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An Ecological Overview of Halophytes and Salt-Affected Soils at El Hito Saline Pond (Central Spain): Baseline Study for Future Conservation–Rehabilitation Measures

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Abstract: In an attempt to boost the potential ecological viability of wetlands, this study aimed to discover the relationship between soil salinity and vegetation composition in a quasi-pristine saline pond, "El Hito Lagoon". This wetland is situated in the largest continuous natural semi-arid steppe land of western Europe (specifically in Castilla La Mancha, Central Spain). Several soil profiles and a series of surface samples (0–10 cm) extracted from a systematic network throughout the saline pond were described, sampled, and analyzed. The most significant results included the detection of elevated levels of soil salinity, with distinctive sub-areas of extreme elevated surface salinity where the pH reading peaked at 9.89 and the electrical conductivity was higher than 40 (dS/m). The very high content of total available P displayed quite an irregular scatter within the soil profile. Specifically, the range oscillated between 8.57 mg/kg and 388.1 mg/kg, several samples having values greater than 100 mg/kg. An aspect that the abundant presence of *Salsola soda*, a plant frequently found growing in nutrient-rich wetlands, was able to confirm.

Keywords: semi-arid environment; Natura 2000 network; halophytic flora; salt stress; soil salinity; ecological environment; basin filling

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1. Introduction

In semi-arid and arid regions, soil salinization and environmental problems go hand in hand, due to the severe effects of salinity on agricultural productivity and long-term sustainable development. Indeed, soil salinization normally produces severe effects on soil quality through changes in soil structure and chemistry, soil biology, and crop productivity and yield. Under such conditions, plants such as halophytes can survive and complete their life cycle in the presence of significant concentrations of soluble salts. So, it is generally accepted that identifying saline soils is of great importance for protecting land resources and ecological niches and for sustainable agricultural development.

The issue of soil salinity is a result of both natural and anthropogenic causes. Salts are naturally present in soil due to the weathering of parent minerals.

Although the soil-science community has generated abundant information on the current state of soil salinity [1–5], the idea still persists that salt-affected soils of high salinity are of low quality. Nevertheless, wetlands are among the most productive ecosystems on Earth and provide various key ecosystem services for humans and other flora and fauna. Hence, there exists a need for appropriate conservation policies and a more comprehensive understanding of both wetland ecosystem services (especially saline ecosystems) and the drivers behind their change.

Globally speaking, about 900 million ha of soil in over 100 countries has been affected by salinization or sodification [6–8]. With that global perspective in mind, soil salinization management is vital to the achievement of "Zero Hunger" (SDG2) and "Life on Land" (SDG15) among other sustainable development goals.

Generally, saline wetlands are important for the conservation of many endemic and rare plant species and the migration of water birds, its salinity being a result of both natural and anthropogenic causes [9–11] (Nachshon, 2018; Corwin, 2021; Stavi et al., 2021). Halophytes are plants that can survive in saline wetlands where the salt concentration exceeds 200 mM of NaCl ($\sim$20 dS m^{-1}) [12] (Flowers and T. D. Colmer). When the soil has a shallow water table, then the salinity of the soil solution will be strongly affected by the salinity of the groundwater. In this context, it is worth asking what are the main soils' properties as well as their edaphic and biogeochemical processes in geographic and geological areas such as the El Hito saline wetland. The aim is to assess whether the use of autochthonous species from saline environments may have advantages due to their better tolerance to edaphoclimatic conditions, besides having several uses.

Salinity is a continuous and a complex global problem that cannot be solved simply. And as is known, the salinity problem is increasing rapidly throughout the world. Hence, in this study (necessary for monitoring this specific kind of wetland), the aim is to analyze the compositional features, especially the contents of the main elements and ions relevant to understanding the source of salinization and its spatial variability, and to design a successful plant community. The specific questions concerned the following three points: (1) whether different soil compositions will emerge as the primary variables for explaining the presence and abundance of sub-communities within the saline pond; (2) whether there are consistent patterns across surface horizon soil salinity levels; (3) which factors are more than any other exerting a substantial influence on the structure of abundant and rare sub-communities. With that in mind, the following specific objectives were addressed: (1) to report relevant features such as pH, electrical conductivity, and other soil properties of a hypersaline wetland located in the municipalities of El Hito-Montalbo; (2) to identify and to evaluate the soil salinity of the study site with special emphasis on the relation between soil salinity and plants; (3) to relate those parameters to the different types of natural plants, in order to detect the main problems concerning salinity versus halophytes, while investigating new proposals for conservation–rehabilitation measures.

2. Materials and Methods

2.1. Description of the Study Area

The study area is El Hito Pond (Cuenca, Spain), located between 39°52′28″ to 2°42′06″ North latitude and 39°51′08″ to 2°40′56″ South latitude (Figure 1). It is an endorheic, palustral, ephemeral depression, with little topographic contrast, and a floodable lagoon basin with an estimated volume of around 250–573 ha [13–15]. Dry and hot summer and cold winter seasons are characterized by low levels of irregular precipitation, in which potential evapotranspiration exceeds precipitation, with such high rates of evaporation causing salts to accumulate on the soil surface. Mean annual precipitation stands at 587 mm and the average temperature at 11.7 °C. The relief of the surrounding area is largely flat and sometimes undulating, where the main soil types are Cambisols, Luvisols, Calcisols, Regosols, and Leptsols [16].

The dominant species of the vegetation are all salt-tolerant. Fortunately, there is detailed information on saline continental Mediterranean wetlands such as El Hito and their plant characteristics [15,17–21]. Figures 2 and 3 show photographs of various halophilic plant communities colonizing El Hito Pond.

