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Salada Farrachuela, a saline wetland in Tamarite de Litera, Spain

Salada Farrachuela, un humedal salino en Tamarite de Litera, España

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ABSTRACT

This paper gives, for the first time, details of the vascular plants plus the soluble salts and other major components of their natural substrate in Salada Farrachuela, a hypersaline wetland located in the municipality of Tamarite, NE Spain. The wetland is situated on the outcropping evaporite-cored Barbastro Anticline, an area declared by the environmental authorities to be of community interest and part of the Natura 2000 network. This uncultivated and occasionally flooded wetland harbors plants able to withstand the conditions of their substrate whose upper layer (0–25 cm) has an average of 41% gypsum ($CaSO4•2H2O$), and 7.2 dS m^{-1} at 25 °C electrical conductivity in 1:5 soil-to-water weight ratio (EC1:5) extracts. The EC1:5 value in the soil samples up to a depth of 2 m ranges from 6.23 to 7.95 dS m^{-1}. At this depth, the average EC in the saturation extracts (ECe) is 37.0 dS m^{-1}, with sulfate being the most abundant ion (503 meq L^{-1}), followed by magnesium (492 meq L^{-1}), sodium (113 meq L^{-1}), and chloride (41 meq L^{-1}). Salinity, hydric conditions, and halophilous vegetation contrast distinctly with the surrounding nonsaline gypseous land and its gypsophilous vegetation. This article provides a baseline for future investigations of the ecology of this wetland in relation to salinity, and a reference for the monitoring needed to guarantee its conservation.

RESUMEN

Este artículo da por primera vez noticia de las plantas vasculares y de las sales solubles y otros componentes mayoritarios del suelo de la Salada Farrachuela, un humedal hipersalino situado en el municipio de Tamarite de Litera, provincia de Huesca, en el NE de España. El humedal se localiza en el afloramiento del núcleo evaporítico del anticlinal de Barbastro, un área declarada de interés comunitario incluida en la Red Natura 2000. Este humedal, inculto e inundado ocasionalmente, alberga plantas adaptadas a un suelo cuya capa superior (0-25 cm) tiene por término medio un 41% de yeso ($CaSO4•2H2O$), 7.2 dS m^{-1} a 25 °C de conductividad eléctrica en el extracto acuoso 1:5 en peso de suelo:agua (EC1:5). Para ese espesor de suelo, la conductividad eléctrica en extracto de saturación (ECe) a 25 °C es 37.0 dS m^{-1}, siendo el sulfato el ión más abundante (503 meq L^{-1}) seguido del magnesio (492 meq L^{-1}), sodio (113 meq L^{-1}), y cloruro (41 meq L^{-1}). La salinidad, las condiciones de humedad y la vegetación halófila contrastan fuertemente con las tierras circundantes, yesosas y no salinas. Este artículo puede ser un punto de partida para futuras investigaciones de la ecología del humedal en relación con la salinidad, y una referencia en el futuro seguimiento necesario para garantizar su conservación.

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1. Introduction

Years ago, Williams (2002) stated that "limnologists and other groups interested in inland waters have largely ignored salt lakes until recently" and discussed the reasons for this. Later, Downing (2010) stressed that "the small parts of aquatic ecosystems, e.g., small lakes, ponds, puddles, marshes, and streams, [are] of disproportionately great importance in world cycles and processes." In the last decades, environmental concerns have promoted the societal appreciation of traditionally undervalued wetlands, which are now considered of interest because of their biodiversity, including those that have not yet been cataloged, as reflected in the wildlife protection laws passed in some countries. In Spain, Barrera *et al.* (2012) have reviewed and discussed other reasons for the appreciation of wetlands and Domínguez-Beisiegel *et al.* (2013b) have illustrated the fate of some saline wetlands.

Society's appreciation of gypseous lands has undergone a similar evolution. The 60-km-long strip of outcrops of the Barbastro Gypsum Formation, in NE Spain, stands out in the landscape because of its linear reliefs and whitish color (Mallada, 1878). People living close to this strip refer to the gypseous land as *chesas* (Herrero, 1991), derived from *ches*, the local name for gypsum. *Chesas* were considered marginal for agriculture and used as rangeland, owing to their limited production in rainfed agriculture, mainly because of their low water-holding capacity (Moret-Fernández & Herrero, 2015).

The vegetation on the gypseous soils is considered a priority habitat in Annex I of the Habitats Directive (European Union, 1992). In 2007, the *chesas* were included in the EU Natura 2000 network established by the European Union. *Chesas* were designed as the Site of Community Importance "ES2410074 Yesos de Barbastro" with its Standard Data Form (SDF) updated in 2012 as can be seen at http://natura2000.eea.europa.eu/Natura2000/SDF.aspx?site=ES2410074 (consulted in September 2020). These lands overlie the Late Eocene–Early Oligocene evaporitic Barbastro Gypsum Formation outcrops in the core of the Barbastro Anticline (Figure 1), NE Spain. Its geology has been studied by several authors, such as Mallada (1878), Pardo & Villena (1979), Lucha *et al.* (2012), and Barnolas (2017) (Figure 1).

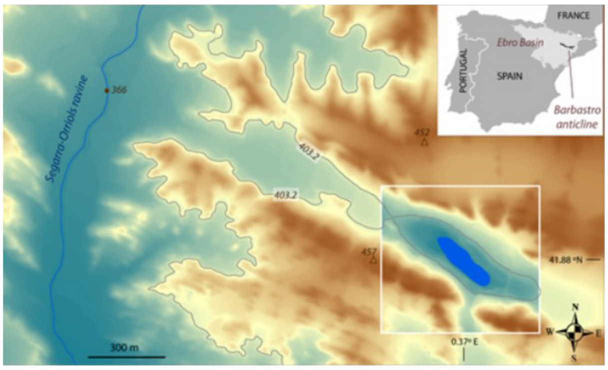

Figure 1. Digital elevation model derived from LiDAR data showing the location of Salada Farrachuela (in blue) within a flat-bottomed valley in the Barbastro Anticline (Ebro Basin, NE Spain). The inset shows the Ebro Basin in light grey and the Barbastro Anticline in black.

