Fe and Mn oxides and hydroxides, releasing their reduced soluble forms (Fe^{2+} y Mn^{2+}) into interstitial water; these forms are phytotoxic, mainly for dicotyledonous species such as *Halimione portulacoides* (Figure 3). However, in permanently flooded soils, surface conditions are already anoxic, characterized by the reduction of sulfate ion to hydrogen sulfide (H_2S), which is highly phytotoxic for most saltmarsh species except for *Spartina maritima*. The ability to endure salinity and phytotoxicity of reduced forms determines the distribution of communities within the saltmarsh. Figure 3 shows the geochemical conditions that characterize each one of the main plant communities in Galician saltmarshes.

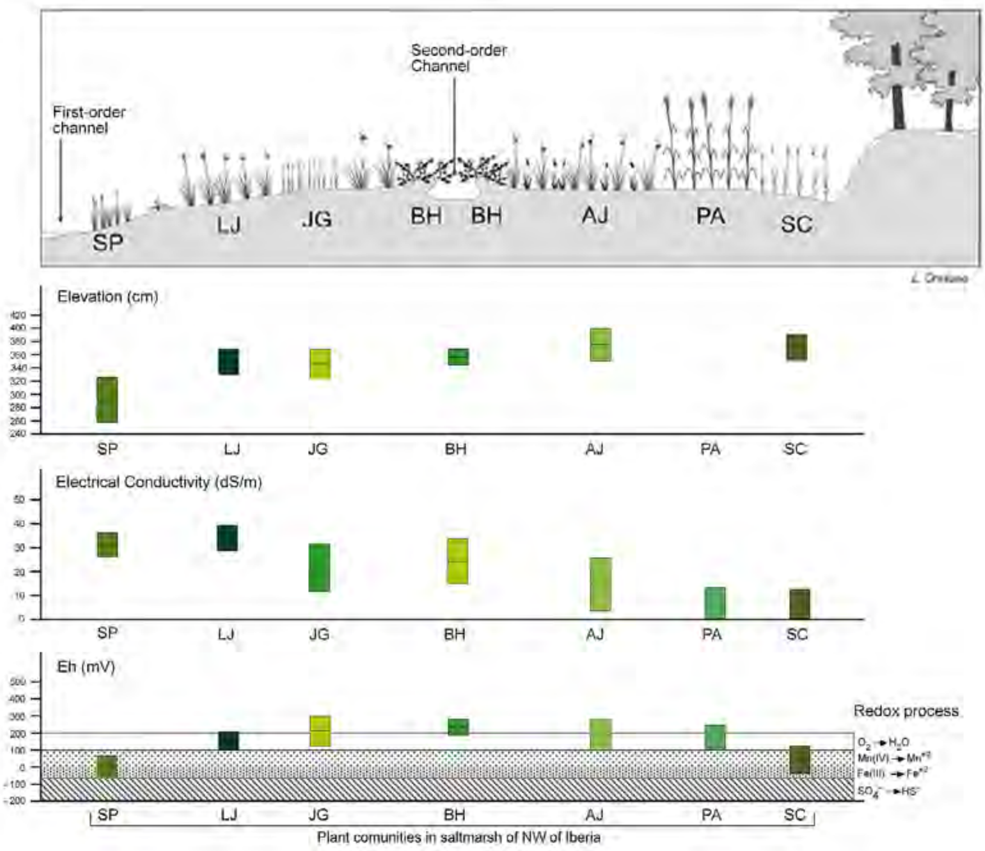


Figure 3. Schematic profile of the NW Iberian Peninsula saltmarshes. SP: Spartinetum maritimae: this community is the only one able to colonize saline, highly reduced substrates with high hydrogen sulfide concentrations in interstitial water. LJ, JG, AJ: Juncus maritimus communities: LJ: Limonio-Juncetum maritimae subass. typicum; JG: Limonio-Juncetum maritimae subass. Juncetosum gerardi, AJ: Agrostio-Juncetum maritimae. Reed beds occupy most of the higher saltmarsh, with soils that present suboxic oxidation-reduction surface conditions. The three formations are distributed within the saltmarsh according to salinity: LJ occupies the most saline environments (electric conductivity: 30-40 dS/m), while AJ occupies the least saline ones (electric conductivity: 10-25 dS/m). BH: Bostrychio-Halimionetum portulacoidis. This community appears mainly on soils with oxic surface conditions and is therefore closely associated with saltmarsh channel banks, where tidal flooding periods are short and aeration is favoured by the channel. When soils are sandy, it can expand towards the inner part of the saltmarsh. It tolerates wide variations in electric conductivity, while redox potential must be over 300 mV. SC: Scirpetum compacti. This community occupies saltmarsh banks connected to continental areas, which show strongly reduced conditions with high sulfide concentrations but, unlike in the case of Spartina maritima, flooding water must be either fresh or brackish water. PA: Phragmitetum australis community. Reed beds are also associated with saltmarsh banks flooded by circulating freshwater; therefore, redox.

