

Best Practices in Evaluation and Restoration of Degraded Mediterranean Environments

Monografías do IBADER - Serie Territorio

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Contents

Preface	13
Introduction	15
I. Land use and agricultural practices	16
1. Introduction	17
2. Land management and soil conservation	19
2.1. Land uses/land cover and land use changes	19
2.2. Soil organic matter in managed soils	21
2.3. Soil physical properties and soil management	23
2.4. Soil nutrient balance and cycles	25
2.5. Soil salinization and alkalization	26
2.6. Erosion in managed soils	28
2.6.1. Extent of the erosion	28
3. Implementing agricultural and forest sustainable practices in agricultural and forest lands	31
3.1. Conservation agriculture and erosion control	32
3.1.1. Increase nutrient-and water-use efficiencies	33
3.1.2. Conservation tillage	34
3.1.3. Mulching, cover crops and organic inputs	36
3.1.4. Use of crop rotation and agronomic measures	40
3.1.5. Special techniques for erosion control in agricultural and forest lands	41
3.2. Low-intensity farming systems and ecological restoration	42
3.2.1. Conversion of cropland to lower intensive managements	42
3.2.2. Managing abandoned landscapes	43
4. Conclusions	45
5. References	45
6. Study cases	50
6.1. Application of charcoal for reclamation of intensively managed soils in temperate regions: linking energy production and sustainable agriculture	50
6.2. Land use: a case study regarding the effect of agriculture on land degradation in Greece due to increase in soil salinity	53
6.3. Plant cover by use of almond tree (<i>Prunus dulcis</i> da Webb) and organic farming to ameliorate soil quality in Southern Italy	57
6.4. Improvement functions of degraded soils by application of organic amendments	61

II. Degradation and rehabilitation of freshwater wetlands	66
1. Wetlands: definition and types	66
2. Importance and causes of wetland degradation	68
2.1. Importance and challenges	68
2.2. Causes of wetland degradation	70
2.3. Protection, Rehabilitation and Restoration	71
3. Strategies for rehabilitation of major wetland types	73
3.1. River rehabilitation	73
3.1.1. Understanding rivers functioning as a basis for rehabilitation	73
3.1.2. River and riverscape restoration in Europe	74
3.2. Lake rehabilitation	77
3.2.1. Lakes and eutrophication	77
3.2.2. Eutrophication: causes and challenges	78
3.2.3. Characterization and diagnosis	80
3.2.4. Eutrophication mitigation methods in lakes	84
3.2.5. Internal measures	86
3.2.6. Destratification by air injection	88
4. References	90
5. Acknowledgements	94
6. Study cases	95
6.1. Restoration of an agricultural drained peatland: the case study of the Massaciuccoli Lake Basin in Tuscany (Italy)	95
6.2. An eutrophication case study of a lake in Azores (Portugal)	102
6.3. Morphological stabilization of Estuarine Banks after dredging (River Lima, Portugal)	105
6.4. Mitigation in Agricultural Streams of Alqueva Multi Purpose Project	113
6.5. Multi-functional restoration of the Arga-Aragón River System (Navarre, Spain)	121
6.6. Louros River - Rodia Swamp restoration (1999-2003), Amvrakikos (Greece)	128
6.7. New tools for riparian restoration: predictive modelling of vegetation dynamics	134
III. Coastal rehabilitation: general strategies and examples	142
1. Introduction	142
2. General strategies for coastal rehabilitation and examples	144
2.1. Coastal dunes and rehabilitation	144
2.2. Coastal wetlands and rehabilitation	149
2.2.1. Wetland rehabilitation in the Mediterranean area	151
2.2.2. Marshes and rehabilitation	152
3. Study cases	154
3.1. Restoration of Pobra do Caramiñal saltmarsh (NW Iberian península)	154
3.2. Coastal degradation and dune habitats in Tuscany coasts (Italy): the study case of the Regional Park of Migliarino San Rossore Massaciuccoli	162
3.3. Rehabilitation of coastal wetlands from Greece	167
3.4. Dune rehabilitation example from the Netherlands	172
4. References	173