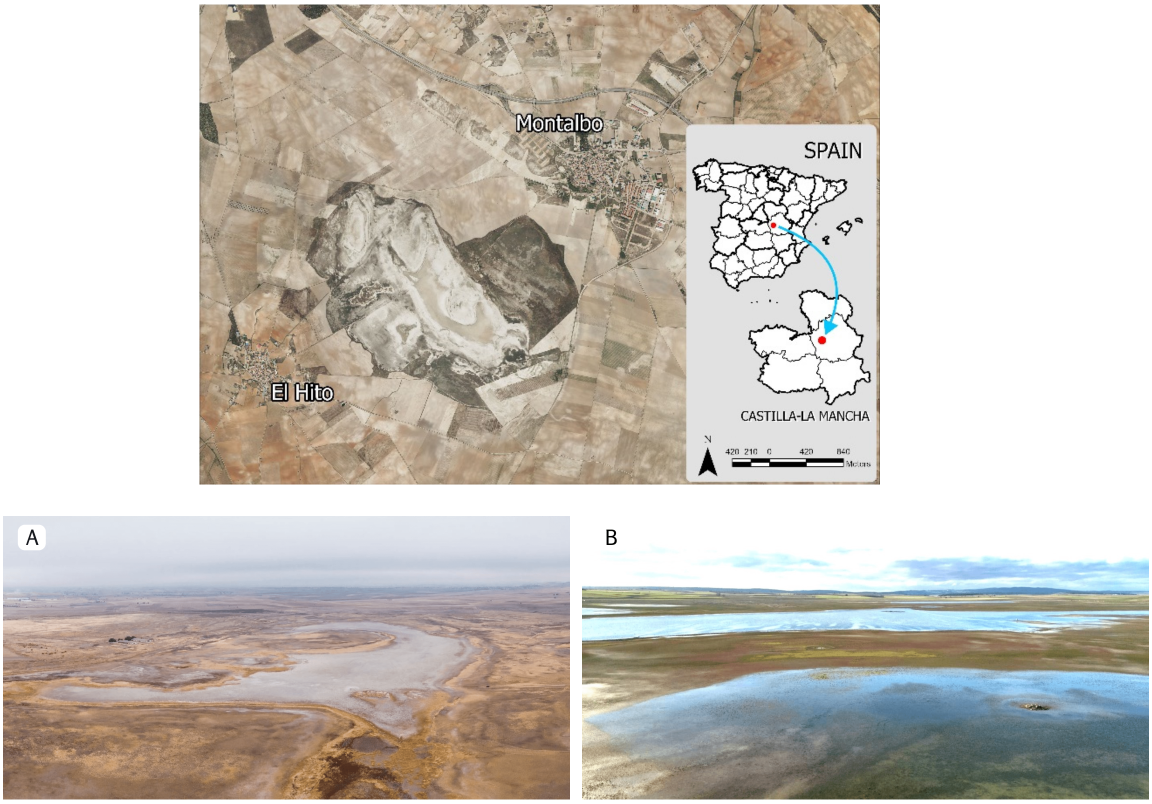

Figure 1. Orthophoto of the study area in Castilla La Mancha at (**A**) summer time; (**B**) winter time.

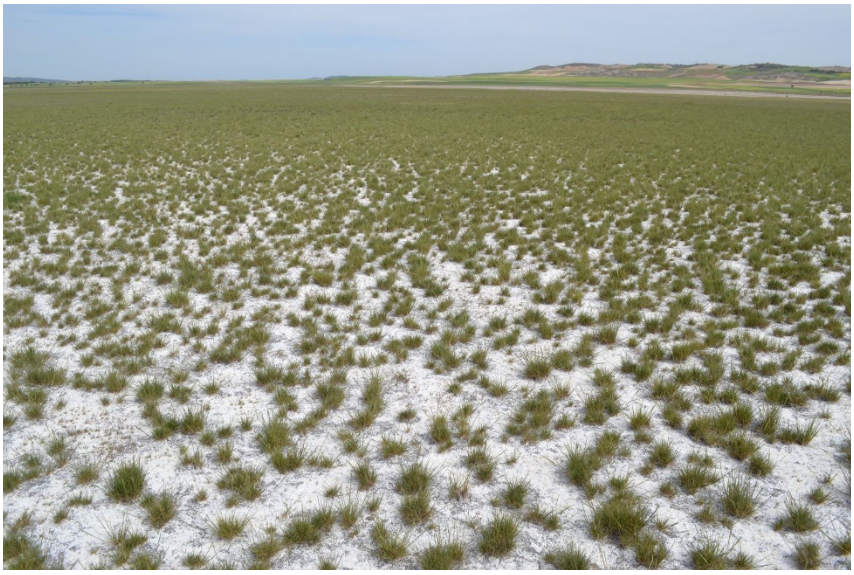

Figure 2. *Puccinellia festuciformis* formations now colonize extensive areas of the basin, as the pond waters recede over increasingly shorter periods.

Among other species found in this wetland and of great biogeographical interest is the endemic presence of Phanerogam *Limonium soboliferum* around the lagoon. Likewise, numerous insects, including the orthopteroid *Roseliana oporina*, known as the “Cuenca Meadow Bush-Cricket”, and the small crustacean *Branchinecta orientalis*, now threatened with extinction, are also prevalent in the same location.

Regarding the conservation figures, we can mention that the natural area around El Hito lagoon is included in the Natura 2000 Network (ZEPA-LIC-ZEC ES0000161) and in the Ramsar List of Wetlands of International Importance.

