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Actions for the Conservation and Restoration of the Dunes and Wetlands in the Salinas of San Pedro del Pinatar: LIFE-Salinas Project (Murcia, Southeast of Spain)

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Abstract: The LIFE SALINAS project, co-financed by the European Union, aims for the conservation and improvement of the protected area named the Regional Park of Las Salinas and Arenales de San Pedro del Pinatar (Region of Murcia, Spain). The main objectives are, among others, to stop the erosion of the dunes in front of a 500 m long beach and to expand the breeding habitat of aquatic birds. Between the dune and the beach, a barrier was placed to protect the dune from the effects of storms. The dunes were fenced, placed with sand traps and revegetation was carried out with native species in the most degraded areas. Within the salt pans, 1800 m of new sandy dikes were built to separate the salt ponds. The results have been the recovery of the dune ecosystem and the increase in the population of nesting aquatic birds and other species, as well as an increase in the quality and production of salt.

Keywords: conservation; dune erosion; ecosystem services; sustainability

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1. Introduction

Wetlands are some of the most productive and ecologically valuable ecosystems [1]. According to Barbier et al. [2], wetlands perform critical ecosystem functions and services as stopovers for migratory birds, critical nursing grounds, the production of raw materials and food, the maintenance of coastal fisheries, coastal protection, erosion control, and carbon sequestration. Despite their importance and the increased efforts to preserve them, wetlands are still being transformed for urban development and other activities, such asaquaculture, at a rapid pace [3]. Some authors indicate the existence of a greater awareness of the importance of wetland ecosystem functions as well as growing concerns among environmentalists [4], and this growing restlessness has resulted in a range of conservation and management approaches [5–8]. These approaches include policy instruments at different administrative levels [4], such as implementing various wetland restoration programs [9], in order to mitigate the negative impacts of socioeconomic development on these unique ecosystems [10,11] and provide resources and monetary incentives for their conservation [12,13].

There are numerous highly productive wetlands with varied ecosystem services [14] affected by anthropogenic stress due to the large coastal population [15,16]. One of the main problems encountered affects the reduction and disappearance of biological diversity, a consequence of habitat modification, usually due to the conversion and degradation of wetlands [17]. The objectives in these cases are to promote the reduction of ecosystem stress through the identification of environmental problems in a diagnostic analysis, then establishing strategic action programs [18]. Normally, among the programmed strategies, public awareness campaigns are carried out to increase environmental awareness directed at different levels of society [19–21], including parliamentary workshops for politicians, training events for local government officials, scientific conferences, and the participation of scientists in research and reporting to university and high school students, sometimes conducting environmental camps [22].

Networks are also usually created and associations that collaborate and work with environmental organizations and NGOs [23,24] carry out biodiversity assessments that have contributed to scientific development toward the improvement of densities, distributions, and the genetic diversity of populations of endangered and endemic species as well as favourable actions for the maintenance of habitats according to norms and regulations and a reduction of the risk of introduced species. The final goal of these programsis to ensure that biodiversity remains present to benefit future generations. There seems to be, therefore, an urgent need to develop and improve ecological restoration methods to rehabilitate or restore degraded coastal wetlands. It is in this context that the LIFE Project whichwe describe below is framed.

The Salinas de San Pedro del Pinatar can be considered a model of sustainable development, where salt production has favoured the creation of one of the most important wetlands in south-eastern Spain. An number of 170 species of birds have been cited, including 32 species in Annex I of Directive 2009/147/EC on the conservation of wild birds with prominent breeding populations in the national and global context, such as the nesting colony of Audouin's gull (*Ichthyaetusaudouinii*), which represents 2–3% of the world population, or the gull-billed tern (*Gelochelidonnilotica*), with 1–2% of the European population; as well as the presence of endemic species, such as the Spanish toothecarp (*Aphaniusiberus*), and 18 habitats of community interest, of which three are priority: 1150* Coastal lagoons, 1510* Mediterranean salt steppes (*Limonietalia*) and 2250* coastal dunes with Juniperus plants (*Juniperus* spp.) [25].

The Programme for Environment and Climate Action (LIFE) is the financial body of the European Union (EU) dedicated exclusively to the environment. Its objective is to promote sustainable development through policies that provide solutions and best practices to achieve environmental and climate objectives, as well as promote innovative technologies in this field [26].

