Temporal changes in soil salinity at four saline wetlands in NE Spain

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Juan Herrero* and Carmen Castañeda

Estación Experimental de Aula Dei, CSIC, Ave. Montañana 1005, 50059 Zaragoza, Spain

Corresponding author. Tel.: +34 976 716 152; fax: +34 976 716 145.

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E-mail address: jhi@eead.csic.es (J. Herrero)

ABSTRACT

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The knowledge of soil salinity and the temporal changes of its distribution in the soil profiles can give warnings for the protection of saline habitats. This study described and compared the salinity profiles of the soils from four hypersaline wetlands at inland, ill-drained depressions in NE Spain, which were sampled throughout the year in 1979-1980 and 1999-2000, and differed in land use. The halophytic communities dictated the location of sampling sites. After the saturated pastes of 404 soil samples were prepared, the electrical conductivity of the extracts (ECe) and the concentrations of major ions were measured, and additional supplementary analyses were performed. A subset of the samples was titrated for calcium carbonate equivalent and gypsum content. ECe and ion concentrations calculated for synthetic soil layers facilitated the comparisons of the vertical distribution of soil salinity among dates, depths, and sites. The shape of the mean ECe profiles over all sampling dates indicated moderate differences between the two wetlands closest to each other, Plan de Callén (PC) and Paúl de Almuniente (AL), which had similar ($< \sim 10$ dS m⁻¹) ECe. In contrast, the ECe profile at Paúl de Anzano (AN) ranged from 40 dS m⁻¹ to 50 dS m⁻¹ in the upper meter of the soil, which decreased steadily to 20 dS m⁻¹ at a 2-m depth. At Saladar de Agustín (AG), ECe was much higher and the profile had the opposite shape, ECe ~ 55 dS m⁻¹ at the surface and > 80 dS m⁻¹ at an 80-cm depth. The shape of ECe profiles at AL, PC, and AG was rather stable over time, contrasting with the measured desalination of the soil at AL after its conversion into a rice paddy. The changes in the sodium adsorption ratio (SAR) in the soil profiles at AN, PC, and AL are indicators of the potential extremes in the hydric behavior of the soils. At AG, the mineralogical clays are a minor component of these gypseous soils; therefore, the SAR, only, was used as a measure of the relative concentrations of Na⁺ versus Ca²⁺ plus Mg²⁺. The median SAR of all AG soil samples did not differ significantly among sampling sites or dates. The shorter sampling depth intervals used in 1979-80 were responsible for the greater spread in the distribution and the increase in extreme SAR values compared to the data collected in 1999-2000.

Keywords: halophytes; hypersaline wetlands; salinity profile; soil salinity; Ebro Valley

1. Introduction

Environmental concerns have increased society's appreciation of saline wetlands, which have been disdained, historically, because they lacked agricultural value. In the 20th C, scientists such as Aramburu (1904), Dantín (1911, 1929, 1942), and Quirantes (1965) stressed the interest of the athalassohaline wetlands of NE Spain. The legal protection of those wetlands, which was triggered by the conservation of birds, occurred much more recently (Ramsar Convention Secretariat, 2010; Pérez-Bujarrabal, 2014). Endemic or rare halophytes and other organisms designated by the Commission of the European Communities (1991) are now protected by Spanish Law. Hence, studies of soil salinity, which have focused on the feasibility of cash crops, have to be expanded to include aspects associated with the protection of saline ecosystems.

A monitoring at an adequate spatial and temporal detail ought to be undertaken by the Agencies in charge of protection as a first step for establishing protocols for both dissuasion and law enforcement when facing activities disturbing the soil. These issues are out of our duties, but the methods and data displayed in this article linked with other techniques pave the way for improving the management of the saline protected habitats. The research on the adaptation of electromagnetic induction (EMI) methods for agricultural purposes in wetlands is promissory. EMI has been used in paddy soils for mapping salinity, e.g., Li et al. (2013) or Herrero and Hudnall (2014), or other soil features (Islam et al., 2011), but a baseline from direct measurements and the unavoidable calibrations of EMI methods will need soil sampling and lab analyses.

The lateral and vertical anisotropy of soil salinity, and the intrinsic temporal fluctuations in salt content, laterally and throughout the soil profile, caused by the displacement of soluble salts inside the soil, makes it challenging to study. Often, reports of soil salinity in saline ecosystems are based on averages for an arbitrary soil depth, and do not provide information about the vertical distribution of salinity in the pedon. Most published studies using soil sampling are based on a single date and are limited to the electrical conductivity of the soil saturation extract (ECe). Fewer studies have examined the temporal changes in the salinity profile. Early depictions of the vertical distribution can be found for four pedons in Servant (1969). This author formalized the concept of salinity profile (Servant, 1973) during the survey with agricultural purposes of soil salinity in a coastal environment, and measured (Servant, 1971, 1973) ECe and ionic composition in soil samples collected bimonthly for one year at several saline sites. At an inland area, Lavado (1978) measured ECe, pH, and sodicity in soil samples collected from one saline site for two years, and Lavado and Taboada (1988) measured ECe in soils collected from the surface horizon at one site on 38 different dates over four years, but less frequently at deep horizons. McBratney et al. (2000) emphasized the importance of identifying the vertical variation in soil attributes within a profile, and Li et al. (2013) discussed the importance of understanding the vertical variation in soil salinity and the reasons why there have been few three-dimensional studies of soil salinity.

The soil salinity of protected wetlands, which often is unknown, must be maintained if the conservation of the ecosystems is to be achieved. The knowledge of soil salinity is also important if land is

75 to be used for agriculture. The early detection of changes in salinity is favored by the monitoring of
inundation episodes, soil moisture, and fluctuations in the ionic content of the soil solution. Yet, early
detection of undesirable changes requires the recording of the temporal variability in soil salinity. However,
under arid climates most saline wetlands undergo intermittent inundation, often with scattered saline pools
or with oozing water, and their almost permanent and variable soil moisture make impractical the methods
80 used in the permanently flooded wetlands commonly found in temperate-humid environments.