IV. Soil degradation and soil rehabilitation. Treatments after wildfire	178
1. Wildfires in the Mediterranean region	178
2. Effects of fire on soil properties and soil conservation	180
2.1. Soil Burn Severity	180
2.2. Changes in key soil properties related to erosion and revegetation in burnt areas	183
2.3. Soil hydrological properties, hydrological processes and erosion	186
3. Land restoration after wildfire: revegetation and erosion control in burned areas	188
3.1. Natural mechanisms of soil protection after wildfire: natural revegetation and litterfall in wooded areas	188
3.2. Emergency actions against erosion in burnt forest areas	190
3.3. Erosion barriers	191
3.4. Channel treatments	192
3.5. Seeding	193
4. References	194
5. Study cases	197
5.1. Assessing the effectiveness of different emergency post-fire rehabilitation. Treatments for reducing soil erosion in NW Spain	197
5.2. Comparing survival and size of resprouts and planted trees for post-fire forest restoration in central Portugal	201
5.3. Multitemporal burnt area detection methods based on a couple of images acquired after the fire event	204
5.4. Fighting fire with fire: do prescribed burns impact soils? Examples from Melbourne, Sydney and Perth (Australia)	213
V. Pollution: soil contamination and soil rehabilitation treatments.	217
1. Introduction: Causes of soil contamination in the Mediterranean region	217
2. Soil-contaminant interaction	221
2.1. Key properties of contaminants	221
2.2. Effects of contaminants on soil properties	222
2.3. Soil properties related with contaminant behaviour	224
2.3.1. Organic contaminants	225
2.3.2. Inorganic contaminants	227
3. Soil and sediment decontamination	228
3.1. In situ treatments	229
3.1.1. In situ biological treatments	229
3.1.2. In situ physical/chemical treatments	232
3.1.3. In situ thermal treatments	234
3.2. Ex situ treatments	234
3.2.1. Ex situ biological treatments	234
3.2.2. Ex Situ physical/chemical treatments	236
3.2.3. Ex Situ thermal treatments	238
4. Conclusions	240
5. References	241

3. Study cases

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

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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 eutrophication (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 O₂ 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 (H₂S) 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 H₂S, 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-Puccinellietalis* 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-Puccinellietalis* 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.

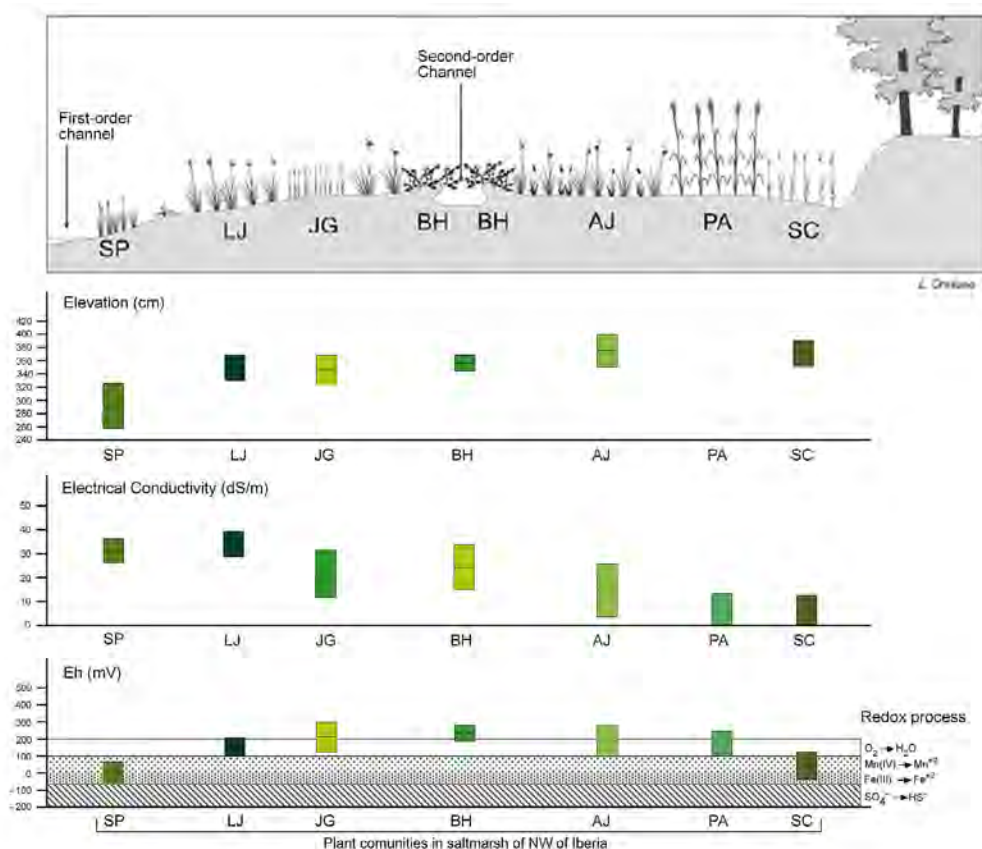


Figure 3. Schematic profile of the NW Iberian Peninsula saltmarshes. SP: *Spartinetum maritimae*: this community is the only one able to colonize saline, highly reduced substrates with high hydrogen sulfide concentrations in interstitial water. LJ, JG, AJ: *Juncus maritimus* communities: LJ: *Limonio-Juncetum 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.