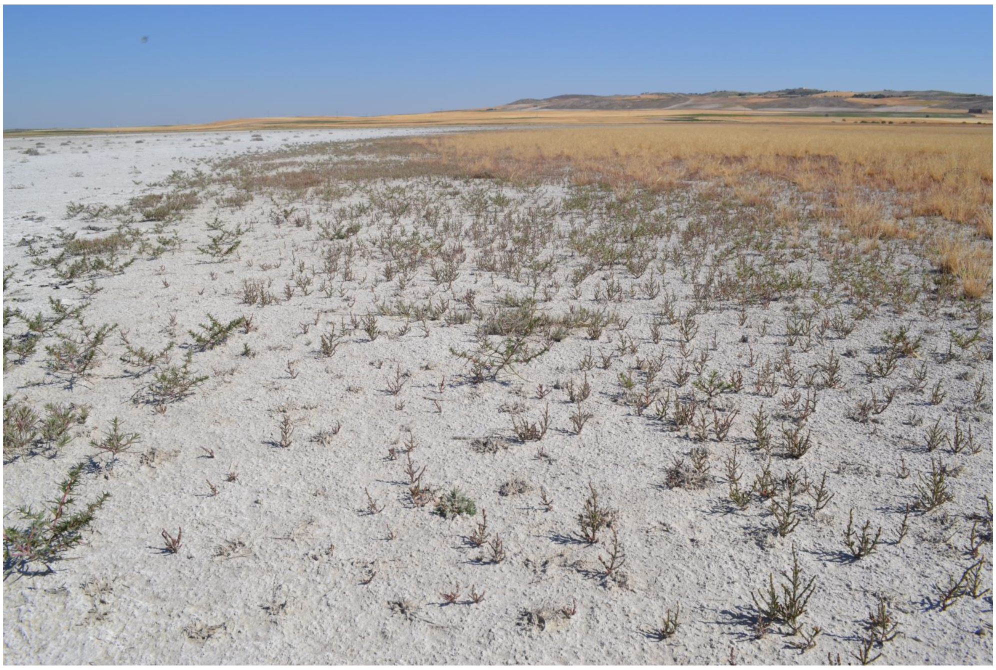

Figure 3. *Salsola soda* and *Salicornia ramosissima* communities at the edges of the flooded area. In orange, *Puccinellia festuciformis* formations.

2.2. Soil Samples Collected

Soil selection for sampling was dependent on certain soil-related features, such as drainage, presence or absence of salt crust at the soil surface, and especially vegetation type and density (Figure 4). For example, during sampling, the epsomite efflorescences appeared in the form of fibrous or hairlike acicular crust, while the structure of the hexahydrite efflorescences tended to be columnar. The soil profiles were described and sampled, having previously been opened up with a backhoe machine (Figure 5). Both the soil profiles and the surface sampling points were geo-referenced using Global Positioning System (GPS) coordinates. Probably, the most striking visual expressions of salinity at El Hito are, on one hand, the efflorescence on the soil surface (in dry periods) and, on the other, the halophilous vegetation (Figure 4). The samples were bagged, properly labelled, and transported to the laboratory for analysis. In total, 49 final soil samples were collected, consisting of 18 from several soil profiles and 31 from surface soil horizons.