The Central Ebro Valley, NE Spain, has a semi-arid climate and broad irrigation districts and
additional irrigation systems are being built. The region illustrates the need for detecting the changes in
saline wetlands to monitor the effects of irrigation or other ongoing and future human activities. When
trying to quantify changes, the temporal lapse between measurements must be defined because the
85 distinction between disturbed and undisturbed wetlands in Spain is hazy due to the varied and old land uses.
As an example of the long history of irrigation (Butzer et al., 1985), the Romans left inscriptions in the
Ebro Valley about irrigation canals and communities of irrigators from 87 B.C. (Fatás and Beltrán, 1997;
Beltrán, 2006).

In the region, 149 athalassohaline wetlands have been inventoried (Conesa et al., 2011; Castañeda et
90 al., 2013), and an assortment of techniques have been used to study the hydrology (Castañeda and Herrero,
2005), the changes in facies (Castañeda et al., 2005), the degradation of wetlands (Castañeda and Herrero,
2008; Domínguez et al., 2013a), and their categorization based on geological and vegetation features
(Castañeda et al., 2013).

This study is based on research started in 1979 (Herrero, 1982). Herrero (2008) collected ECe and
95 complementary data to quantify the changes in soil salinity over 20 years, and Herrero and Castañeda
(2013) quantified the relationships between soil salinity and the presence of five species of halophytes. That
study focused on the conditions for plant life, and documented the ECe, SAR, and the concentrations of
major ions for the soils of each halophytic species, but did not include the temporal changes in soil salt-
affection, i.e., salinity and sodicity, or the salinity profiles; i.e., how salinity is distributed vertically in the
100 soil, and how the salinity profiles vary seasonally or change over time.

The objectives of this study were to (i) quantify the temporal changes in soil salt-affection at four
athalassohaline wetlands that differed in geological setting and land use, and (ii) describe the temporal
variations in the vertical distributions of soil salinity and sodicity.

105 **2. Materials and methods**

2.1. Study area

The four athalassohaline wetlands studied were (from north to south) Paúl de Anzano (AN), Plan de
Callén (PC), Paúl de Almuniente (AL), and Saladar de Agustín (AG), in the Central Ebro Valley, Spain
(Fig. 1). The elevation declines from north (500 m a.s.l.) to south (328 m a.s.l.). The underlying materials
110 are saliferous Miocene horizontal strata of lacustrine origin. Alternating sandstone and lutites predominate
at AN, PC, and AL, and alternating limestone, lutites and gyprock are predominant in AG. Outcrops of

saliferous Keuper and lacustrine Miocene lutites (Barnolas, 1992) a few km north of AN are the source of salty arroyos and runoff.

The climate is Mediterranean and, at the study sites, aridity was lowest in the north (AN) and highest in the south (AG). Mean annual temperature ranged from 13.7 °C to 14.4 °C and annual rainfall ranged from 550 mm to 388 mm. A water deficit occurred from February to November, and the annual mean deficit ranged from 536 mm at AN to 653 mm at AG. The saliferous geological materials of the Central Ebro Valley provide the wetlands with persistent shallow saline groundwater. The soils at the wetland bottoms are permanently wet or saturated, with episodic standing water. In addition, the PC wetland was irrigated in the recent past, and the AL wetland was a rice paddy, which had been inundated annually. At PC and AL, the irrigation water was non-saline ($EC = 0.33 \text{ dS m}^{-1}$, $SAR = 0.9$) and came from the Pyrenees, more than 100 km distant. Mean electrical conductivity of the groundwater at PC, AL, and AG was 8.28 dS m^{-1} , 2.28 dS m^{-1} , and 102.84 dS m^{-1} , respectively (Herrero and Castañeda, 2013). At PC and AL, the parent material is “hojaldre,” a varved Quaternary formation of micritic silty layers that alternate with clayey layers of mica and chlorite (Herrero et al., 1989; Rodríguez et al., 1990). Four soil profiles at AN, AL, and AG were described in Herrero (1982) and one at PC in Vizcayno et al. (1995). Based on the criteria of Soil Survey Staff (2014a), the soils were Typic Aquisalids (AN and AL), Oxyaquic Xerofluvent (PC), and Gypsic Aquisalid (AG).

For details on climate and land use at each of the wetlands, see Herrero and Castañeda (2013). Plant inventories by Herrero (1982) indicated that the halophytes *Suaeda vera* Forssk. ex J.F. Gmel., and *Arthrocnemum macrostachyum* (Moric.) Moris in Moris & Delponte were the only perennial plants at the bottoms of the wetlands. The latter was present at AG, only, and *S. vera* was present at all of the saline depressions. *Artemisia herba-alba* Asso, *Puccinellia festuciformis* (Host) Parl., and *Salicornia ramosissima* Woods were the other predominant plants at the wetlands. During the studied period, the plant composition has remained the same at AN, PC, and AG, but the AL wetland was leveled and then used for irrigated agriculture within the studied period.

2.2. Soil sampling

The presence of halophytes dictated the selection of sampling sites within each wetland as sketched in Fig. 2. In 1979 and 1980, samples were collected in spring, summer, and winter. In subsequent sampling years (1985, 1999, and 2000), the seasonal distribution of soil sampling detailed in Herrero and Castañeda (2013), was influenced by weather and labor availability. Overall, 404 soil samples were collected at 12 sampling sites, 386 samples from 52 auger holes (mean sampling depth = 105 cm), and 18 samples from four pits. At each site, the augerings that were repeated were within 2 m of the remains of the initial pit or auger hole, an acceptable distance for measuring temporal changes in soil salinity (Herrero et al., 2011). Herrero and Castañeda (2013) provide details about the sampling sites and dates, validated the analyses, and discussed the results.