The ubiquity and abundance of gypsum in the landscape govern the genesis and properties of the natural vegetation and soils. Typical *chesa* soils are gypseous, nonsaline, with a low water-holding capacity, and a xeric soil-moisture regime (Herrero, 1991). No soil map is available, but according to the studies of Herrero (1991) and Artieda & Herrero (2003), the main component of *chesa* soils is gypsum, followed by calcite.

The best-known hypersaline spots in the central Ebro Basin form a myriad of shallow lacustrine depressions, known as *saladas*, developed on structural platforms (Castañeda *et al.*, 2013). These saladas have been studied from different points of view, for example, mineralogy (Mees *et al.*, 2012), hydrology (Salvany *et al.*, 1996; Castañeda & Herrero, 2005) and paleohydrology (Valero *et al.,* 2004), botany (Conesa *et al.*, 2011), pedology (Domínguez-Beisiegel *et al.*, 2013a), ecology (Pedrocchi & Sanz, 1991), or degradation assessment (Castañeda & Herrero, 2008).

In contrast, Salada Farrachuela is located around 60 km from this constellation, on the Barbastro Gypsum Formation at the north of the Ebro Basin. Most importantly, to our knowledge, no previous studies on the salinity and other conditions of this salada are available.

Farrachuela was not recorded on the SDF (European Commission, 2011) of the Natura 2000 Site of Community Interest ES2410074. This omission precludes the application of protection measures. On the other hand, the SDF does not list any habitats with a floral composition similar to that found at Farrachuela, showing that other saline spots are probably absent at this Natura 2000 site. After including the *chesas* in the Natura 2000 network, data on the salinity, vegetation, and other traits of Farrachuela must be recorded to track the condition of this athalassohaline enclave for conservation purposes.

This article aims to (i) report relevant features -namely, vascular plants, salinity, pH, gypsum, and calcium carbonate content- of a saline wetland located on the Barbastro Gypsum Formation, and (ii) present easy statistical procedures to describe the relationships between the chemical features studied and check their coherence. The features described -most of them for the first time- plus the procedures to check data coherence will allow the future monitoring of Farrachuela's conservation.

2. Materials and methods

2.1. The studied saline wetland in its context

Salada Farrachuela (41°53'05"N, 0°22'20"E) is an elongated saline wetland of about 3.4 ha, located at 400 m a.s.l. The strongly saline taste of the water standing at the surface after the rains, the halophilous vegetation, and the white and strongly reflective efflorescence when the *salada* dries up (Figure 2) comprise field evidence of salinity. The *salada* occupies the bottom of a WNW–ESE-oriented flat-bottomed valley formed along the backslope of a cuesta resulting from the dip of strata in an anticline, as shown by the oblique aerial view in Lucha *et al.* (2012). The valley is ≈ 4 km long, has impeded surface drainage, and hangs approximately 30 m above the N–S trending Segarra ravine (Figure 1), which remains dry for most of the year (Calvo, 1985). According to Sancho (1989), this ravine probably underwent entrenchment during the Quaternary due to the local uplift of the evaporitic substrate, as revealed by the two Quaternary levels of ravine infill. Salada Farrachuela is developed on Quaternary materials (Barnolas, 2017) and is delimited by a net escarpment of approximately 2 m along both the northern and southern margins. The land around Farrachuela is cultivated with rainfed barley, whereas Farrachuela itself is home to halophilous plants (Figure 2).

Records (2003–2020) from the Tamarite automatic weather station, located 11.5 km to the south of the wetland studied, reveal that the mean annual rainfall in the area is 337 mm/year, the mean temperature is 14°C (range, 12.2°C–14.7°C), and the mean evapotranspiration rate is 1027 mm/year, according to the Spanish network of agroclimatic stations (SIAR, Sistema de Información Agroclimática para el Regadío) of the Spanish Ministry of Agriculture. Using the criteria of Köppen, the Government of Aragon (2019:157) classifies the climate of Tamarite as continental Mediterranean.

Figure 2. The white bottom of Salada Farrachuela in Tamarite de Litera, Aragón, Spain, stands out in the aerial photograph when the wetland is not inundated or covered by vegetation. The sampling sites locations (TMT1 to TMT6) and selected contour lines are superimposed on both pictures. The picture (A) from 20 April 1957 shows the now absent ditch connecting with the two crossed furrows that are still visible. The picture (B) is from PNOA 2015 (https://pnoa.ign.es/). Source: Spanish National Geographic Institute, https://www.ign.es. PNOA stands for Plan Nacional de Ortofotografía Aérea.

2.2. *Field work*

In July 2013, that is, 32 years after our first visit to Farrachuela, we had the means to sample this wetland. The sites studied are located on aerial photographs (Figure 2). Sites TMT1–TMT5 were distributed along the saline vegetation within the *salada*. We sampled the soil at sites TMT1–TMT4 by hand augering 25-cm-depth intervals, down to a depth of 2 m. We also sampled the topsoil from 0 to 25 cm at site TMT6, which is located in a conterminous barley field set to fallow. Visual appearances and touch examinations were assessed on all samples. Groundwater was reached and sampled at three sites. The elevation of the sampling sites was measured using a total station, prior to the availability of LiDAR data. Plants were collected in May 1981 and July 2013, with no new taxa found in our visits of July 2018 and August 2018.