Figure 4. *Cont.*

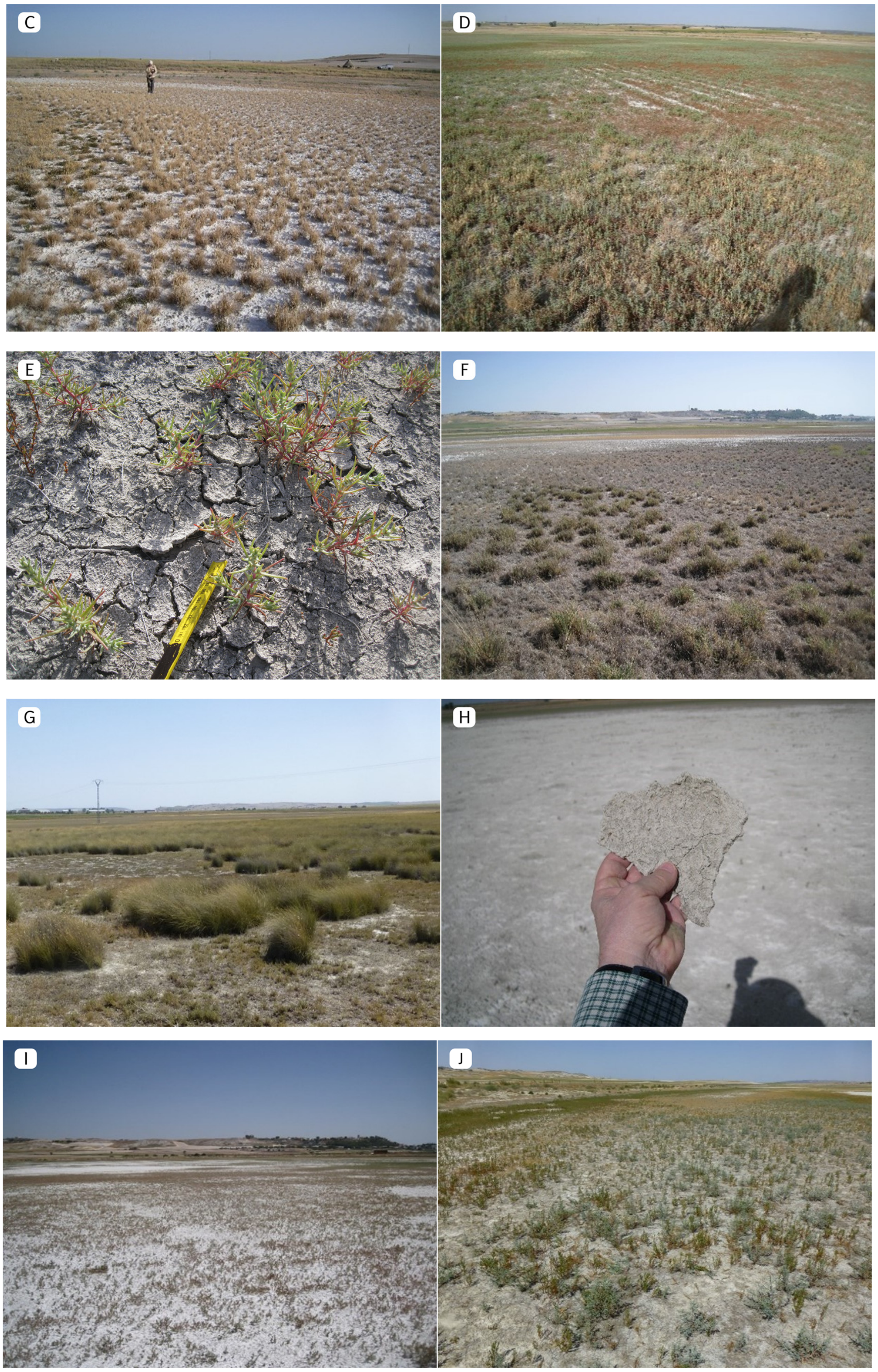

Figure 4. Criteria for sampling: (**A**) grassland interspersed with formations of *Lygeum spartum*, *Puccinellia festuciformis*, and *Elymus curvifolius*; (**B**) bare soil with dry remnants of formations of *Puccinellia festuciformis*; (**C**) *Puccinellia festuciformis*; (**D**) *Salsola soda*, *Hordeum marinum*, and *Puccinellia festuciformis*; (**E**) shrinkage cracks with a few examples of *Salsola soda*; (**F**) grassland of *Puccinellia festuciformis* and annual plants of nitrified soils; (**G**) *Lygeum spartum* formations; (**H**) saline crust in bare soil; (**I**) sparse grassland of *Salicornia ramossisima*; (**J**) grassland with *Salsola soda* and *Salicornia ramosissima*.

Figure 5. All soil profiles for description and sampling purposes were dug with a backhoe machine.

2.3. Soil Sample Analysis

Soil samples were dried and sieved at 2 mm (separating out thick fragments and roots from the remainder of the material). The same samples were then divided into two parts: one to determine the general physico-chemical properties of the soil; the other to determine the elemental spectrum via X-ray fluorescence (XRF) spectroscopy. Likewise, the physico-chemical properties were determined with the techniques listed in Table 1.

Table 1. Methods used for the soil sample analysis.

Parameter	Method	References
Texture	Touch	[22]
pH	pH meter measurements of 1:2.5 soil/water suspension	[23]
Electric conductivity (EC)	Conductivity meter measurements of 1:5 soil/water suspension	[24]
$CaCO_3$	Bernard method with a calcimeter	
Organic matter (OM)	Dichromate digestion (Walkley and Black)	[25]
CEC	Percolation with ammonium acetate solution at pH = 7	[26]
P	The Olsen method	[27]
N	The Kjeldahl distillation method	[28]
Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}	Inductively coupled plasma optical emission spectrometry (ICP-OES)	
SO_4^{2-}, Cl^{-}	Ion chromatography	
Mineralogy	X-ray diffraction	
Elements	X-ray fluorescence spectrometers	

2.4. Statistical Analysis

Statistical analysis was performed with the Statistical Product and Service Solutions (SPSS) 19.0 software package for Windows, SPSS Inc., IL, USA, with the institutional license of the Fundación Global Nature (Spain). The following analyses were performed: mean, minimum and maximum, median, standard deviation (SD), coefficient of variation (CV), and kurtosis of pH and EC results.

3. Results

All the pedons under study were deep and had no shallow water table. The soil profiling and field sampling results were in morphological terms monotonous; the morphology is of the Az-C type, with neither cambic (Bw) horizons nor, of course, argillic (Bt) horizons detected, typical of the nearby environment that borders the lagoon [29]. Indeed, the pedons showed similar morphological characteristics emanating from similar ecological conditions and modes of formation. No redoximorphic features (iron mottle due to reductive/waterlogged soil conditions) were detected.

In general, the structure was weak to moderate, in subangular blocks alternating with massive clods and with a single grain (with no structure); the weak structure or its complete absence could be attributed to the presence of Na^+ that acted as a dispersant, slowing down hydraulic conductivity [26,27,30,31]. What was really happening, as previously explained by He et al. [32], was that the suspended particles had the potential to clog the soil pores and consequently to diminish the capillary effects within the soil. Indeed, little porosity was detected (except in some sandier horizons) and no stoniness in each horizon of the soil profiles. Dispersal of wet, clay particles within the soil was observed, covering the macropores of the soil surface. The consequence was that root growth through the soil and surface crust was blocked, restricting plant emergence and thereby limiting root growth in salt-affected soils.

All the above contributed to the definition of "pedogenon" characteristics. Indeed, following the concept of "genon", defined by Boulaine [33] as "a soil volume comprising all the pedons that have the same structure, the same characteristics and result from the same pedogenesis", the concept of "soil genoforms" has more recently appeared in the work of Rossiter and Bouma [34], understood as "soil classes", identified in the soil classification system used for detailed soil mapping of local areas. Following the classification of soil classes, the term "pedogenon" emerged, proposed as a conceptual soil taxon derived from a set of quantitative state variables representing the soil-forming factors [35,36]. If each pedogenon is characterized by a soil type formed under a dominant parent material occupying a unique position in the landscape, then at El Hito there is a characteristic pedogenon that can, finally, be used as a benchmark soil.

Table 2 presents the physico-chemical parameters of El Hito pedogenon. The general morphology is the Az-C_1-C_1 type (and therefore poorly developed), where the A horizon is resting upon C material. Referring to the Keys to Soil Taxonomy [37] (Soil Survey Staff, 2014), the pedogenon was classified as Aridisols, with Great group Aquisalids, correlating to Solonchaks of the IUSS Working Group WRB [16].

Table 2. Physico-chemical properties of the pedogenon in the study area.