At **Paúl de Anzano (AN)**, an ~ 65-cm-high erosional escarpment separated two flat surfaces. The two sampling sites were ~ 80 m apart, on the upper (AN3) and lower (AN4) level, respectively. Since the start

of the study, *S. vera* (AN3) and *A. herba-alba* (AN4) have predominated in the plant community (Herrero, 1982; Herrero and Castañeda, 2013). At **Plan de Callén (PC)**, the two sampling sites were ~ 15 m apart within a plot left abandoned for years because of the nil yields from the impervious soil. The plot, which was surrounded by sprinkler-irrigated plots and rice paddies (Fig. 2), was not flood-irrigated between the years in which the soils were sampled, but a small area received experimental sprinkling in the summer of 1985. Like most of the plot, the PC1 sampling site was bare; however, the PC2 site was drilled near one of the few patches of *Puccinellia festuciformis*, which was near a drainage ditch (Fig. 2). Augerings were performed at the beginning of the irrigation season, before the neighboring paddies were inundated. At **Paúl de Almuniente (AL)**, one site (AL0), which was sampled from a pit, was in an uncultivated plot that had mature *Suaeda vera* shrubs and a continuous bryophytic stratum. Two other sites with repeated sampling were in a plot 800 m away: AL1 was in an area that had few *S. vera*, and AL2 was 15 m away in a stand of annual halophytes, *Salicornia ramosissima* and *Parapholis* sp. After soil samples had been collected in 1979-80, that plot was restructured for use as a paddy, and all vegetation in the plot was removed. After the conversion, on March 12, 1985, we sampled a new site (ALx) on the leveled wetland which was between AL1 and AL2. Both AL1 and AL2 sites were sampled again in 1999-2000. At **Saladar de Agustín (AG)**, the presence of impenetrable materials limited the depths to which the auger could reach at all the four sampling sites located on differentially vegetated zones (Fig. 1).

To achieve equal representation among the dates and sites in the study, the comparison of soil salinity in the four wetlands was based on the samples collected from the 52 auger holes, only. The 385 ECe measurements from the 386 samples collected by augering were used to generate 258 synthetic ECe values for 20-cm-thick layers. These values, calculated with Slices software vers. 1 (<http://hdl.handle.net/10261/60892>), enabled the construction of synthetic profiles (Herrero and Pérez-Coveta, 2005) by assigning the weighted values of the ECe or Cations to 20-cm depth increments.

2.3. Laboratory analyses

Laboratory analyses were based on the aqueous extract of saturated paste (United States Salinity Laboratory Staff, 1954). The electrical conductivity (ECe, dS m⁻¹ at 25°C) was measured in and the major ions were titrated from the saturation extracts from 385 samples taken by auger and 18 more by pits. The sum of the concentrations of the major cations (Cations, meq L⁻¹) except K⁺, which was assumed negligible in hypersaline soils (Hernández-Bastida et al., 2002; Herrero and Castañeda, 2013), was used as a measure of the salt content in the soil solutions.

In the field, gypsum was identified as a major soil component at AG, and thermogravimetry per Artieda et al. (2006) was used to titrate gypsum from 56 soil samples collected at this wetland, and 40% gypsum was used as threshold for high-gypsum soils according to Casby-Horton et al. (2015). Gasometry was used to measure the calcium carbonate equivalent of the soil samples.

The data were analyzed using resistant measures from exploratory data analysis (Tukey, 1977; Chambers et al., 1983). Boxplots were drawn following Chambers et al. (1983, page 21) and included 95%

confidence intervals (CI) for the medians, which were estimated based on Hettmansperger and Sheather (1986). The regression lines were calculated using the Ordinary Least Squares (OLS) method ($p = 0.05$).

2.4. Temporal changes in soil salt-affection

2.4.1. Salinity profiles

The synthetic profiles of ECe and Cations from multiple dates at sampling sites were collated. We did not calculate the synthetic profiles for the saturation percentage (SP) of the soil paste, pH, and sodium adsorption ratio (SAR) because these magnitudes are non-additive.

2.4.2. Temporal changes in soil salt-affection

Temporal changes in soil salt-affection were quantified by calculating single values of ECe and SAR for each sampling site and date, to a common sampling depth (D , cm) at each wetland. The comparable ECe was calculated by weighting the ECe of each soil sample by its depth interval, up to D (Herrero and Pérez-Coveta, 2005); i.e., ECe_{100} if $D = 100$ cm. To quantify the soil sodicity at each sampling site and date, we calculated the median, maximum, and minimum SAR from the samples collected down to D ; i.e., SAR_{100} , SAR_{max100} , and SAR_{min100} if $D = 100$ cm. At AN, PC, and AL, D was = 100 cm or, in three cases, the maximum depth within 100 cm (Herrero and Castañeda, 2013, Table 1). At AG, the augerings had to be shallow; therefore, to include all of the sampling dates, $D = 40$ cm; which was biologically relevant at AG given the rooting depths of perennial plants in neighboring saline wetlands (Badía et al., 1988). To compare the seasonal variation between the two sampling campaigns, a day number was assigned to each sampling day based on conventional origins at January 1st of 1979 and 1999 for the sampling campaigns of 1979-1980 and 1999-2000, respectively; and at January 1st of 1985 for the samplings of this year at PC and AL. The single values of ECe and SAR were plotted against day number.

2.4.3. Salinity of soil saturation extracts.

The decimal logarithm transformations of ECe and ionic contents proposed by Marion and Babcock (1976) are linearly correlated at the sampling sites (Herrero and Castañeda, 2013). Similarly, in the present study, we calculated the OLS regressions of $[\log_{10} \text{Cations}]$ on $[\log_{10} \text{ECe}]$ for the synthetic values at each of the four wetlands. The bulk soil salt-affection was quantified by computing single ECe and SAR values for each sampling site and date. In addition, we present ECe profiles drawn based on the synthetic values for soil layers of equal depth calculated using the method of Herrero and Pérez-Coveta (2005), and several examples of cationic profiles that were calculated from the synthetic layers of the ionic contents of the saturation extracts. The synthetic profiles allowed us to compare the vertical distribution of the measurements of soil salinity at multiple sites and dates.

3. Results

3.1. Coherence of analytical results

ECe was most strongly ($r > 0.95$) correlated with Cl^- , and was significantly correlated with Mg^{2+} , Na^+ , and SO_4^{2-} , in the two sets of analytical determinations made at different labs (Table 1). Cl^- was strongly correlated with the concentrations of other ions, and the concentrations of Mg^{2+} and SO_4^{2-} were strongly correlated ($r = 0.90$, $r = 0.96$). For the soil samples, collectively, the coefficients of determination for the concentrations of the major cations and anions regressed on ECe using decimal logarithms (Marion and Babcock, 1976) were 98.3% and 97.6% for the two sampling campaigns, respectively (Herrero and Castañeda, 2013, Table 4), which indicated that ECe was not linearly correlated with the salt content of the extracts from these hypersaline soils. Similarly, the coefficients of determination for the decimal logarithms of the synthetic ECe and ionic concentrations were high (Table 2). The mean SP in samples collected in 1979-1980 was 45.4%, and in 1999-2000 it was 41.1%, and the medians were 46.5 SP and 41.0 SP, respectively.