2.3. *Laboratory procedures*

The fresh soil samples were transported to the laboratory in plastic bags and the percentage of coarse fragments in all the samples was recorded. The fine fraction obtained after air drying the samples and passing them through a 2 mm sieving mill was analyzed. The pH was measured using potentiometry in a soil to to-water ratio of 1:2.5 (weight:weight) according to Peech (1965).

Gypsum, identified in the field as a major component of the soil, was titrated in all the samples using thermogravimetry method (Artieda *et al.*, 2006; Herrero *et al.*, 2018), and the calcium carbonate equivalent (CCE) was measured by gasometry (Soil Survey Staff, 2014). Electrical conductivity (EC) was used as a proxy for salinity. The soil salt stock was appraised using the two fixed-ratio dilution approach (Herrero *et al.*, 2015), that is, preparing the aqueous extracts of all 33 soil samples at both 1:5 and 1:10 soil-to-water dilutions (weight:weight) and measuring their EC (EC1:5 and EC1:10), expressed in dS m^{-1} at 25 °C. Following the rationale in Casby-Horton *et al.* (2015), the particle size distribution of the samples was not determined in the laboratory, and the saturation percentage (SP) was considered a surrogate for textural composition.

Saturated paste extracts (United States Salinity Laboratory Staff, 1954) were prepared for 16 soil samples from the *salada*, in addition to one from the conterminous cultivated field. For all the extracts, the SP (%) was recorded and the pH (pHe) and EC (ECe, dS m^{-1} at 25 °C) were measured. Cations Ca^{2+}, K^{+}, Mg^{2+}, Na^{+}, and NH_4^{+}, and anions Br^{-}, Cl^{-}, F^{-}, NO_2^{-}, NO_3^{-}, PO_4^{3-}, and SO_4^{2-} were analyzed using ion chromatography (Metrohm 861 Advanced Compact IC, Metrohm AG, Herisau, Switzerland). CO_3^{2-} and HCO_3^{-} were analyzed using acid titration (Soil Survey Staff, 2014). The average ionic content of each soil sample was reported as the sum of all the determined cations and anions (meq L^{-1}) divided by two. For the groundwater samples, the EC (dS m^{-1} at 25°C) and pH were determined a few hours after collection. The pH and EC in both the saturation extracts and the groundwater samples were measured with a pH electrode and a conductivity cell, respectively (Orion 9157BNMD and Orion 013605MD, respectively, Thermo Fisher Scientific Inc., Beverly, MA, USA).

Our first collection of plants was performed during a botanic trip in May 1981. Specimens were dried using the traditional method with only soft warm forced air. Herbarium specimens were filed and preserved in the herbarium MA, international code of the herbarium of the Real Jardín Botánico, CSIC (cf. Thiers, 2020). Identification and nomenclature were updated continuously with Flora Iberica (Castroviejo, 1986–2019), from 1981 to the present.

2.4. *Statistical procedures*

The numerical data were analyzed using resistant measures from exploratory data analysis (Tukey, 1977; Chambers *et al.*, 1983). Boxplots were drawn following Chambers *et al.* (1983), including 95% confidence intervals for the medians estimated based on Hettmansperger & Sheather (1986). The regression lines were calculated using the Ordinary Least Squares (OLS) method ($p = 0.05$) and checked with nonparametric simple regression using Theil's method (Daniel, 1990; Glaister, 2005), provided the distribution of EC was not Gaussian after the Anderson–Darling test. OLS, which is more popular than Theil's method, facilitates the coherence checking of data from future prospections by other teams.

3. Results and discussion

3.1. Field observations

Salada Farrachuela is the only natural wetland found in the *chesas* and is one of the most northern hypersaline endorheic locations in the Ebro Basin. The scarcity of natural stagnant areas in the *chesas* can be inferred from the work of Lucha *et al.* (2008) and from the SDF for the ES2410074 Site of Community Interest. This scarcity is related to the ease of deep percolation favored by the almost vertical dip of the outcropping strata of the Barbastro Gypsum Formation, as shown in the figures published by Lucha *et al.* (2012) and on the geological map by Barnolas (2017). Lucha *et al*. (2008) argued that most of the active subsidence and sinkholes in the *chesas* occur in areas where the water is recharged artificially. This is not the case at Salada Farrachuela, where the intermittent ponding is due only to natural waters, as the *salada* is situated in an area that has never been irrigated. These features accentuate the natural value of Farrachuela, a saline wetland that has been omitted in the official document for habitat protection.

A several-hectometer-long ditch is visible in the aerial photograph of April 20, 1957 (Figure 2A), but not in a previous aerial photograph, taken on August 21, 1946, that is not presented in this article. The ditch is connected with a system of two straight furrows crossing the bottom of the *salada* at almost right angles. When Farrachuela is not flooded or covered by vegetation, these furrows are still visible in the field and in the aerial images (Figure 2A and B). We found no remains of the outlet ditch, probably because of its abandonment and the subsoiling and reiterated plowing of the fields. These works, carried out in years of strong agricultural pressure, were presumably an attempt to drain the wetland.

The soil samples taken in the field were monotonous in terms of their hand-estimated texture, whitish color, and plasticity throughout the four sites sampled. As shown later in this paper, calcium carbonate and gypsum are the predominant components in both Farrachuela and the surrounding *chesas* (Herrero, 1991; Artieda & Herrero, 2003). In contrast, the vegetation seen at Farrachuela is different and reveals the presence of water and hypersaline soil, as supported by our study.

3.2. Plants identified

Our first visit to Farrachuela was in May 1981, on a trip of the Royal Botanical Garden of Madrid across the *chesas* in the Barbastro Gypsum outcrop. On the trip, when descending from the abandoned hamlet of Rocafort on May 2nd, we encountered the Salada Farrachuela, a wetland with shallow salty water in the municipality of Tamarite de Litera (Herrero & Castañeda, 2020). On May 25th, the wetland was covered by a centimetric-deep puffed algal mat, retaining gas.