Pedogenon	Horizon	pH (H_2O)	EC (dS/m)	OC (%)	N (%)	C/N	P (mg/kg)	$CaCO_3$ (%)
El Hito	Az	9.06	10.38	1.10	0.16	1.9	155.31	10.5
	C1	8.75	6.19	0.25	0.04	6.3	95.62	11.6
	C2	8.69	8.12	0.23	0.03	7.6	41.31	4.8

With the above in mind, the pedogenon of El Hito lagoon can be characterized by its dominant parent materials, silt, gypsum, and margogypsum, nurturing its natural vegetation of Mediterranean salt meadows and grasslands growing on flat terrain. The soil texture is heavy (clay silty), and the predominant soil color is whitish to greyish. Cracks, crust, and efflorescence appear in the dry season. The soil class is Typic Aquilasids [33,37]. Soil pH peaked at a value of 9.06, which is highly alkaline in nature. Electrical conductivity (EC1:5) was recorded at a value of 10.38 dS/m.

The dominant cations within salt-affected soils are sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^+), and the dominant anions are chloride (Cl^-), sulphate (${SO_4}^{2-}$), carbonate (${CO_3}^{2-}$), bicarbonate (HCO^-), and nitrates (${NO_3}^-$) [24]. Its contents are high in the case study (Table 3). Based on the above values, it can be assumed that Mg^{2+} and sometimes Ca^{2+} dominates, followed by Na^+ and finally K^+. Regarding the anions, sulphate and chloride mainly dominate and, to a lesser extent, carbonate and bicarbonate; in that way, although carbonate concentration may not be negligible, Na^+ is probably responsible for the high pH values. In other words, sodium bicarbonate remains within the water, producing trace amounts of soda that raises the pH.

Table 3. Results of the analyses of the paste saturation extract.

Pedogenon	Horizon	Ca^{2+}	Mg^{2+}	Na^+	K^+	SO_4^{2-}	Cl^-	CO_3H^-	CO_3^{2-}
		mg/kg							
El Hito	Az	5621	6800	930	754	32,652	7110	138	147
	C1	3627	5250	1150	503	18,017	7503	96	101
	C2	3559	6350	1275	450	25,125	9750	106	113

Biomass accumulation is limited in many saline wetlands and soil organic matter is unsurprisingly also limited at El Hito Pond. The high temperatures within the zone cause fresh residual vegetation to decompose, which can therefore explain the low organic matter (OM) value. The calcium content probably decreased, because of a competitive effect with magnesium. Generally, soils are considered to be salinized when a soil saturation extract has an ECe value of 4 dS/m or greater. As can be seen in the majority of the surface sample results, the ECe values ranged between 1.39 and 41 dS/m (Table 4), clearly confirming that El Hito site samples were highly salinized in 31 surface soil samples.

Table 4. Results of pH and electrical conductivity (ECe) analyses on 31 surface soil samples. The characteristics of the type of vegetation/use are also shown.

Soil Surface	Vegetation Type	Coordinates	pH (H_2O)	ECe (dS/m)
C1	*Puccinellia festuciformis* meadows	39.877087–2.701919	9.42	41.00
C2	*Salsola soda* meadows	39.876511–2.701869	9.48	30.70
C3	Bare soil with *Salsola soda*	39.872515–2.702211	9.61	32.70
C4	*Puccinellia festuciformis* meadows	39.870211–2.700909	9.71	16.26
C5	*Aeluropus litoralis* meadows	39.867876–2.698168	8.62	2.18
C6	*Puccinellia festuciformis* meadows	39.866100–2.695747	8.74	2.89
C7	Bare soil with *Salsola soda*	39.866407–2.692898	9.89	39.70
C8	*Salsola soda* and *Salicornia ramosissima*	39.869053–2.687970	9.71	4.99
C9	*Lygeum spartum* formations	39.871532–2.684968	8.78	2.58
C10	Grassland among *Lygeum spartum*	39.871252–2.684295	9.25	5.83
C11	Grassland among *Lygeum spartum*	39.875732–2.678837	8.54	1.39
C12	Fallow with Bassia scoparia	39.865365–2.673279	8.79	2.10
C13	Elymus repens meadows	39.866324–2.674148	8.68	4.00
C14	*Aeluropus litoralis* meadows	39.866599–2.674488	8.37	1.96
C15	Fallow	39.860569–2.678548	8.79	1.99
C16	*Frankenia laevis* and *Plantago coronopus*	39.860592–2.679418	9.65	27.40
C17	*Salicornia ramosisima* and *Puccinellia caespitosa*	39.862437–2.679445	9.54	12.97
C18	Bare soil	39.863784–2.682094	9.51	20.00
C19	*Salsola soda* meadows	39.863516–2.684056	9.46	8.00
C20	Grassland among *Lygeum spartum*	39.858481–2.686284	8.96	2.13
C21	Bare soil-fallow	39.858233–2.694175	8.93	3.94
C22	Grassland among *Lygeum spartum*	39.858594–2.699989	8.29	2.13

Table 4. *Cont.*

Soil Surface	Vegetation Type	Coordinates	pH (H_2O)	ECe (dS/m)
C23	Fallow with *Salsola kali*	39.860900–2.709894	8.42	2.33
C24	Fallow	39.867409–2.711967	8.64	2.06
C25	Fallow	39.872950–2.710535	8.92	0.74
C26	Bare soil-fallow	39.878496–2.709827	8.99	0.49
C27	*Puccinellia* caespitosa meadows	39.876401–2.695190	9.59	16.89
C28	*Salsola soda* meadows	39.874595–2.701872	9.60	9.50
C29	Bare soil with *Salsola soda*	39.872515–2.702211	8.53	8.06
C30	*Puccinellia festuciformis* meadows	39.866100–2.695747	8.44	2.69
C31	Bare soil with *Salsola soda*	39.866407–2.692898	9.67	21.30

Careful observation of the above data highlights the lateral anisotropy of soil salinity, which was attributed to the temporal fluctuations of salt content following the appearance and/or displacement of soluble salts within the soil. Those salinity variations constitute an important driving factor of vegetation zonation.