The LIFE17 NAT/ES/000184 project "Conservation of habitats and aquatic birds in the SCI and ZEPA ES0000175 Salinas and Arenales de San Pedro del Pinatar" (LIFE-Salinas) was developed between 2018–2022, with a budget of EUR 1,790,845 and 56% co-financed by the EU. The project was coordinated by the Spanish Salinera company and the following participated as partners: the Department of Geography of the University of Murcia, the City Council of San Pedro del Pinatar, the Autonomous Community of the Region of Murcia, the Association of Naturalists of the Southeast (ANSE) and Mae d'água, a Portuguese environmental consultant.

The LIFE-Salinas Project addresses some of the main conservation problems faced by the Salinas y Arenales de San Pedro del Pinatar Regional Park:

1. Erosion of the dunes of La Llana beach, due to the alteration of the coastal dynamics of north–south sediment transport, with a reduction in the supply of sand to the beach located to the south of the port and the retreat of the coastline, which in some profiles exceed 100 m of losses in the last 60 years [27,28].

2. A reduction of the optimal breeding area for aquatic birds (from 406 ha in 1994 to 85.4 ha in 2015) due to the development of the vegetation that covers a large part of the dikes separating the salt ponds, as a consequence of the increase in the population of the yellow-legged gull (*Larusmichahellis*), which has gone from wintering concentrations of about 200 individuals in the early 1990s to more than 2000 individuals in the 2010s.

3. Difficulties in the circulation of water from the Coterillo pond to the salt route is generating problems of eutrophication [29] and producing a progressive decline in the populations of aquatic birds [25].

In this way, the actions of the LIFE-Salinas Project facilitate the conservation of the territory and prioritize species of fauna and habitats in the EU, further adding value to the ecosystem services, with the increase in production and improvement in the quality of salt contributing to the application and the development and implementation of European policy and legislation on nature and biodiversity.

With regard to the Birds Directive (Directive 2009/147/CE), the conservation actions increase the breeding and feeding habitat of the Audouin's gull (*Ichthyaetusaudouinii*), a priority species in the EU that makes up 2–3% of the world population in the Salinas de San Pedro del Pinatar and also favours sixspecies from Annex I of the Birds Directives that have relevant populations in the EU and/or in Spain.

Regarding the Habitats Directive (*Directive* 92/43/EEC), it improves the conservation of fourteenhabitats included in Annex I of this directive, among which twopriority habitatsstand out (*)—1210, 1310, 1410, 1420, 1510*, 2110, 2210, 2230, 2250*, 2260, and 92D0 [30,31]—and recovers an important population of Spanish toothcarp (*Aphaniusiberus*), an endemic fish of the southeast of the Iberian Peninsula [32].

Fencing, the placement of sand collectors and the limitation of people's access to the dunes of La Llana beach, have allowed the recovery of the dune ecosystem, reducing the risk of the Mediterranean Sea flooding the salt ponds closest to La Llana beach during storms. Invasive exotic species are also acted upon: *Agave americana*, *Carpobrotusacinaciformis*, *Nicotiana glauca* and *Myoporum acuminatum* [33].

The objectives and contents of the LIFE-Salinas Project are reflected in its vision for 2050 of the EU's biodiversity strategy, since "biodiversity and the ecosystem services it provides are duly protected, valued and restored, giving the intrinsic value of biodiversity and its essential contribution to human well-being and economic prosperity" [34].

The main objective of this paper is to publicise the engineering works developed within the framework of the LIFE-Salinas Project in order to improve the state of conservation of the territory where the Audouin's gull lives and of the priority habitats 1510* (Mediterranean salt steppes *(Limonietalia*)) and 2250* (coastal dunes with *Juniperus* spp.), in addition to favouring other habitats and species included in the Habitats Directive and the Birds Directive.