The plant specimens collected in 1981 and deposited in the Botanical Garden MA were identified as *Hornungia procumbens* (L.) Hayek, *Helianthemum salicifolium* (L.) Mill., *Frankenia pulverulenta* L., and *Lepidium subulatum* L. We also recorded *Phragmites australis* (Cav.) Trin. ex Steud. Table 1 lists the plants collected on July 26th, 2013. At this *salada,* Ferrández Palacio (2008) recorded the tassel grass *Ruppia drepanensis* Tineo ex Guss., a strictly aquatic herb, in addition to two halo-nitrophilous grasses, *Puccinellia distans* (Jacq.) Parl. -probably a misidentification of *P. festuciformis*- and *Polypogon maritimus* Willd., as well as various species from the aquatic algae belonging to the genus *Chara*.

From our observations of the flora at Farrachuela, this saline location cannot be assigned to either of the two saline habitat types: 1420, that is, *Sarcocornetea fruticosi* (Espinar, 2009), and 1510, that is, *Limonietalia* (de la Cruz, 2009), recorded in the SDF for the ES2410074 Site of Community Interest. Both habitats have plant compositions different from that seen at Farrachuela, where *L. subulatum* denotes the gypsophilous nature of the vegetation (Mota *et al.*, 2015).

Table I. Salada Farrachuela in Tamarite de Litera, Aragón, Spain. Sites studied in July, 2013, elevation meters a.s.l., collected plants, and water table depth (cm), electrical conductivity (EC, dS m-1 at 25°C) and pH.

Sampling site	Elevation	Collected plants	Water table			
			18 July			26 July
			Depth	EC	pH	Depth,
TMT1	399.95	*Suaeda spicata* (Willd.) Moq.(1), *Puccinellia festuciformis* (Host) Parl.(2)	110	52.7	7.09	61
TMT2	399.89	*Salsola soda* L.(3)	167	55.8	7.32	31
TMT3	400.00	*S. soda*	105	53.5	6.97	68
TMT4	400.13	*P. festuciformis*	195	*	*	60
TMT5	400.23	*Frankenia pulverulenta* L.	*	*	*	*
TMT6	402.00	*Hordeum vulgare* L.(4)	*	*	*	*
Wild boars rooting pits	≈ 400	*P. festuciformis*	*	*	*	*

(1), green plants; (2), dry plants; (3), in regression; (4), two rowed barley in a cultivated field; * not measured, or does not apply.

3.3. Soil salinity

The most eloquent visual expressions of salinity at Farrachuela are (i) the efflorescence on the soil surface when the *salada* dries up and (ii) the halophilous vegetation. The white efflorescence comprising crystals of gypsum and soluble salts is conspicuous both in the field and in remote sensing images (Figure 2) after the surficial free water disappears. An easy way to quantify the salinity is by determining the EC of the aqueous extract of soil, as a classic comprehensive measure of the ion content of the soil solution (United States Salinity Laboratory Staff, 1954). For the EC to be representative of the stock of soluble salts in the soil, complete ionic dissociation must be achieved, that is, ion pairs must be absent in the extracts. We verified this condition using the two fixed-ratio dilution approach as discussed in Herrero *et al.* (2015).

In this way, the data in Table II were used to establish the regressions between EC1:5 and EC1:10 (Eqs. 1–4 in Table III). Both the OLS and Theil's methods were applied to the 32 soil samples from the *salada,* as well as for these samples plus the one from the conterminous field, that is, a total of 33 samples. The same methods were applied to the samples selected to prepare the saturated pastes, and similar results were obtained (Eqs. 5–8), supporting the representativeness of these samples.

3.4. Directions for future appraisals of the soil salt stock

The coefficients of determination (R^2) of the regressions between EC1:5 and EC1:10 were the same when using both the OLS and Theil's methods, and there were negligible discrepancies in the standard error (S), with a maximum difference of 0.03 dS m^{-1}. We therefore propose the use of the OLS method in these circumstances, as its popularity will facilitate the checking of the coherence of analytical results in future years and the comparisons between samples taken on different dates. According to the rationale in Herrero *et al.* (2015), the high R^2 values in the regressions of EC1:5 over EC1:10 (Table III) denote that the 1:5 extracts are free of either neutral ion pairs or those with other charges. This confirms the adequacy of EC1:5 in expressing the stock of soluble salts in the soil, at least within the EC1:5 ranges shown for Farrachuela in Table III. An increase in R^2 is obtained by including the sample from the conterminous cropped field in the calculations (Eqs. 2, 4, 6, and 8). This increase could be reinforced if future sampling campaigns returned more intermediate and lower EC1:5 and EC1:10 values from the small transitional areas that slope gently toward the surrounding fields, to the NE and SW of the *salada*.

Table II. Electrical conductivity (EC) of the 1:5 and 1:10 extracts (weight/weight), pH, gypsum, and calcium carbonate equivalent (CCE) from 32 soil samples from the sampling sites TMT1 to TMT4 in Farrachuela and one from the conterminous cultivated field, site TMT6.