3.2. Temporal changes in the mean ECe and median SAR

Paúl de Anzano (AN) has remained unplowed and used for grazing sheep since antiquity. Fig. 3 shows the ECe100 variation along the different sampling sites and dates. The median SAR100 of the soil samples at AN3 was 110.5 and 76 in the first and second sampling campaign, respectively, and 53 and 30 in the samples at AN4 (Fig. S1 in Appendix A). The temporal changes in soil salt-affection are illustrated by Fig. 4.

The plot at **Plan de Callén** (PC), which was almost bare soil, did not receive surface runoff from the adjacent lands, but became ponded, even after light rains, which lead to plantules being scalded when it occurred in summer. Table 3 displays ECe100 and SAR100 at PC1 and PC2 in the two sampling dates, and Table 4 collates the regression equations calculated for the extracts of saturation from PC with the equations calculated for the district where PC is located. At PC, the soil saturation extracts had a median SAR = 126 (range = 33 – 311) and mean ECe = 10.1 dS m^{-1} (range = 3 dS m^{-1} – 27 dS m^{-1}).

Paul de Almuniente is the only wetland in the study that underwent a radical anthropogenic change in the interval between the sampling campaigns, when the land was re-leveled and converted into a rice paddy. In 1979-1980, before the conversion, ECe100 at the AL1 and AL2 ranged from 25.2 dS m^{-1} to 44.6 dS m^{-1} (Fig. 5), while SAR ranged from 39 to 188 in 1979-1980, and was < 3 in 1999-2000 (Fig. S2 in Appendix A). The changes in ECe100 and SAR100 between the first and the last sampling campaign are indicated by the dashed arrows in Fig. 6.

Saladar de Agustín, in the interval between sampling campaigns was not affected by the new irrigation system in the region. At AG, for the two sampling campaigns combined, mean ECe40 = 62.6 dS m^{-1} (range = 44.0 dS m^{-1} at AG8, to 77.3 dS m^{-1} at AG5) (Table 5). Fig. 7 shows the values of ECe40 in the augerings for each sampling day.

Gypsum, a ubiquitous mineral at AG, was present in all of the soil samples from that wetland. Mean percentage gypsum in 56 samples was 62% (range = 10% - 88%); 46 samples had > 40%, i.e., high-gypsum soil (Soil Survey Staff, 2014a), and 25 had $\geq 75\%$ gypsum. In the 54 samples in which both gypsum and calcium carbonate equivalent were measured, the combined mean was 69% (range = 22% - 93%); 44 samples had > 50% and 29 had > 75%.

At AG, in 122 samples collected by auger, median SAR = 28 (CI = 27.0 - 29.3) (Fig. 8). In 1979-1980 and 1999-2000, the mean depth interval of the soil samples was 9.86 cm (CV = 20.7%, n = 70 soil samples) and 12.92 cm (CV = 41.7%, n = 52), respectively.

3.3. Vertical distribution of soil salinity

The conditions at the four wetlands during the studied period were heterogeneous; therefore, central tendencies or other statistics were not calculated for the individual layers of Fig. S3 in Appendix A. This Figure shows that for the four wetlands combined, ECe was highest at the surface, with a median of 45.4 dS m⁻¹ for the two shallowest layers. One reservation about this Figure is the limited depth of samplings at AG. At AN and PC, where the sampling sites were sufficiently deep, ECe decreased with depth, and the median ECe of the two deepest layers was 17.8 dS m⁻¹ (Fig. 9).

Sampling depths at AN were deeper than they were at the other wetlands because augering was largely trouble free, although dry, compact soils could be impenetrable beyond a point on some sampling days (Fig. 9). At PC and AL, the auger reached supersaturated horizons, which it could not retain because they were in a dispersed state due to their sodicity, and to the fabric and mineralogy of hojaldre. At AG, the auger met an impenetrable material, which could be barely penetrated. Those physical features of the soils were reflected in the differences in the mean depths of the auger holes at AN (151 cm), PC (172 cm), AL (119 cm), and AG (63 cm). At the four wetlands, the vertical distributions of ECe were multimodal in some of the synthetic layers, which were derived from specific samplings at different sites and/or dates (Fig. 9). Fig. 10 is a summary diagram of the salinity profiles computed from all the samples, i.e., taken by auger and by pits. The ECe and Cation profiles had similar shapes, but the ECe profiles provided the best means of visually discriminating between different dates; therefore, those are presented and discussed throughout the article.

3.4. Variation in the salinity profiles at each wetland

For **Paúl de Anzano (AN)**, Fig. 11 shows the ECe profiles for 20 cm-thick synthetic layers calculated from the auger samples for the six sampling dates.

At **Plan de Callén (PC)** with the inundation of the neighboring paddies and the irrigation in the conterminous plots in 1985, raised the water table in the plot from a mean depth of 140.7 cm in the non-irrigation season to a depth of a few decimeters in the irrigation season, with artesianism at the floor of the drainage ditch. Table 6 shows some statistics for the composition of the saturation extracts, and Fig. 12 shows the salinity profiles.

At **Paúl de Almuniente (AL)**, sampling depths were variable because occasional water supersaturation and the dispersed state of the hojaldre materials prevented the auger from retaining samples from these soils. The salinity profiles AL1 and AL2 are depicted in Fig. 13.

At **Saladar de Agustín (AG)**, the impenetrable materials limited the depths reached by the auger, as shown by the depth of the synthetic profiles in Fig. 14.

4. DISCUSSION

4.1. *The studies on temporal changes of soil salinity*

A large literature is available on the monitoring of saline wetlands by remote sensors. Some of these methods allow synchronic and quick studies over broad areas but do not inform about the vertical distribution of salinity. Moreover, these methods do not detect directly soil salinity, because the response of the sensors is mediated by vegetation cover, efflorescences, soil moisture, or other variable factors.