The specific objectives of the conservation actions presented are:

1. Remodelling the salt circuit located to the north of the Salinas, through the adaptation of 1800 metres of new earthen dikes separating the salt ponds, in order to increase salt production by 2%, increase the nesting habitat of Audouin's gulls and seven other nesting species in Annex I of the Birds Directive: the gull-billed tern (*Gelochelidonnilotica*), comprising1–2% of the European population in the San Pedro del Pinatar salt flats and 3–4% of the Spanish population; the little tern (*Sternulaalbifrons*),comprising0.5% of the European population and 5–6% of the Spanish population; the common tern (*Sterna hirundo*),comprising11–12% of the population of the Spanish population; and the pied avocet (*Recurvirostraavosetta*) and the Kentish plover (*Charadriusalexandrinus*), comprising1–2% of the Spanish population [35];

2. Solving the water circulation problems of the Coterillo pond, conditioning the water inlet channel and creating a new outlet channel, which will allow the recovery of the populations of aquatic macroinvertebrates, Spanish toothcarp and the feeding area of aquatic birds [36];

3. Stopping erosion in the 2 ha, which are the most affected in the dune system of La Llana beach, through the installation of sand traps, thus improving the conservation of priority habitat 1510* and benefiting another 10 habitats of Annex I of the Habitat Directive. Finally, although not a direct objective of the Project, the actions face the challenges of climate change (a rise in sea level and increased frequency of storms) and help reduce the risk of the Mediterranean invading the adjoining salt ponds with nesting aquatic bird colonies. Likewise, the repopulation of 2 ha in the dunes of La Llana beach will repair some 20.58 Tm/year of CO_2, which helps reduce emissions of the main greenhouse gases.

2. Study Area

The project is carried out in the salt flats that are within the Regional Park of the Salinas and Arenales de San Pedro del Pinatar (Figure 1). Of the 856 ha of total area, 558 ha are occupied by ponds for salt exploitation and adjacent ecological systems of great environmental interest [25].

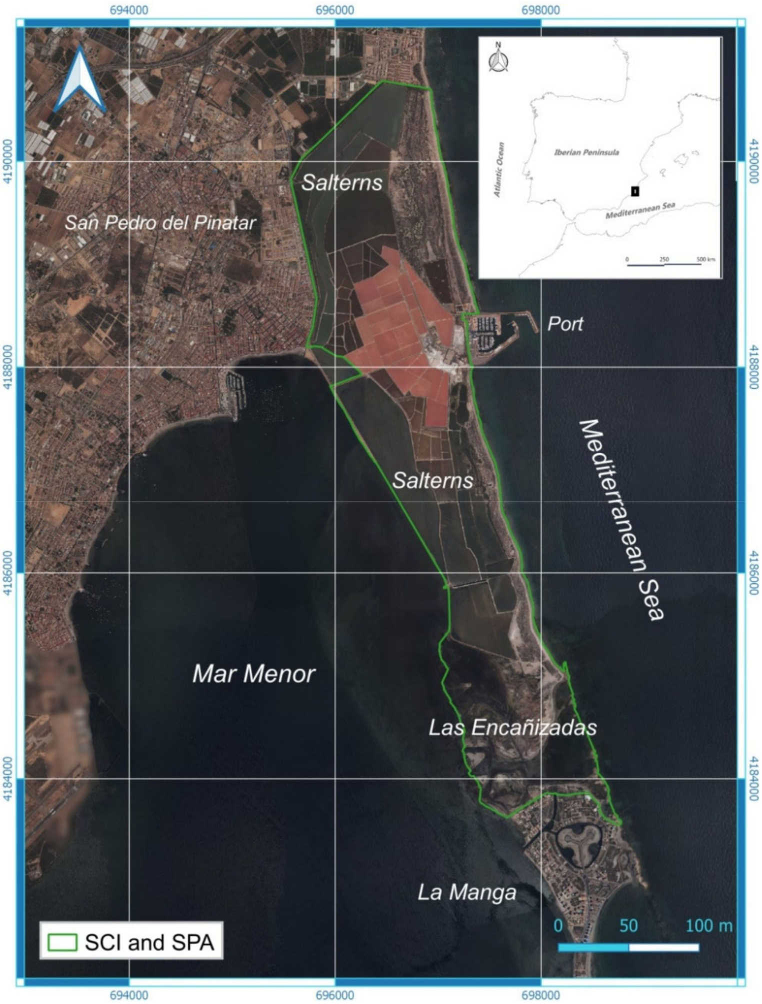

Figure 1. Regional Park of the Salinas and Arenales de San Pedro del Pinatar (Source: own elaboration).

The area is located at the northern end of the coast of the Region of Murcia, in the municipality of San Pedro del Pinatar. Its northern limit coincides with the Mojón urbanization and the southern limit with Las Encañizadas, an area of natural communication between the Mediterranean Sea and the Mar Menor lagoon. They were declared a Regional Park in 1992; in 1994, together with the lagoon, they were included in the List of Wetlands of International Importance (Ramsar Convention); since 1998, they have been part of the EU's Natura 2000 Network, and are also a Specially Protected Area of Mediterranean Importance (ZEPIM).