Site	Depth interval	EC 1:5	EC1:10	pH 1:2.5	Gypsum	CCE	Gypsum + CCE
	cm	dS m^{-1} at 25°C				%	
TMT1	0-25	6.73	4.57	7.72	43.6	27.4	71.0
	25-50	6.39	4.31	7.70	43.8	22.7	66.4
	50-75	7.24	4.69	7.73	40.9	22.1	63.0
	75-100	6.94	4.61	7.79	32.1	26.6	58.7
	100-125	6.89	4.60	7.85	25.5	23.7	49.2
	125-150	6.89	4.61	7.79	16.3	27.6	43.9
	150-175	6.58	4.42	7.88	45.4	20.8	66.2
	175-200	6.23	4.21	7.89	54.5	17.6	72.0
TMT2	0-25	7.44	4.81	8.19	49.6	24.5	74.1
	25-50	7.04	4.62	8.09	35.3	23.5	58.8
	50-75	7.65	5.01	7.99	31.8	25.7	57.4
	75-100	7.72	5.06	7.85	29.0	23.0	52.0
	100-125	7.95	5.05	7.80	19.9	24.3	44.2
	125-150	7.80	5.02	7.67	33.2	21.8	55.0
	150-175	7.57	4.90	7.56	31.8	22.2	54.0
	175-200	7.25	4.71	7.19	30.3	22.9	53.2
TMT3	0-25	7.76	5.11	7.70	36.9	23.9	60.8
	25-50	7.83	5.12	7.68	26.1	26.1	52.2
	50-75	7.65	5.02	7.78	25.5	24.6	50.2
	75-100	7.02	4.68	7.69	27.8	23.9	51.6
	100-125	6.98	4.64	7.73	21.1	23.1	44.3
	125-150	7.25	4.91	7.60	23.3	24.5	47.8
	150-175	6.70	4.57	7.47	30.2	26.6	56.8
	175-200	7.15	4.75	7.34	24.6	25.2	49.8
TMT4	0-25	6.81	4.57	7.66	32.3	25.4	57.8
	25-50	7.46	4.89	7.70	22.0	24.9	46.9
	50-75	7.80	5.05	7.73	19.7	26.7	46.5
	75-100	6.83	4.68	7.73	21.2	25.1	46.3
	100-125	6.48	4.47	7.66	12.2	23.6	35.9
	125-150	7.54	4.97	7.62	19.3	24.9	44.2
	150-175	7.27	4.86	7.49	25.5	25.1	50.6
	175-200	7.04	4.70	7.39	24.7	24.5	49.2
TMT6	0-25	2.31	2.02	7.33	6.4	38.2	44.6

3.5. Spatial variability of the main soil components

The mean gypsum content of the soil at Farrachuela (Table II) is 29.9%. The means for each of the four sampled sites (Figure 3) increase in a regular manner from the ESE to the WNW. A similar pattern is not seen in the other soil parameters studied. The differences in the median gypsum content of the successive pairs of sites, that is, TMT1–TMT2, TMT2–TMT3, and TMT3–TMT4, are not statistically significant (Figure 3), but they show a tendency for some gypsum enrichment at the westernmost end

Table III. Regression equations of the shape EC1:5 = a + b × EC1:10 (dS m-1 at 25°C) with the standard error (S), calculated for n observations by ordinary least squares (OLS) method, and by Theil method using the median of n interceptors.

Method	n	*a*	*b*	R^2, %	S, dS m^{-1} at 25°C	Range of EC1:5, dS m^{-1} at 25°C	
OLS	32	-1.83	1.90	94.6	0.11	6.23 to 7.95	Eq. 1
	33	-1.39	1.80	98.7	0.11	2.31 to 7.95	Eq. 2
Theil	32	-1.74	1.87	94.6	0.12	6.23 to 7.95	Eq. 3
	33	-1.39	1.80	98.7	0.11	2.31 to 7.95	Eq. 4
Only the samples having saturated pastes							
OLS	16	-1.63	1.86	89.9	0.12	6.70 to 7.95	Eq. 5
	17	-1.33	1.80	99.2	0.12	2.31 to 7.95	Eq. 6
Theil	16	-1.54	1.83	89.9	0.15	6.70 to 7.95	Eq. 7
	17	-1.37	1.80	99.2	0.14	2.31 to 7.95	Eq. 8

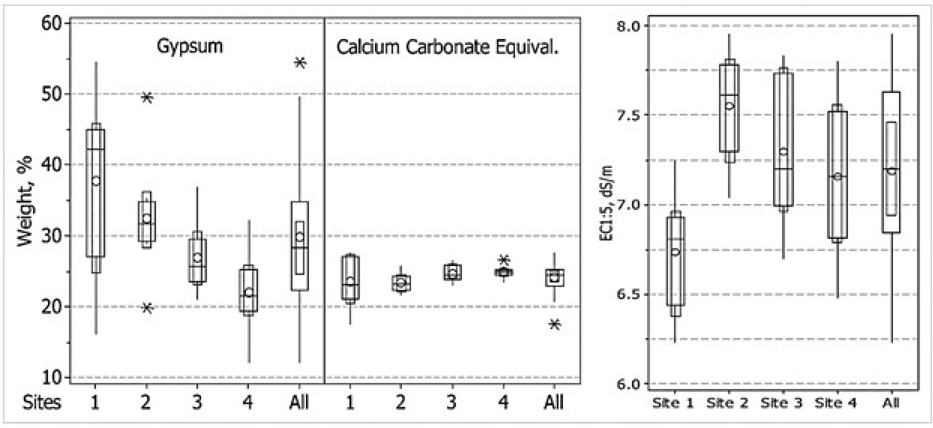

Figure 3. Boxplots for the four sites (TMT1 to TMT4) sampled at Salada Farrachuela, and for these four sites together.

of Farrachuela. The location of Salada Farrachuela in a valley between almost vertically dipping strata could have promoted subsurface runoff and the translocation of soluble materials through the soil and landscape. In this gypsum-rich region, the waters easily become saturated with calcium and sulfate. Moreover, gypsum can be transported in suspension, provided that fine particles of gypsum are the main constituents of the frequent, flour-like, gypsic horizons in the *chesas* (Herrero, 1991; Casby-Horton *et al.*, 2015) (Figure 3).