Finally, the estuarine habitat corresponds to the lower portion of the saltmarsh. It does not cover a large area, but it has a high ecological interest since it represents the confluence of three different environmental systems: beach-dune, saltmarsh, and marine environment. Tidal flow and its associated fish species, such as eels, go through this area.

3. Action proposal

According to the previous diagnosis, the following interventions were proposed: 1) landscape improvement: removal of artificial elements and urban solid waste, 2) removal of introduced species and protection of exceptional specimens, 3) preparation of the saltmarsh environment for recreational use, and 4) restoration of the saltmarsh and riparian forest, the latter being the most relevant action within the project as a whole.

Restoration of the riparian forest

The first intervention corresponded to the removal of invasive species occupying a large portion of the saltmarsh banks, as well as of waste of diverse origins. The main species removed were *Acacia melanoxylon, Eucalyptus globulus, Arundo donax*, and *Cortaderia seollana*, and the riparian forest was restored by planting the main species that characterize this habitat: *Alnus glutinosa, Salix atrocinerea, Fraxinus angustifolia, Quercus robur, Corylus avellana*, and *Sambucus nigra*. Additionally, microhabitats within riparian forest areas (specifically small temporary pools, important for reproduction of amphibians) were restored (Figure 2).

Restoration of the saltmarsh system

Recovery and restoration of the saltmarsh area was the main action within the project. Using aerial photographs from 1954 as a reference, it was determined that 50% of its initial area was occupied by filled areas of different nature. The inner portion and banks of the saltmarsh (approximately 10%) were urbanized and were therefore impossible to restore. Recovery of the saltmarsh area focused on areas used for storage of materials or occupied by an old water treatment plant built in the wetland area. The area covered by these filled areas was approximately 4 Ha, and the filling was between 1 and 4 m thick. Total recovery of the saltmarsh involved the extraction of large volumes of filling material and its transportation to an authorized dumping site. Taking into account the peri-urban nature of the saltmarsh, the decision was made to remove only the filled areas in the center of the saltmarsh and part of the ones on the banks, which represented approximately a 50% increase in the saltmarsh area. The remaining filled area was transformed into an island that served as refuge and breeding area for Anatidae species, and riparian forest species were replanted along saltmarsh banks with the aim of generating a green barrier. Consequently, there was a 50% increase in shrub area as well.

The main environmental challenge was to reach full restoration of saltmarsh vegetation in the new areas created by removing filled areas. For this, a detailed land survey was required to determine the height of the newly generated saltmarsh surface so that its degree of flooding could be predicted. Likewise, a channel system surrounding the saltmarsh and the island was designed to protect aquatic birds from predators such as foxes, cats, or dogs.

Figure 4. Photographs showing the area before and after the intervention in filled area 1 (see Figure 1). A) Filled area 1 before the intervention; B) and C) show its aspect immediately after removing the filled area; D) shows the aspect of the new intertidal surface once repopulated with Juncus maritimus and Halimione portulacoides, the latter only on the channel banks (January 2015); E), G), and F) show different panoramic views of the same area 18 months later (June 2017).

Figure 4 shows different saltmarsh restoration stages. Seedlings used for restoration were obtained from the saltmarsh itself, using a hand shovel to cut small areas (400 cm^2) and directly planting them on the newly generated surfaces. For this, it was essential to know the characteristics of each environment, as indicated in Figure 3, so that the most suitable species were assigned to each environment according to its geochemical soil conditions. Thus, *Halimione portulacoides* was replanted in channel banks, *Juncus maritimus* in lower tidal plains, and *Scirpus maritimus* in higher areas with greater freshwater influence (Figure 4). Contrarily to other interventions in similar environments, the restoration of the saltmarsh area can be considered completely satisfactory in this case, to the point that only a few years later it was hard to distinguish the regenerated sections from the previously existing ones. Additionally, the new areas are being recolonized by new species such as *Salicornia ramosissima* or *Aster tripolium*.