3. Materials and Methods

The methodology used in this project was based on the preparation of preparatory actions, through the drafting of technical documents for the detailed description of the environmental conservation work, which in turn would allow the necessary authorizations to be obtainedfrom the administrations with competences in the territory: City Council of San Pedro del Pinatar, Autonomous Community of the Region of Murcia and Ministry for the Ecological Transition and Demographic Challenge of the Government of Spain.

Once the authorizations were obtained, the projects were carried out and in particular, the following:

1. Stabilization and reinforcement of the dune ecosystem of La Llana beach to reduce the erosive processes of the dune ridge in the first 500 m of length located at its entrance, which has an area of just over 2 ha (Figure 2). The action was proposed as a priority restoration of the habitat 1510* salt steppes and the implantation of the habitat 2250* coastal dunes with *Juniperus* spp. [37,38]; although in a complementary way, it has directly favoured the conservation ofthe dunes and indirectlyfavoured the habitats that colonize the dunes: 1210, 1410, 1430, 2110, 2120, 2210, 2230, 2260, and 92D0. To stop the erosive processes of the dunes of the Llana beach, which separate the Mediterranean Sea from the Salinas de San Pedro del Pinatar, a network of sand collecting palisades with a total length of approximately 3000 metres, was installed along of the first 470 metres of beach. The collectors, made of giant cane (*Arundo donax*) and arranged in an orientation perpendicular to the direction of the prevailing wind, retain the sand transported by the wind, using natural processes to achieve the fixation and balance of the sandy sediment [39]. In addition, the network of existing paths was removed and access was closed to visitors. Revegetation with native species has also been carried out in the most deteriorated sections of the dunes of La Llana beach, thus increasing the vegetation cover. Subsequently, in response to the need to protect the projected conservation actions, the placement of a barrage barrier with material from the summer conditioning of beaches was installed along the first 600 m, its length about 2 m high and about 4 m wide. This was due to the fact that the storms continue to erode the dune, and, in December 2019, a storm demolished the entire fence parallel to the beach, causing the dune to recede in some sectors up to 4 m.

Figure 2. Stabilization and reinforcement of the dunes of the Llana beach (Source: own elaboration).

2. The adaptation of 1800 metres of new sandy dikes to separate salt ponds with native material from the salt substrate, and the reinforcement of the closure of accesses from the road (Figure 3), which has allowed an increase of 17% in the optimal habitat foraquatic bird breeding. The salt dike construction process was carried out, taking the lower section of a dike with a base of 6 m, an upper base of 5 m, a height of 1.20 m and depositing 0.20 m of salt substrate from heating ponds (Figure 4). It is considered that 1 m3 is equivalent to 2.5 tonnes of stone, so the total volume of stone used was 11,880 m^3 (29,700 tonnes).