The calculated statistics included mean, standard deviation (SD), coefficient of variation (CV), minimum, maximum, and kurtosis, as seen in Table 5. The saline soils of El Hito Pond display high spatial variability in soil salinity at a field scale, caused by temporal and spatial variations of external factors. It is worth noting that the SD of ECe (12.15) was larger than that of the pH (H_2O) (0.49), with the coefficient of variation (CV) of ECe (113%) larger than that of the pH (H_2O) (5%); a CV value lower than 10% indicated low variability. Both data sets had large values of kurtosis with the ECah0 (6.64) larger than ECav0 (4.53), with both being leptokurtic (value is greater than + 1.0) (Table 5).

Table 5. Basic summary statistics of the measured pH (H_2O) and ECe (dS/m).

Variable	Mean	Median	Min	Max	SD	CV	Kurtosis
pH (H_2O)	9.08	8.96	8.29	9.89	0.49	0.05	−1.48
ECe (dS/m)	10.67	4.00	0.49	41.00	12.15	1.13	0.38

The graph in Figure 6 below represents the linear relationship between soil pH and soil EC for the depth of 0–10 cm. Visual observation and statistical analyses indicated that the soil pH had a significant positive relationship with the soil EC (pH = 5.403–0.152 EC). The correlation coefficient was −0.88.

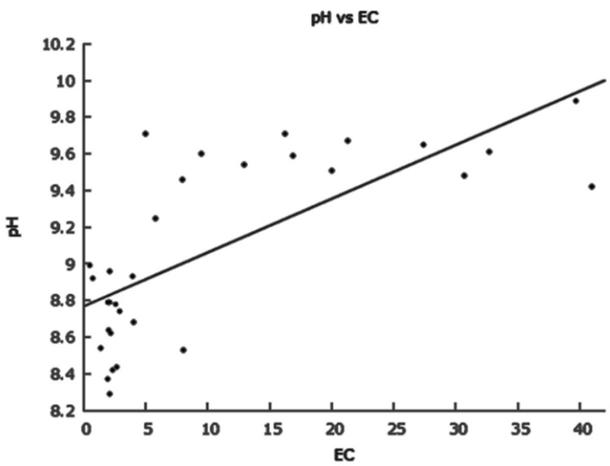

Figure 6. Linear relationship of soil pH versus soil ECe at 0–10 cm.

The elemental spectrum of the pedogenon is presented in Table 6. The most abundant element was S, whose presence ranged between 36.88 (%) and 27.94 (%), expressed as $S0_3$. Ca came second in quantitative terms, ranging between 28.21 and 31.12 of CaO (%) and then, in much smaller proportions, Mg, Si, Al, Na, K, Fe, and Cl, in descending order.

Table 6. Results of the chemical elemental analysis.

Pedogenon	Horizon	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	Cl	PPC
		(%)									
El Hito	Az	4.15	1.02	0.27	30.63	4.02	0.33	0.24	36.88	0.19	21.74
	C1	4.01	0.83	0.27	31.12	2.30	0.35	0.23	33.59	0.21	23.09
	C2	6.45	1.28	0.48	28.21	9.34	0.40	0.31	27.94	0.25	24.56

Mineralogically, the three fundamental mineral components were gypsum, carbonates, and more labile salts, i.e., epsomite ($SO_4Ca \bullet 7\ H_2O$) and hexahydrite ($SO_4Ca \bullet 6\ H_2O$).

Finally, if the five salinity classes established in 1983 by [34,38] (Table 7) are applied to the samples, almost half may be considered extremely saline soils; around one third, very saline soils; approximately 11%, moderately saline soil; only 4% can be considered slightly saline soils; finally, only 4% can be termed non-saline soils.

Table 7. Classification of El Hito lagoon soils based on electrical conductivity (EC) following the criteria of Duran [38]. Number of saline samples and percentage within the lagoon.

EC (dS/m)	Salinity Classes	Number of Soil Samples	% Soil Samples
≤ 0.6	Non-saline soil	1	3.7
$0.6 < EC \leq 1$	Slightly saline soil	1	3.7
$1 < EC \leq 2$	Moderately saline soil	3	11.1
$2 < EC \leq 4$	Very saline soil	9	33.3
>4	Extremely saline soil	13	48.2

The electrical conductivity values for the surface soils, which must be borne in mind for ecological purposes, therefore indicated that a large portion of the total wetland area was classified as saline soil.

4. Discussion

4.1. On the Origin of Soil Salinity in El Hito Saline Pond

El Hito saline pond occupies a flat-depressed zone, which favors preferential water circulation and accumulation. As within other European salt steppes, the natural process of soil formation shows specific patterns. Salts evidently accumulate, leading to salinization, although temporal dynamics were observed within specific areas, which explains the substantial variability of the data throughout the lagoon. In the opinion of Boettinger and Richardson [39], wet soils and wetlands are in general not prevalent in dry and seasonally dry climates, but their morphology and characteristics are considerably different from those in more humid climates. Indeed, the major pedogenic process involved in the formation of saline wetland soils in semi-arid climates, such as El Hito, is salinization.

The combined effects of high levels of evaporation together with insufficient leaching leads to the accumulation of salts within the soil and consequently to the development of salt-affected soils [40]. The only prerequisite is water with sufficient salts for further accumulation. The levels of silt and clay favor drastic impermeability. Shao and Zhang [41] suggested that an increase in silt content results in the thickening of the bound-water film and a reduction in soil porosity.