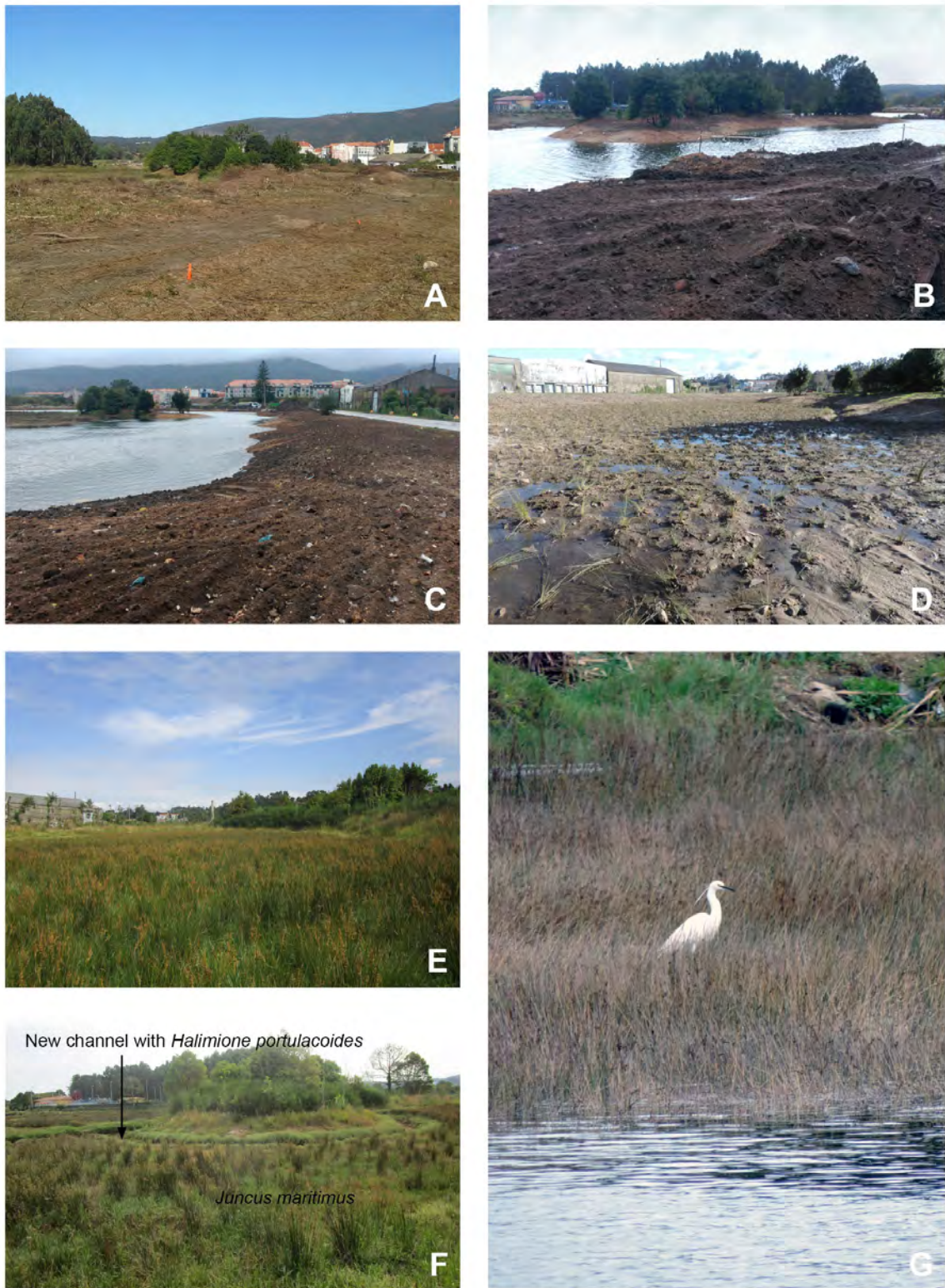


Figure 4. Photographs showing the area before and after the intervention in filled area 1 (see Figure 1). A) Filled area 1 before the intervention; B) and C) show its aspect immediately after removing the filled area; D) shows the aspect of the new intertidal surface once repopulated with *Juncus maritimus* 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 cm²) 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*.