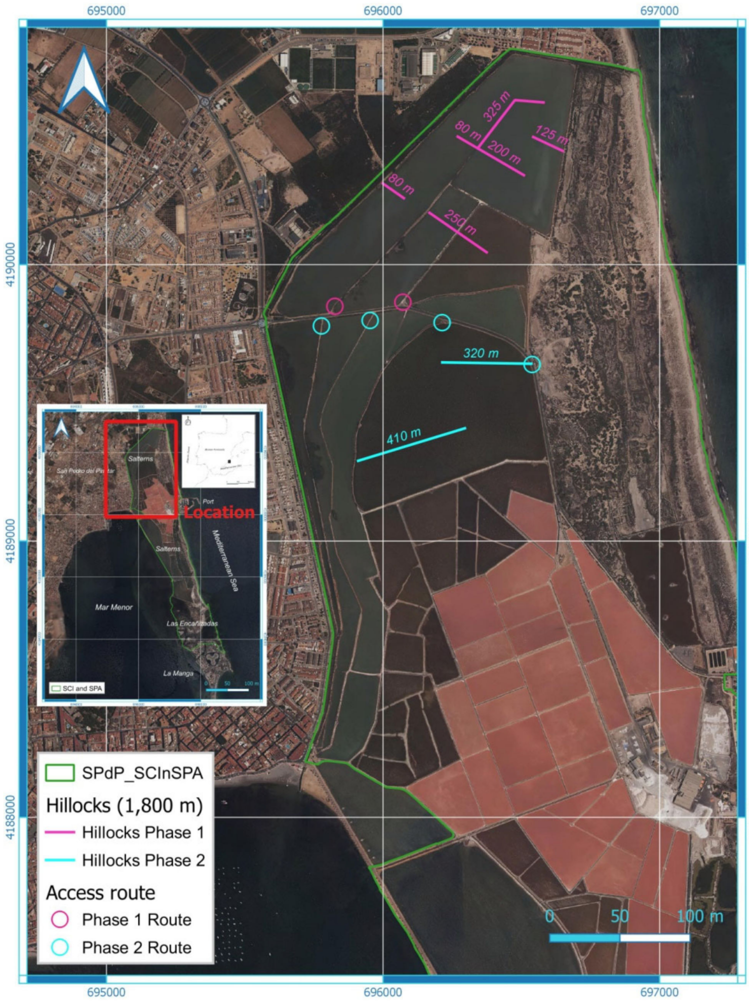

Figure 3. Adaptation of salt dams and reinforcement of accesses (Source: own elaboration).

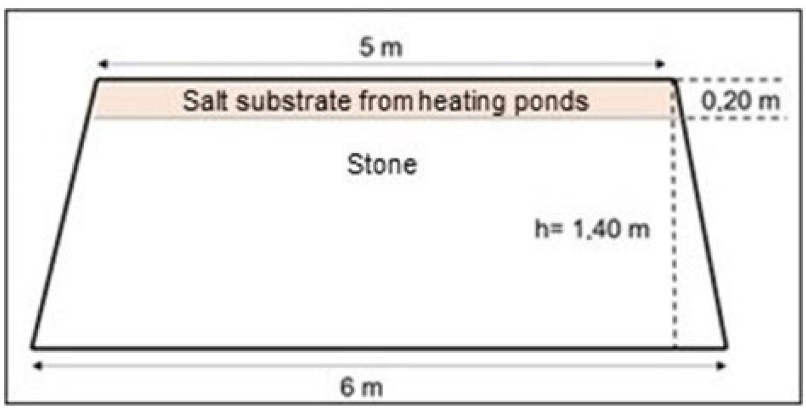

Figure 4. Construction profile of the salt pond separation dike (Source: own elaboration).

3. The improvement of the connection of the Coterillo pond with the salt circuit, which has an area of 8.3 ha and a depth of between 20–30 cm, was carried out by adapting an inlet and an outlet of water through different channels (Figure 5), facilitating water circulation and renewal, regulated by a system of opening and/or closing gates, which allows salinity values to be maintained at around 40–90 g/L. To favour water circulation, sediment has been removed in some sectors, givingthe pond a maximum depth of up to 50 cm. The extracted material was used to reinforce the interior islands.

Figure 5. Connection of the Coterillo pond with the salt circuit (Source: ownelaboration.).

4. Results

The actions carried out in the LIFE SALINAS Project, between 2018 and 2022, have resulted in the recovery of the dune system of La Llana beach and the increase in breeding habitats for aquatic birds, the expansion of the distribution habitat of the Spanish toothcarp (*Aphaniusiberus*) and the different species of aquatic invertebrates, as well as the improvement of ecosystem services with increased production and quality of salt.

4.1. Stabilization and Reinforcement of the Dune Ecosystem of La Llana Beach

Since the construction of the San Pedro del Pinatar seaport in 1958, La Llana beach has suffered a continuous process of erosion and retreat, being one of the most eroded beaches in the Region of Murcia. The port prevents the entrance of contributions of sand to the beach, since it interrupts the marine currents that go from North to South. The sediments carried by the currents are deposited in the northern area of the port while the southern area, where the La Llana beach is located, does not receive any contributions. However, the storms have been reducing the sand on this beach, resulting in the loss of more than 100 metres of beach since 1956, affecting an ecosystem as fragile as the dunes [28].

To prevent erosion, a series of sand catchers have been arranged to prevent the Llana beach from losing sand while helping to retain the sediment carried by the wind. On the other hand, a multitude of *Posidonia oceanica* has been distributed over the dunes as barriers, so that the force and impact of the water is slowed down. In addition, the accumulations of Posidonia act as sand captors and help increase the surface of the dunes (Figure 6). Just behind these Posidonia barriers were the collectors, formed by reeds perpendicular to the ground that allow the entry of sand carried by the wind but reduce the force of the wind, making it easier for the sand to fall to the ground.