El Hito saline pond is located within areas where water accumulates, closely related to an endorheic basin (i.e., with little or no external drainage). There are briefly three factors or processes shaping the distribution and genesis of El Hito: geomorphology of water concentration, lithological sources of sediments, and evapo-concentration of salts, or in an environmental setting, pedogenesis. But globally speaking, a distinction is made between the primary (natural) and secondary (human-induced) processes. In the primary formation process, the nature of the parent geological material plays an important role, alongside the natural climatic conditions (arid or semi-arid), i.e., a lack of precipitation and an excess of evapotranspiration. On the contrary, the secondary process is caused by human activities [4,42–44].

Indeed, El Hito Pond is filled with a shallow body of water (maximum depth 15–20 cm) [45] for several months, approximately between November and May. Fundamentally, surface runoff replenishes the water layer, favored by the depressed topography, so that it is only during the rainy seasons when the lagoon retains water. Therefore, the primary drivers of soil salinization are closely related to both the mineralogical and the chemical characteristics of the parent materials and to both the topography and the type of climate. The process is well known: salty water rising through the soil profile by capillary action contributes to the salts, which remain in the soil when the water evaporates [46]. Given the topographic situation of the wetland, water accumulation occurs. The summer evaporation rates are higher than the precipitation rates within the region, so the normal pattern over many years is more or less rapid water evaporation. The salinity levels therefore rise as evaporation continues, and the surrounding soil salinization is continuous as water salinization gradually adds to soil salinity levels. Anthropic sources have been cited in other areas of the world [4,10,43,47–49], as are also glimpses of anthropic effects in the case of El Hito Pond. In any case, the evaporation process accelerates salt encrustation and formation, and the salts rise by capillarity action to the surface of the soil where crusts may even form.

4.2. Discussion on Halophyte Adaptation to Salt-Affected Soils

There is, to the best of our knowledge, limited research on soil salinity levels and the specialized vegetation that can prosper under such conditions. Halophyte formations generally reflect the chemical composition and the levels of soil salinity under natural conditions quite accurately. Soil pH and EC, in particular, emerged as primary environmental factors shaping the abundance of some plant species.

One of the identifying features of El Hito saline pond soils is their salt accumulation levels, especially within the surface horizons. The origin of the salt must be linked to the materials (gypsum and silt and gypsum marl) and their composition, as well as to the semi-arid climatic conditions that facilitate the water evaporation and saline precipitation. The following salt types were identified: epsomite ($SO_4Mg \bullet 7H_2O$), mirabilite ($SO_4Na_2 \bullet 10H_2O$), bloedite [$(SO_4)_2Na_2Mg \bullet 4H_2O$], halites (ClNa), etc. [14]. Sometimes, together with those saline accumulations, the same salts form crust-shaped accumulations (Figures 2–4), a type of crusting layer that forms at different stages (between approximately 0–10 cm) where salts accumulate at the onset of the dry summer season.

Soil salinity has a twofold influence on plant growth: high toxic ion concentrations and negative water potential [50,51]. Simply mentioning the word salinity in the context of soil can refer to problematic issues, since it negatively affects the growth of most plants. However, the so-called halophytic plants are salt-tolerant plants, that can normally prosper at levels of approximately 20 dS m^{-1} of EC [52,53]. Authors such as Rozema and Schats [54] pointed out that plant growth could be stimulated within salinity ranges between 15 and 25 dS/m.

In general, plants growing under saline conditions have to adapt to three types of stress: (a) water stress (caused by osmotic pressure); (b) mineral toxicity stress caused by salt; and (c) alterations in mineral balance. Excess salts can inhibit water extraction through plant roots, i.e., less water is available to the plant, with a consequent reduction in soil productivity. Additionally, the salts provoke swelling and dispersion of the colloidal particles (caused by an excess of exchangeable Na), which generates both water infiltration and root penetration problems, as well as complicating the emergence of the seedlings.

Finally, in the summer, coinciding with maximum evapotranspiration, capillary rise occurs, generating saline crust formations on the surface.

The plants that colonize El Hito Pond are salt tolerant. The distribution of different species is dependent upon the duration of flooding. In this regard, plant tolerance to waterlogging can be summarized as follows: *Lygeum* < *Frankenia* < *Puccinellia* < *Salicornia* = *Salsola.* Principio del formulario

Crops such as potatoes, wheat, *Vitis vinifera*, *Citrus*, *Prunus*, *Lactuca*, and *Cucumis* and plants such as *Lavandula* and *Calendula* are damaged by soil salinization. In contrast, the growth and the development of plants such as *Salsola* is, on one hand, common at El Hito saline pond, which is nothing strange in itself given that its growth is not negatively affected by salt stress; on the other hand, plants and crops commonly found within the environment of El Hito Pond are negatively affected, because of the disruption of certain physiological processes such as an imbalance in the ratios of macronutrients, nutritional deficiency, and even Na phytotoxicity [55,56]. In fact, saline stress may somehow affect processes such as photosynthesis and respiration, causing inhibition, wilting, drying, and the demise of entire plant organs of most plants and vegetable crops [57,58]. Indeed, from the biological point of view, soil salinization processes affect several ecological soil functions. Thus, respiration and microbial activity are both worth mentioning, insofar as they interact with processes related to organic matter, decomposition, and the N cycle, eventually affecting microbial activity [53,59,60].

Globally speaking, soil salinity is an important variable that plays a relevant role in reducing fertility levels. Soil salinization is therefore a very severe problem that is mainly due to irrigation strategies and other intensive agricultural activities [61,62]. It becomes an issue for agricultural productivity, but not within ecological niches where saline soils are produced by natural processes.