Proximal sensing, especially electromagnetic induction (EMI) has been used mainly in agricultural lands but the depiction of the saline profile is still in a developing stage. EMI techniques have also practical shortcomings in muddy areas with shallow water tables as are our wetlands. Field studies are needed for calibration of both proximally and remotely sensed data (Metternicht and Zinck, 2003), but also to obtain unquestionable evidences for environmental warnings or for law enforcement.

Li et al. (2013) remarked that little literature is available about the tridimensional variability of soils. This is especially true for saline wetlands. In the case of our study area the novelty of the results we have obtained hampers their consideration in regard to the international or the local literature. Thus, the discussion on the saline profiles and the temporal changes of soil salinity in these wetlands is based in our own works. Hopefully the presented methodology and the varied settings of the four studied wetlands will inspire similar studies in other wetlands around the world.

4.2. *Coherence of analytical results*

A comparison of the SP of samples from successive samplings of the same soil is a basic precaution for detecting bias in the endpoint of the saturation extract in samples prepared in different labs. The difference between the mean SP in samples collected in 1979-1980 and 1999-2000 was within the allowable 5% (Soil Survey Staff, 2014b, page 265), and the median SP did not differ significantly.

The correlations between E_{Ce} and the concentration of individual ions in the extracts, and between these ions, were similar for the different labs (Table 1). This is a support of the coherence of the analytical procedures followed with the extracts from 1979 to 1985 against the extracts from 1999-2000. If new samples are collected or new analyses are performed, these correlations can be used to determine whether an indirect estimate of a specific ion is worthwhile.

4.3. *Temporal changes in the mean E_{Ce} and median SAR*

On all of the sampling dates at **Paúl de Anzano**, the soil which was on the lower surface (AN3), the E_{Ce}100 was higher; i.e., more saline, than it was the soil at AN4 (Fig. 3). At AN3, mean E_{Ce}100 was 62.6

dS m⁻¹ and 51.4 dS m⁻¹ in the first and second sampling campaign, respectively. At AN4, mean ECE₁₀₀ was 25.8 dS m⁻¹ and 13.6 dS m⁻¹ in the two sampling campaigns. Thus, ECE₁₀₀ decreased ~ 11.7 dS m⁻¹ at the two sites in 20 years, and the difference between the most (AN3) and the least (AN4) saline soil remained almost constant at ~ 37.3 dS m⁻¹. Differences between AN3 and AN4 ranged from 58.7 dS m⁻¹ in April 1979 to 26.8 dS m⁻¹ in February 1980. The differences between the two sites in minimum, mean, and maximum ECE₁₀₀ were similar in the two sampling campaigns, about 39.1 dS m⁻¹. Several factors might have caused the decrease (11.7 dS m⁻¹) in ECE at AN; e.g., previous weather, fluctuations in the water table, saline surface runoff caused by saliferous materials outcropping in the upper landscape positions, and the state of the drainage ditch (Fig. 2), which was cleaned occasionally. Most of that information is unavailable for the period covered by the study: therefore, it cannot be confirmed that the changes proceeded continuously over the 20-yr period.

At AN3 and AN4, the variations in median SAR, and their distinct quantitative difference in sodicity were similar on all sampling dates (Fig. S1 in Appendix A). Few of the differences between AN3 and AN4 were meaningful as indicators of the dispersion state of the soil because all median SAR and most individual SAR values were much higher than the classical threshold of SAR for sodic soils (13).

The changes in salt-affected (Fig. 7) at AN3 and AN4 differed slightly, even though the two sites were only ~ 80 m apart. AN3 was in the lower position and was more strongly influenced by the saline water table than was AN4, and often was flooded by surface runoff that came from the upper fields, which were used to grow rainfed, salt-tolerant barley. Soil conditions for *S. vera* (AN3) and *A. herba-alba* (AN4) were distinct (Fig. 4). At AN3, the representation of SAR₁₀₀ against ECE₁₀₀ values from each sampling clustered the sampling campaigns, which suggested an overall reduction in salt affection. At AN4, the differences in SAR between the two campaigns was less distinct than it was at AN3, although the two clusters of the samples from AN4 points out that salt affection decreased slightly. The data from AN3 were more dispersed than were those from AN4 (Fig. 4), which suggested a linear relationship between SAR₁₀₀ and ECE₁₀₀. That relationship was confirmed, based on the 128 soil samples collected at AN3 and AN4, by regressing SAR on ECE for two groups, individually, which were distinguished by a threshold ECE = 40 dS m⁻¹ (Fig. 4). Among the 71 samples that had ECE < 40 dS m⁻¹, R² = 87.6%, which was much higher than the R² = 25.4% among the other 57 samples.

At **Plan de Callén** (PC), the alternating clay/silt millimetric layers in the sedimentary parent material, the hojaldre, and the high sodicity (Table 6) caused the high dispersivity and imperviousness of that soil.

Both the mean ECE and the median SAR were much lower than they were in the soils of the other three studied wetlands. The pH, SAR, and ECE indicated that the soil at PC was very strongly alkaline and moderately saline (Table 6). The sodicity and alkalinity were reflected in the high Na⁺ and pH in the saturation extracts. These chemical features were consistent with the dispersion and imperviousness of the soil, and the extraction of organic matter at the soil surface, which are diagnostic features of the “black alkali” soils identified by pedologists such as Eugene W. Hilgard in the early 20th C. Those features of the soil surface were associated with the distribution of the patches of halophytes, and the absence of a

relationship between this distribution and the salt-affection of the pedon up to 1-m deep (Table 3). In both sampling dates, ECe100 and SAR100 were higher at PC2 (*Puccinellia*) than they were at PC1 (bare soil). At those sites, ECe100 decreased between 1985 and 1999, and SAR100 decreased substantially at PC1 and increased ~ 10% at PC2, which was close to a drainage ditch.

The regression equations between ion concentrations and electrical conductivity in the soil solution at PC (Table 4) were similar to those of other plots within the same irrigation district (Herrero and Pérez-Coveta, 2005). Those correlations can reduce the lab workload for salinity monitoring at that plot by providing a means of estimating the concentrations of ions.