The differences between the CCE medians are not significant for the four sites (Figure 3). The distribution of CCE means across the four sites suggests an inverse distribution for gypsum, compatible with the supposed gypsum enrichment in the west and the much lower solubility of calcium carbonate than gypsum. The salinity differences (EC1:5) between the sites (Figure 3) may be unrelated to the supposed general flux because soluble salts are subject to the variable short-term displacements of soil water that are associated with the weather.

The mean of gypsum plus CCE is 54.1%. The sum of these two components exceeds half the weight of the fine earth in 62.5% of the samples, that is, the fraction composed by silicic-silicatic material plus organic matter is minor in most samples. The number of samples where this fraction is minor would increase if the soluble salts were also computed. The soil samples from depths of 150–175 and 175–200 cm at site TMT4 were the only samples that contained coarse fragments: 4.2% and 2.3%, respectively.

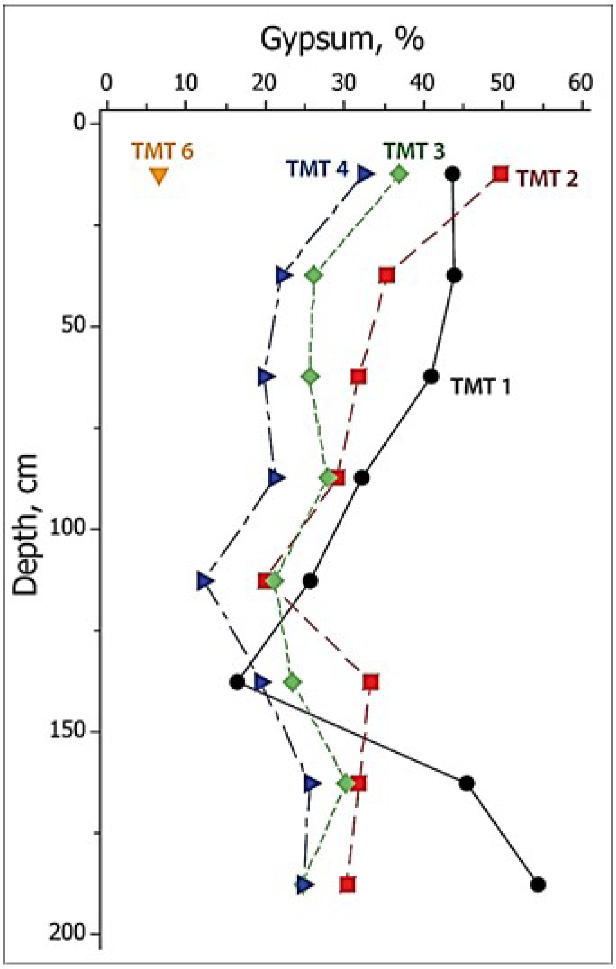

Figure 4. Gypsum content profiles in the soil at sites TMT1 to TMT4 in the Salada Farrachuela wetland, and the gypsum content in the upper layer of the conterminous cultivated field, site TMT6.

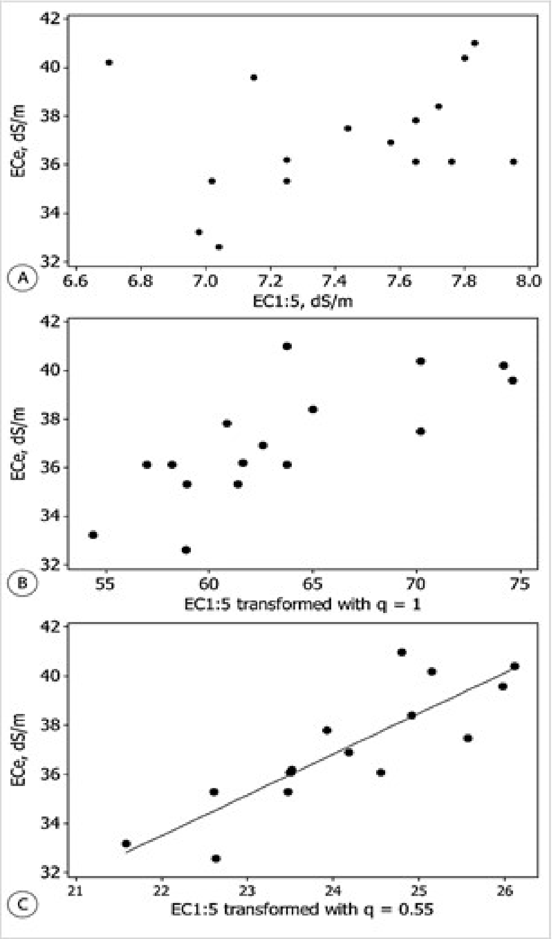

Figure 5. Scatterplots of ECe against: (A) EC1:5; (B) EC1:5 transformed by the plain ratio of the dilutions, q = 1; and (C) by this ratio transformed with q = 0.55.

These modest contents are of low functional relevance, but could indicate that the auger was nearing a consolidated stratum or a layer containing coarse fragments.

A significantly lower EC1:5 occurs at site TMT1 compared with sites TMT2 and TMT3, but not with site TMT4 (Figure 3). These distributions agree with the relative locations of the four sites within the *salada*.

The gypsum content profiles from the bottom of Farrachuela are coherent for the four sites (Figure 4), with an overall decrease in the mean gypsum content from 40.6% in the 0–25-cm layer to 19.7% in the 100–125-cm layer, followed by an increase to 33.5% in the 175–200-cm layer, with the most gypsum-rich sample (54.5% gypsum) being found at the bottom of site TMT1, located downstream in the probable subsurface water flux to the Segarra ravine. The surface of the conterminous site TMT6, corresponding to a cultivated field, had a much lower gypsum content than any of the Salada Farrachuela samples (Figure 4).