Figure 6. Recovery of La Llana beach after the creation of a Posidonia barrier (Source: LIFE-SALINAS Project).

After four years, the state of the beach and dunes has been improved. On La Llana beach there was an area known as "blowout" of approximately 50 metres, which was an area of deflation of the sand caused by the action of the wind. After placing the sand collectors, this blowout has been completely transformed, and dunes have already begun to form.

The improvement of the dune ecosystem has been associated with the restoration of the most degraded areas of the dunes of La Llana beach. Prior to September 2021, 16,000 seedlings of native species of dune ecosystems hadbeen planted, of which 80% were from the target habitat 1510* and 2250* (12,800 seedlings) and the remaining 20% were from dune habitats (3200 seedlings).

So far, the results obtained are very satisfactory, with the recovery of the plant cover and the natural aspect of the environment evident.

4.2. Adaptation of Sandy Dikes in Salt Ponds

The presence of the yellow-legged gull (*Larusmichahellis*) in the salt flats has increased in recent years, reaching over 2000 overwintering birds, and nearly 1000 breeding pairs. The excrement from the high concentrations of these birds during the winter months or in their breeding areas have modified the properties of the substrate of the salt specks, increasing the nitrogen in the soil and developing a dense vegetation cover that is unsuitable for these breeding areas. In this sense, the space available for the nesting of other aquatic birds was reduced by 79% in 20 years, a fact that has been translated in the decrease in the populations of other important species [35].

As a measure to provide the salt flats with new spaces for the breeding of aquatic bird species, 1800 m of sandy dikes separating the salt ponds were adapted with native material from the salt substrate (Figure 7).

Figure 7. New sandy dikes separating salt ponds (Source: LIFE-SALINAS Project).

These new dikes have been built with a surface finish deposited on top of them made up of a sandy substrate material from the bottom of the heating ponds, which generates the appropriate ecological requirements for the reproduction of *larolimícolas* birds (Figure 8), in such a way that in 2021 it has allowed the reproduction of 152 pairs of aquatic birds to be included in Annex I of the Birds Directive (92/147/EEC): 83 pairs of *Sternulaalbifrons*, 2 pairs of *Sterna hirundo*, 41 pairs of *Recurvirostraavosetta*, 9 pairs of *Charadriusalexandrinus* and 17 pairs of *Himantopushimantopus*. Likewise, the submerged rocks that form the base of the 1800 m of sandy dikes are new habitats for the Spanish toothcarp (*Aphaniusiberus*) and have allowed the speciesto expand its area of distribution within the salt flats.

Figure 8. Little tern (**left**) and avocet (**right**) breeding colony (Source: Antonio Zamora López).

4.3. Benefits for Salt Production

Economically, the quality and quantity of salt production has improved, since the longer route through the salt ponds increases the capacity for emptying fresh water when heavy rains occur, preventing it from mixing with the water from the salt pans and therefore, the salinity is reduced and affects the production of salt. On the other hand, there is a greater decantation of calcium carbonate ($CaSO_3$), magnesium sulfate ($MgSO_4$) and magnesium chloride ($MgCl_2$), and a greater purity of sodium chloride (NaCl) in the crystallizer ponds where the salt is extracted. According to data from Salinera Española, the salinity of the water entering the crystallising pools has increased by 4° Baumé, which represents an increase in salt production, which is difficult to precisely quantify since salt production varies annually based on the different climatic phenomena that intervene annually, such as precipitation and evaporation. That being said, it is estimated that it should represent around 2% (currently some 80–100 thousand tons/year are generated), thanks to the lower dependence on climatic factors due to the greater passage of seawater through the salt flats [40,41].

The improvement of the connection of the Coterillo pond with the salt circuit has allowed the recolonization of aquatic vegetation (*Ruppiamaritima*), an increase in the diversity and abundance of macroinvertebrates and the recolonization of *Aphaniusiberus* from the salt pools.

5. Discussion

Although there are numerous scientific articles that offer methodologies and proposals for actions to be carried out in places with similar environmental characteristics, there are not so many that describe actions developed in LIFE projects and specifically address their replicability and transferability to other projects that contain related environmental improvement objectives [42,43]. Related projects and with similar characteristics are detailed in Ibarra-Marinas et al. [44], and some of them are mentioned below.