At **Paúl de Almuniente** (AL), the seasonal variation of ECe100 for the two sites sampled in 1979-1980 and again in 1999-2000, i.e., AL1 and AL2, was little, with a maximum difference between them of 19 dS m⁻¹ (Fig. 5). Those levels of salinity, which preclude agriculture, abated to < 2 dS m⁻¹ by 1999-2000. In 1979-1980, SARmax100 and SARmin100 of these soils from a depth of up to 1 m (Fig. S2 in Appendix A) were highly variable and did not exhibit a seasonal pattern. In 1999-2000, SARmax100 and SARmin100 showed little seasonal variation. The decrease in SAR, from a range of 39 - 188 in 1979-1980 to ≤ 3 in 1999-2000, paralleled the decrease in ECe. In 1999-2000, ECe and SAR were well below the standard threshold for soil salt-affection. The simultaneous large reductions in soil salinity and sodicity were caused by the inundation of running fresh irrigation water and the puddling of the soil with the fallow straw, which created a continuous densic pan that hampered the rise of the saline water table (Herrero and Hudnall, 2014).

The ECe100 and SAR100 at all of the sampling sites at AL reflected the temporal changes in soil salinity and sodicity (Fig. 6). ECe and SAR varied throughout the sampling campaign in 1979-1980. Weather and the irrigation events in the adjacent agricultural fields, that produce oscillations of the saline water table, probably influenced the ECe and SAR in that non-irrigated field. In contrast, in 1999-2000 this field was irrigated and ECe and SAR were stable (6 overlapping points, lower left corner of Fig. 6). The changes in ECe100 and SAR100 between the first and the last sampling campaign (Fig. 6), suggested that AL0 and ALx were in an intermediate state because there was a dense cover of halophytes at AL0, and rice cultivation began just before the ALx site was sampled in March 1985.

In both sampling campaigns at **Saladar de Agustín** (AG), the mean ECe40 increased almost steadily between the highest (AG8) and the lowest (AG5) site. At AG, ECe40 was least variable at AG8 in both sampling campaigns (Table 7), and the difference between 1979-1980 (mean = 53.4 dS m⁻¹) and 1999-2000 (mean = 40.8 dS m⁻¹) was greater than were the differences at any of the other three sampling sites (Table 7). Frequent, intermittent inundation contributed to the high variability in ECe at the other sites, which was paralleled by the changes in the location of the boundaries between the associations of halophytes. The highest variability (Fig. 7) occurred at AG5, the bare soil and lowest site, which experienced the highest frequency and duration of inundation episodes. Between the two sampling campaigns, ECe40 decreased > 10 dS m⁻¹ at the three lowest sites, but increased 8.5 dS m⁻¹ at the highest site (AG8). The 6.3 dS m⁻¹ average reduction in mean ECe40 at all of the sites after 20 years was about 10% of the mean (62.6 dS m⁻¹)

(Table 6).

At AG, 44 of the 54 samples with both CCE and gypsum determined, had more than 50% in weight of these two components. The richness in gypsum and calcium carbonate equivalent, also reported by Mees et al. (2012, Table 2), Domínguez et al. (2013b, Table 2), or by Herrero and Castañeda (2013, Fig. 6), plus the undetermined quantities of other components, e.g., organic matter and quartz or other detritic minerals, reduce the proportion and the role of mineralogical clays (Herrero et al., 2009; Casby-Horton et al., 2015) in the soils at AG. In addition, the high salinity observed at AG brings into question the use of SAR as an index of clay flocculation in those soils; however, SAR reflects the relative amounts of Na^+ compared to the antagonistic Ca^{2+} and Mg^{2+} , which can influence the salt tolerance of plants. The conditions at AG led us to assess SAR using an approach that differed from the one used at the other three wetlands.

In both sampling campaigns, SAR was more variable at individual sites AG5 through AG8, and in both of the sampling campaigns than it was at AG, overall (Fig. 8). Median SAR did not differ significantly between any of the pairs of the seven groups by site, by sampling campaign, or all samples together (Fig. 8). The ranges of SAR were widest at the highest sites (AG7 and AG8), where distribution of SAR was negatively skewed. At AG5 and AG6, the distribution of SAR was positively skewed; i.e., a disproportionate number of high values. The high Na^+ content in the hypersaline water table and frequent inundation influenced those results and the interquartile range, which was shorter than it was at the other two sites.

At AG, the median SAR = 29 (CI = 27.0 - 31.0) in 1979-80 and 27 (CI = 26.0 - 28.5) in 1999-2000, which indicated that SAR did not change significantly after 20 years, although the distribution of SAR was narrower in 1999-2000 than it was in 1979-1980, which reflected a reduction in extreme SAR in the samples (Fig. 8). The differences between the two sampling campaigns in the sampling depth intervals of individual samples contributed to the difference in the shape of the distributions. In 1979-1980 and 1999-2000, the mean depth interval was 9.86 cm (CV = 20.7%, $n = 70$ soil samples) and 12.92 cm (CV = 41.7%, $n = 52$), respectively. The difference in CV, 20.7% and 41.7% in the first and second campaign, respectively, reflected that 60 of the 70 samples collected in the first sampling campaign had a 10-cm depth interval but, in the second campaign, the range of depth intervals from which samples were collected was greater and much more variable.

The two lowest SAR values in the first sampling campaign came from the upper 10 cm of the soil at AG7 (April, 1979, SAR = 10; March, 1980, SAR = 12), which was underlain by soil layers that had SAR = 22 and SAR = 35 on those dates, respectively; i.e., if the samples had been taken with wider depth intervals, the SAR values would have been closer to centrality. Other eccentric values came from similar conditions.

Extreme ion concentrations are more likely to be detected if the depth intervals are short, which might not have an effect on the measures of centrality in the SAR distributions, but the shape and range of these distributions can be influenced unduly, which can affect the ecological interpretations. The assessment of ECe was not affected that way because we calculated synthetic layers, a procedure that was not used with SAR (see Section 2.4.1.). The concentrations of single ions or some of the derived indexes defined by

physiologists might be suitable for assessing plant stress if electrical conductivity is deemed too generic an indicator. Those indexes should maintain additivity, which allows the calculation of synthetic layers that were used to generate salinity profiles in our study.

4.4. Vertical distribution of soil salinity

The salinity profiles for the four wetlands combined (Fig. S3 in Appendix A), show the predominance of the annual evaporative deficit in the region in spite of the arrival to the wetlands of some water from surface runoff or from irrigation. At AN and PC, where the sampling sites were sufficiently deep, ECE decreased with depth, and the median ECE of the two deepest layers was 17.8 dS m⁻¹ (Fig. S3 in Appendix A).