3.6. Saturation extracts

The low coefficient of variation, CV = 0.11, of the SPs (Table IV) suggests a fairly homogeneous profile with regard to both composition and particle size distribution. The pH of the 17 saturation extracts (Table II) ranged from 7.8 to 8.4, while for the 33 determinations at a ratio of 1:2.5, it ranged from 7.2 to 8.2. As expected, the 17 soil pH measurements for the saturation extracts (Table IV) were, in all cases, higher than those in the 1:2.5 extracts. The mean of the differences between the two ratios was 0.5 units of pH. The pH measured was in agreement with the absence of carbonate ions in the

Table IV. Saturation percentage (SP, %) of the saturated pastes from the sampling sites TMT2, TMT3, and TMT6, and analytical data of the extracts: electrical conductivity (ECe, dS m^{-1} at 25°C), pHe, ionic concentrations in meq L-1, and sodium adsorption ratio SAR in (meq L^{-1})0.5.

Site	Depth interval	SP	ECe	pHe	Cl$^-$	SO4^{2-}	HCO3$^-$	Na$^+$	K$^+$	Ca^{2+}	Mg^{2+}	SAR
TMT2	0-25	53.0	37.5	8.44	48.7	554.9	2.0	105.9	4.3	17.1	470.7	6.8
	25-50	59.8	32.6	8.39	30.9	427.5	2.0	102.2	3.8	19.5	452.8	6.7
	50-75	60.0	36.1	8.36	35.8	504.2	3.0	108.6	3.4	18.3	501.0	6.7
	75-100	59.4	38.4	8.37	36.7	534.3	4.0	116.0	3.6	18.2	541.7	6.9
	100-125	69.7	36.1	8.32	39.6	549.0	3.0	109.9	3.5	18.7	502.1	6.8
	125-150	55.6	40.4	8.21	40.0	596.8	2.0	129.7	3.4	19.7	618.7	7.3
	150-175	60.5	36.9	8.17	37.0	489.6	4.0	120.4	3.2	19.4	519.5	7.3
	175-200	59.1	35.3	8.17	34.9	426.7	2.0	112.6	3.1	18.0	444.8	7.4
TMT3	0-25	66.7	36.1	8.18	44.4	411.0	1.0	117.5	4.0	18.3	431.4	7.8
	25-50	61.4	41.0	8.26	50.3	604.0	2.0	122.7	3.5	21.1	548.5	7.3
	50-75	62.9	37.8	8.37	46.6	523.8	2.0	117.4	3.2	18.8	495.2	7.3
	75-100	59.6	35.3	8.27	44.5	476.5	2.0	107.7	2.9	18.6	449.5	7.0
	100-125	64.2	33.2	8.26	38.7	436.5	1.0	100.3	3.1	18.4	406.8	6.9
	125-150	58.8	36.2	8.03	38.6	456.0	1.0	99.7	2.7	17.6	431.3	6.7
	150-175	45.1	40.2	7.98	44.6	553.0	2.0	122.8	3.0	21.8	542.5	7.3
	175-200	47.9	39.6	7.92	40.1	506.3	2.0	114.6	2.8	18.2	519.9	7.0
TMT6	0-25	55.2	3.80	7.80	2.7	22.2	2.0	1.9	2.3	21.9	6.2	0.5

Sites TMT2 and TMT3	SP	ECe	pH	Cl$^-$	SO4^{2-}	HCO3$^-$	Na$^+$	K$^+$	Ca^{2+}	Mg^{2+}	SAR
Mean	59.0	37.0	-	40.7	503.1	2.2	113.0	3.3	18.8	492.3	-
Median	60.0	36.5	8.26	39.8	505.3	2.0	113.6	3.3	18.5	498.1	6.7
Minimum	45.1	32.6	7.92	30.9	411.0	1.0	99.7	2.7	17.1	406.8	6.0
Maximum	69.7	41.0	8.44	50.3	604.0	4.0	129.7	4.3	21.8	618.7	7.6

saturation extracts. All the pH values were > 6.5, agreeing with the clay flocculation in all the soil dilutions assayed.

The poor coefficient of determination of the regression of ECe against EC1:5 (R^2 = 8.5%) shown in Table V, seen commonly in gypsiferous soils (HE *et al.*, 2012; HERRERO *et al.*, 2015), precludes the estimation of ECe from EC1:5.

The coherence of the ECe and EC1:5 measurements was ascertained by transforming EC1:5 by the quotient between the dilutions of the two extracts, SP and 1:5, to an empirical power (q) according to SUMNER *et al.* (1998) and HERRERO *et al.* (2015). The scatterplots in Figure 5 illustrate the results of two EC1:5 transformations that include SP, and how these generate a better fit, which is useful in checking the coherence of the EC measurements (Figure 5).

The coefficients of determination (R^2) obtained with regression equations of the shape ECe = a + b × EC1:5 × $(500/SP)^q$ for the 10 checked values of q are shown in Figure 6. The values of ECe and EC1:5 were coherent, as shown by the distribution of the coefficients of determination in Figure 6. The two variables did not correlate (R^2 = 8.5%) when EC1:5 was not transformed by SP, that is, q = 0, but when transformed by the plain ratio of the dilutions, that is, q = 1, the result was R^2 = 58.2%. The maximum R^2 = 74.3% was achieved with this ratio raised to the power q = 0.55, a value comparable with that in previous studies by HERRERO (2008:143) of four *saladas* in the Ebro Basin whose q values ranged from 0.5 to 0.9, and q = 0.65 as reported by HERRERO *et al.* (2015) for 359 soil samples from 10 Monegros *saladas* (Figure 6)

CO_3^{2-}, NO_2^-, and PO_4^{3-} ions were not detected in the saturation extracts, with the exception of 0.48 meq L^{-1} of NO_2^- in the surface sample from site TMT1. Other ions (F^-, Br^-, NO_3^-, PO_4^{3-}, CO_3^{2-}, and NH_4^+) occurred at concentrations of < 0.25 meq L^{-1} in a few samples. This content was deemed negligible and is not presented in Table IV, which

Table V. Regression equations of the shape ECe = a + b × EC1:5 (500/SP)q with the standard error (S) calculated for 16 soil samples by ordinary least squares (OLS) method, and by Theil method using the median of n interceptors.