According to Irene Prisco et al. [45], in relation to dune management, few studies have attempted to assess the effects of walks on the vegetation of the dunes. Several studies have highlighted the value of the ecosystem and the diversity of these habitats, threats, vulnerability and the need for urgent conservation actions. Among other authors, Bonari et al. [46] provided examples of restoration and effective management. In addition, Bezzi et al. [47] developed a coastal dune management geodatabase, while Pinna et al. [48] applied sand trap systems to replant key dune species with the help of fences and boardwalks to reduce human trampling.

In other areas with similar environmental characteristics, dune restoration and conservation has also been carried out with the collection of the banquettes of seagrasses for their protection against maritime storms [49–51], since in front of the coast of these areas there are oceanic Posidonia meadows or other phanerogams capable of generating banquettes that can be used for the protection of the dune front.

On the other hand, in LimnothalassaAngelochoriou (Greece), the LIFE 09/NAT/E/000343 project (2010–2015) also developed actions, in some cases, similar to those mentioned in this paper, but it did not it develop actions to restore hillocks with a salt substrateor implement a quality seal for the salt produced or protect the dune ridge with banquettes. The situation is similar in Seoveljskesoline (Slovenia), where the LIFE 09/NAT/SI/000376-MANSALT project (2010–2019) had the followingobjectives: (i) to establish control over the water regime of the salt flat and restore degraded areas, (ii) raise awareness about the importance of traditional salt production, which preserves nature and allows sustainable development of the local community, and (iii) present a model of good practice on the use of traditional methods in the reconstruction of the salt mine.

In Spain, the LIFE09 NAT/ES/000520 (LIFE-Delta Lagoon) project, developed between 2010 and 2014, carried out actions quite similar to those proposedin this paper, but as in the rest of the projects found, it did not contemplate the recovery of hillocks with a salt substrate or the implementation of a quality seal for the salt produced, since its objective in the old San Antonio salt flats was only to recover the connectivity of the salt ponds. There were also no actions on the dunes. Among the projects prior to LIFE-Salinas whose methodologies inspired the actions carried out in our LIFE-Salinas project, in a Mediterranean environmental context, we can cite the project "MC-SALT—Environmental Management and Restoration of Mediterranean Salt Works and Coastal Lagoons", with actions in Italy, France, and Bulgaria over the period (2013–2016) and with the objective of preserving native species and dunes. This project had a precedent in the LIFE Valli di Comacchio [52], which focused on the ecological restoration and conservation of habitats in the salt flats and SCI of the same name, but in the case of the LIFE MC-SALT, for the first time the optimization of the water flow in the salt flats was contemplated to improve their performance.

Outside the Mediterranean area, the ARCOS LIFE 2014–2018 project focused on actions aimed at improving the state of conservation of the dune ecosystems of the Cantabrian coast (northern Spain), starting from a fragile situation due to both natural and anthropic threats [53]. Its actions included the elimination of non-native tree cover, the elimination of exotic species, the planting of dune species, and the installation of sand traps for the development of the dunes. These last two actions are key to the proper management of Mediterranean dunes [54] and are usually carried out in any project that includes dune restoration.

According to Sun et al. [55], the coordination between different scales and administrative levels, as well as international cooperation, should be fundamental strategies for improving the management and conservation of wetlands. Likewise, according to Gumiero et al. [56], the successful management of natural resources is much more than developing good science, it requires working together with the many agents and/or actors involved, and above all sharing knowledge through diverse case studies

6. Conclusions

The favourable results that have been obtained within the framework of a pioneering project such as LIFE SALINAS reflect the interest in developing nature conservation projects that in turn favour ecosystem services.

Among the most interesting actions, the creation of 1800 m of new sandy dikes to separate salt ponds and the adaptation of the water circuit of the Coterillo pond, which favours the economic sustainability of the salt exploitation and increases the surface of reproduction habitats of aquatic bird species, is increasing the distribution habitat of fish and aquatic invertebrates. It is also worth mentioning the actions that have managed to reduce the erosion of the dunes of La Llana beach, through the creation of a barrage barrier in front of the dunes, the installation of sand collectors, and perimeter fencing to eliminate paths and repopulation with native species of dune habitats in order to repair the sandy substrate in areas with erosive processes.

The experiences developed in this project can be extrapolated, with their respective adaptations, to other salt-producing areas located in territories with similar natural conditions.

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