At AL, soil desalination after the wetland was converted into a rice paddy between February 1980 and November 1981 resulted in a pronounced bimodal distribution, which is important for interpreting the summary diagrams of the salinity profiles, e.g., Fig. 10. The leaching associated to the annual inundation of paddies with low-salinity water plus the modest salinity of the groundwater can explain the strong desalination. The descent of SAR in spite of the low ionic content of the irrigation water denotes the release of soluble calcium by the soil, a condition not met by some other soils of the irrigation district. The salinity profiles at AN and AG were very different from each other and the others (PC and AL) (Fig. 10). The profile at AL was based on the salinity values before and after the wetland had been converted into a paddy. The profiles of ECE and Cations have similar but not identical shapes, which is consistent with the non-linear relationships between the EC and ion concentrations in hypersaline solutions (Table 2). The Cations profiles might be best for appraising the quantity of soluble salts or for comparing ion concentrations in soils.

4.5. Variation in the salinity profiles at each wetland

In the upper layers of **Paúl de Anzano (AN)**, salinity was much lower at AN4 than it was at AN3 (Fig. 11), where the halophyte *S. vera* was present. For the six sampling dates, the mean ECE of the shallow (0-20 cm) layers at AN3 (69.5 dS m⁻¹) was more than double the value at AN4 (13.6 dS m⁻¹). Exposure to weather has contributed to the very wide range in ECE at the surface at both sites. The difference in elevation between the two sites (Fig. 2) is important when comparing the salinity profiles and the high variation in salinity in the upper layers at AN4. These ECE values illustrate the soil salinity tolerance of *A. herba-alba*. The tendency to converge on ~ 20 dS m⁻¹ in the deep layers at the two sites and the conductivity of the groundwater (1.84 dS m⁻¹) in the area reported by Sánchez et al. (2001), seems consistent with their hypothesis that capillary rise causes soil salinity and with our observations on the arrival to AN3 of saline runoff from saliferous strata outcropping at higher elevations. Simultaneous measurements in April 1979 indicated that the depth of the water table at AN3 was 84 cm deeper than it was at AN4; i.e., the water table level is the same, but the difference is due to the presence of the escarpment between the two sites and the gentle slope of the terrain (Fig. 2).

The salinity profiles at **Plan de Callén (PC)** (Fig. 12) were much more uniform than they were in the other three wetlands; particularly, in 1999, except in the upper 20 cm. The PC1 and PC2 profiles were most irregular in 1985, but remained similar, even though the most saline layers were deeper at PC2 than they were at PC1, which along with the slightly lower salinity at PC1 in both sampling campaigns were associated with an internal lateral flux toward a drainage ditch near PC2. In any case, the difference between the salinity profiles at the two sites was small, which is consistent with the erratic distribution of patches of *Puccinellia festuciformis*. In 1985, the two sampling sites were chosen with the intention of comparing soil salinity beneath *P. festuciformis* and the adjacent bare soil; however, this patch was absent in 1999. Neither *P. festuciformis*, the few *Suaeda vera* shrubs, nor other volunteer annual halophytes observed in the field over 35 years exhibited a distinct distribution pattern.

At **Paúl de Almuniente (AL)**, the three ECe profiles at AL2 were similar in the first sampling campaign (Fig. 13). At AL1, salinity was much higher and the three ECe profiles were less similar than they were at AL2, mainly, because the ECe of the surface layer in April 1979 was much lower than it was on the other two sampling dates (August 1979 and February 1980). At AL1 and AL2, in April 1979, ECe was higher than it was on the other two dates, and the soil was least saline in August 1979. The exception was the upper layer in April 1979. The flooding with fresh irrigation water of adjacent paddies from May to September contributed to the low salinity in the August 1979 samples.

In the 20 years between 1979-1980 and 1999-2000, the ECe profiles at AL1 and AL2 changed dramatically after the wetland was converted to a rice paddy. Annual inundation with fresh irrigation water caused the pronounced reduction in the salinity at all sampling depths. The ECe profile at the first sampling site (AL0), an abandoned plot that had well-developed halophilous vegetation, in March 1979, is superimposed with the profile at the ALx site in March 1985 (Fig. S4 in Appendix A). This illustrates the similarities between the ECe profile under almost natural conditions (AL0) and the profile after six years of annual inundation by running irrigation water in the rice paddy (ALx), and the differences between the AL1 and AL2 sites (Fig. 13) in the first sampling campaign, when the plot was uncultivated. Persistent leaching that followed the conversion to a rice paddy was responsible for the shapes of the salinity profiles in 1999-2000 (Fig. 13).

At **Saladar de Agustín (AG)**, the synthetic profiles (Fig. 14) showed that ECe increased steadily with depth at the two most vegetated sites, AG8 and AG7. Increases in salinity in the profiles from AG8 to AG5 paralleled a slight difference in elevation between AG8 and AG5 (Fig. 2). The synthetic ECe values at AG7 were ~ 25 dS m⁻¹ to 60 dS m⁻¹ at the 0-20 cm depth, and > 80 dS m⁻¹ at the 20-40 cm depth, which were indicators of the salt tolerance of *Suaeda vera*. At AG6, the values for *Arthrocnemum macrostachyum* ranged from ~32 dS m⁻¹ to 105 dS m⁻¹. At the AG6 and AG5 sites, the profiles were more irregular and saline than were those at AG7 and AG8. At AG6, in four of the six samplings, all of the synthetic ECe values were > 60 dS m⁻¹, which was similar to the ECe of the layers underneath, and is consistent with the frequent inundation at this site. *A. macrostachyum* is the only perennial plant that lives in this harsh environment. Inter-site differences in salinity (Fig. 14) were greater than the differences between seasons,

515 which suggests that the effects of soil salinity and inundation caused the changes in the locations of *A. macrostachyum* in this wetland observed over the period 1977-2014.

At AG5 and AG6, the salinity profiles were less regular than they were elsewhere (Fig. 14), and ECE was higher at AG5 than it was at AG6. The ECE in the 40-60 cm layer was similar at the two sites, which is consistent with the $\sim 90 \text{ dS m}^{-1}$ ECE in the 60-80 cm layer at AG5 and the conductivity of the four samples of groundwater collected in February 1979 and February 2000 (mean = 102.8 dS m^{-1} , range = 98.4 dS m^{-1} to 105.7 dS m^{-1} (Herrero, 2008, page 140). The estimated ECE in the deep soil was $\sim 100 \text{ dS m}^{-1}$.