4.3. Ecosystem Services of El Hito Saline Pond: Proposal for Conservation–Rehabilitation Measures

Ecosystem services have become a prominent concept in international policy and research agendas [63]. Wetlands are among the most diverse and productive and therefore the most valuable ecosystems [64–68] in the world. Various ecosystem services can co-exist within one ecosystem [69]. El Hito Pond constitutes a small iconic environment representative of the most diverse and productive ecosystems within the Mediterranean region. A fascinating result of interactions between aquatic and terrestrial ecosystems, it provides a wide range of services and benefits to local inhabitants and visitors, including climate regulation, water purification, and flood hazard reduction; although its recreational and cultural value may be highlighted above all, they are in addition to its role as a natural wildlife habitat.

There were until practically a few decades ago hardly any environmental concerns voiced in the society over the importance of wetlands, much less so whether these are saline in nature. In the latter case, they have rather been disdained, based on the fact that they were practically useless for agricultural purposes. With that in mind, given that our findings have demonstrated clearly varied levels of soil salinity and ionic compositions across the lagoon, soil management may consider the spatial heterogeneity of saline soil types. Our results therefore provide scientific guidance for soil management and restoration of the lagoon. Future studies should address the quantification of temporal changes to soil salt-affection patterns in and around El Hito Pond.

Halophytic plants, which are salt-tolerant species, can survive under values of EC of 20 dS/m [52], while [54] pointed out that plant growth can be stimulated within a salinity range of 15 and 25 dS/m. This series of species is equipped with adaptive mechanisms to survive in saline environments; they include biochemical, physiological, anatomical, and morphological characteristics [52,70,71].

Some scholars [72–76] have maintained that halophytes were viable alternatives for food, fodder, bioenergy, ornamental, and pharmaceutical uses. According to Duarte and

Caçador [72], the benefits of halophyte ecosystems are acknowledged, insofar as they improve soil health and ecosystem biodiversity and can store large amounts of carbon, thereby increasing the ecosystem resilience to climate change and offering green solutions to slow climate change. Both [77,78] pointed out that halophytes have long been used for pharmaceutical purposes, in view of their bioactive compounds with medical properties.

Halophytes are considered precious natural resources with potential economic value as grain, vegetable, fruit, medicine, animal feed, and biofuel feedstocks and in greening and coastal protection [79]. In this way, plants from the genus *Salsola* are known to be used in traditional medicine; for example, *Halothamnus somalensis* (N.E.BR.) Botsch (*Salsola somalensis* N.E.Br.) has been used as hypotensive, antibacterial, and anticancer agents. *Salsola* is a halophyte with succulent vegetative structures that can be defined as a successful salt-absorbing species. The genus can also help with the restoration and reclamation of degraded salty areas and saline soils [80]. A halophyte native to the Mediterranean basin, *Salsola soda* L., is considered to be a "biodesalinating companion plant" to tomatoes and peppers in the saline soils of central Italy [81]. The potential use of *Salsola soda* for the phytostabilization of polluted areas has been shown by [79,82,83]. Recently, Ref. [84] stated that planting halophytes in salt-affected areas can improve soil quality and restore biodiversity. It also produces valuable products, such as animal feeds and renewable energy sources. Therefore, the presence of *Salsola soda* at El Hito should be understood as a paradigmatic example of a species to conserve, since it is perfectly adapted to a dominant saline soil environment.

It is expected that as climate change brings drier and warmer conditions to the region, sparser water resources will lower or completely exhaust El Hito lagoon water levels. It is therefore necessary to propose conservation–remediation measures.

Lygeum spartum L. has recently been introduced into areas with high soil salinity levels [85]. Popularly known as Albardín, *Lygeum spartum* is an herbaceous plant with an extensive root system that shows spontaneous growth in saline soils and reduces soil erosion, while enhancing soil phytostabilization. It is therefore used in landscape restoration and for erosion control in the southeastern Iberian Peninsula according to [86], especially in semi-arid areas.

However, Ref. [87] pointed out that the effect of salinity on germination varies considerably with temperature regimes, while [88] through a field experiment concluded that that *L. spartum* can be used as a bio-indicator of soil salt type. Ref. [89] demonstrated that an increase in salinity induces both a reduction in the percentage of germinating seeds and a delay in the initiation of the germination process. More recently, Refs. [90,91] stated that salinity, temperature, and their interaction affected the germination percentage of *L. spartum* seeds. According to our findings, late autumn and early winter sowings are recommended when salinity and temperature stresses are reduced, when plant canopies do not cover the soil, roots are insufficiently developed, and the soil has no protection against erosion (Figure 7).

Figure 7. The formations of esparto grass (*Lygeum spartum*) known as "*albardinares*" are typical of the Iberian "steppes", located in the highest area around El Hito saline pond that the waters leave untouched. These formations protect the soil from erosion and delay siltation within the pond.

5. Conclusions

The different habitats of El Hito saline pond whose conservation is a priority interest in the European Union are of high environmental value. It is a hypersaline wetland, where salinity, hydric conditions, and halophilous vegetation contrast distinctly with the surrounding non-saline gypseous land and its gypsophilous vegetation. It is nevertheless evident that this wetland is fragile in nature, and a better understanding is therefore required of how to promote and to adapt appropriate management strategies. In this paper, useful baseline data have been presented for its conservation.

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Conflicts of Interest: Santos Cirujano Bracamonte, currently serves as President of the Global Nature Foundation (FGN), a non-profit organization based in Spain that works on nature conservation and biodiversity both nationally and internationally. Founded in 1993, its main mission is to promote sustainable development and environmental conservation through collaboration with various sectors, including the business sector, public administrations, and civil society. It develops projects in areas of high ecological value and at risk of degradation, particularly focusing on the restoration and management of wetlands. Mario Álvarez-Soto was employed by Consultores en Biología de la Conservación S.L. He participated in the study by contributing to the generation of GIS maps. The role of the company was to provide assistance and support in data generation and manuscript preparation. Eduardo Palencia-Mayordomo was employed in Global Nature Foundation, working primarily in field work. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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