	OLS				Theil			
q	*a*	*b*	R^2, %	S, dS m^{-1}	*a*	*b*	R^2, %	S, dS m^{-1}
0	22.80	1.92	8.5	2.43	11.02	3.47	8.5	2.71
0.55	-2.96	1.66	74.3	1.29	-2.01	1.62	74.3	1.32
1	17.32	0.31	58.2	1.64	0.32	0.32	58.2	1.84

Table VI. Regression equations of the shape ECe = a + b × EC1:5 (500/SP)q with the standard error (S) calculated for 16 soil samples by ordinary least squares (OLS) method, and by Theil method using the median of n interceptors.

Method	*a*	*b*	R^2, %	S, meq L^{-1}	Range of (an+cat)/2, meq L^{-1}	
OLS	-213.1	21.59	76.1	30.66	502.4 to 705.2	Eq. 9
Theil	-198.8	21.29	76.1	32.73		Eq. 10

Table VII. Some statistical parameters of the determinations in soil samples from Salada Farrachuela.

Number of samples	Determination	Mean	Minimum	Median	Maximum
32	EC1:5, dS m^{-1}	7.18	6.23	7.20	7.95
32	EC1:10, dS m^{-1}	4.76	4.21	4.71	5.12
32	Gypsum, %	29.86	12.20	28.40	54.50
32	CCE, %	24.20	17.60	24.50	27.60
32	Gypsum + CCE	54.06	35.90	52.10	74.10
16	SP	58.98	32.60	59.70	69.70

shows the concentrations of only the major ions. These low concentrations point to insignificant pollution by fertilizers from the surrounding cultivated fields. Sulfate, magnesium, and sodium dominate, with a mean content of 503, 492, and 113 meq L^{-1}, respectively, followed by chloride and calcium. The modest K^+ content seems reasonable for this unfertilized soil.

The EC of fixed-ratio dilution extracts, as is the case for EC1:5 or EC1:10, is a proxy accepted commonly for the soil salt stock, a key feature to track the ecological status of the soil by following the changes in the salt content over time (Bower & Wilcox, 1965). However, saturation extracts are often necessary to directly compare saline stress on organisms in different areas, especially in agriculture, where ECe is the standard for expressing the plant's tolerance to soil salinity. A graphic synopsis of the composition of the extracts can be obtained easily

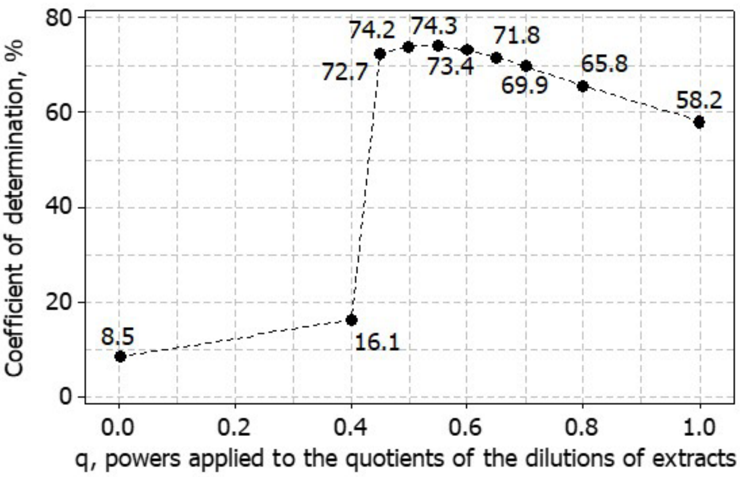

Figure 6. Coefficients of determination (R^2) of the regressions ECe = *a* + *b* × EC1:5 × $(500/SP)^q$ for arbitrary values of q.

by drawing a Piper diagram from Table IV. We do not present such a diagram to avoid misinterpretation, provided that our data are for saturation extracts and neither for the phreatic water nor for the free water that covers the bottom occasionally. Moreover, the numerical data in the table make it easy to detail the future detection of possible drifts in the ionic composition.

4. Conclusions

To the best of our knowledge, this article is the first report of a saline wetland located on the Barbastro Gypsum Formation, its vegetation, and soil composition. The high gypsum content is a feature shared with the soils in the surrounding gypseous lands. The presentation of gypsum, however, differs from that seen in the typical *chesas* soils, as does the salinity, which, together with the wetness and the occasional flooding, govern the ecology of Salada Farrachuela. The soil salinity in Farrachuela is quantified easily using EC1:5. This parameter can be used as a quick test for future assessments of salinity stability or change, a prime factor in the ecology of the *saladas*. The regression of ECe against EC1:5 results in an acceptable coefficient of determination only if EC1:5 is transformed using the SP.

The plants that grow in the *salada* are adapted to both the hydric conditions and salinity. So, the data presented could be used to establish a baseline for the conservation of this valuable biotope, allowing it to be monitored at an adequate spatial and temporal scale. Sulfate, magnesium, and sodium are by far the most abundant ions in the saturation extracts. This composition contrasts with the *saladas* of Monegros, where the chloride and sodium concentrations are higher than those at Salada Farrachuela.

The Farrachuela wetland hosts a valuable biotope that went unrecorded in the official description of ES2410074. Updating the SDF for Salada Farrachuela is crucial to provide information that will assist decision makers and ensure that the Natura 2000 network is fully taken into account in environmental and agricultural policies. Hopefully, subsequent research will examine specific aspects of geology and hydrology, including seasonal changes, to illustrate the ecology of Farrachuela.

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