4.6. The dynamics of soil salinity in the four wetlands

Bulk ECE and SAR in the soil profiles, the distributions of ECE and SAR, and the relationships between ECE and SAR differed substantially among the four wetlands, even between the two closest ones (PC, AL), which were 3 km apart. At AL, only, the ECE and SAR decreased sufficiently in the 20-yr period to allow agriculture (i.e., a rice paddy). Soil salt-affection did not undergo big seasonal variations. It suggests that the circulation of water within the soil profile is not strongly influenced by weather because the physiographical settings strongly affect both the surface runoff and the water table, because the cultivation practices around the wetlands have increased, and because of recent anthropogenic changes at PC and AL.

5. Conclusions

535 For the first time, the change in the soil salt-affection associated with the annual application of continuous flooding with fresh irrigation water and soil puddling has been documented in the Central Ebro Valley, Spain. A comparable change did not occur in the three wetlands that did not undergo anthropic transformations in the period covered by our study.

The conventional interpretation of SAR as a measure of the dispersability of the soil can be based on the extreme values in a profile; however, this interpretation would be inappropriate if clay is a minor component, which it was in the AG wetland. In that case, SAR is a valid indicator of the soil sodicity of the wetland as an index of the relative concentrations of antagonistic ions; however, neither averaging nor calculating synthetic layers of SAR for a profile is possible because this index does not have additivity. For such calculations, either single ions or indexes that have the additive property are required. In addition, the effect of the depth intervals of the soil sampling should to be evaluated when comparisons are made in the SAR distributions between different soils or sampling dates.

This study demonstrated an easy method that provided numerical and graphical comparisons of single values of soil salinity and sodicity, as well as the salinity profiles, at multiple sampling sites and dates. The multitemporal information obtained will be a baseline for future assessments of the conservation status of the wetlands studied in the present work or the change in salt-affection in areas that could be converted to an agricultural use.

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Appendix A. Supplementary data

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- Table 1. Correlation coefficients ($p < 0.001$), between E_{Ce} and the major plant-stressing ions, and between these ions, calculated with 403 saturation extracts of soils collected at four saline wetlands in the Central Ebro Valley, Spain.

	E _{Ce}	Mg ²⁺	Na ⁺	SO ₄ ²⁻
	<u>Extracts from 1979, 1980 and 1985</u>			
Mg ²⁺	0.753			
Na ⁺	0.880	0.413		
SO ₄ ²⁻	0.929	0.900	0.763	
Cl ⁻	0.951	0.842	0.800	0.918
	<u>Extracts from 1999 and 2000</u>			
Mg ²⁺	0.868			
Na ⁺	0.968	0.817		
SO ₄ ²⁻	0.898	0.964	0.873	
Cl ⁻	0.987	0.920	0.951	0.930

675 Table 2. Equations ($p < 0.0001$) in the form $\log [\text{ion, meq L}^{-1}] = a + b \times \log [\text{ECe, dSm}^{-1}]$ for the synthetic values of the concentration of major cations and anions, and of ECe in the saturation extracts of soils at four saline wetlands in NE Spain; n is the number of computed values, and R^2 is the coefficient of determination.

Wetland	Cations				Anions		
	n	a	b	R^2	a	b	R^2
AN	94	0.880	1.13	95.7	1.021	1.08	97.6
PC	34	0.959	1.05	99.6	1.089	0.94	96.2
AL	83	0.986	1.08	99.7	1.082	1.01	98.9
AG	63	0.655	1.34	96.0	0.646	1.36	93.2
All	274	0.926	1.14	98.4	1.001	1.11	97.9

680 Table 3. ECe100 and SAR100 of the soils at the sites PC1 and PC2, Plan de Callén (PC), Central Ebro Valley, Spain.

Sampling date	PC1		PC2	
	ECe100	SAR100	ECe100	SAR100
3 April 1985	12.0	141	19.3	183
30 March 1999	6.1	62	11.5	205

685 Table 4. Regression equations for 32 soil saturation extracts from Plan de Callén, and for the irrigation district of Flumen after Herrero & Pérez-Coveta (2005). Ions are expressed in meq L^{-1} , and EC in dS m^{-1} ; n is the number of computed values, and R^2 is the coefficient of determination

Plan de Callén		District of Flumen		
	R^2		R^2	n
$\text{ECe} = 0.14 + 8.13 \times \text{EC1:5}$	93.9	$\text{ECe} = 0.51 + 7.63 \times \text{EC1:5}$	94.2	422
$\text{Na}^+ = -7.62 + 11.05 \times \text{ECe}$	99.3	$\text{Na}^+ = -7.12 + 11.13 \times \text{ECe}$	94.3	430
$\text{Cl}^- = -11.90 + 7.88 \times \text{ECe}$	99.0	$\text{Cl}^- = -14.09 + 10.53 \times \text{ECe}$	93.7	423
$\text{Na}^+ = 9.77 + 1.39 \times \text{Cl}^-$	98.8	$\text{Na}^+ = 9.08 + 1.01 \times \text{Cl}^-$	90.9	425

Table 5. Extreme and mean for ECe40, dS m⁻¹, and difference between the mean values of the second and the first campaigns in the auger soil samples collected at AG, Central Ebro Valley, Spain.

		AG5	AG6	AG7	AG8	All
Campaign 1979-1980	Minimum	66.3	55.2	49.6	47.0	47.0
	Mean	73.0	75.2	63.4	53.4	66.3
	Maximum	77.4	89.2	71.3	57.8	89.2
Campaign 1999-2000	Minimum	72.1	41.1	38.0	31.0	31.0
	Mean	81.5	64.5	53.1	40.8	60.0
	Maximum	87.0	83.6	68.1	41.3	87.0
Both campaigns together	Minimum	66.3	41.1	38.0	31.0	31.0
	Mean	77.3	69.9	59.2	44.0	62.6
	Maximum	87.0	89.2	71.3	57.8	89.2
Difference between the means of the campaigns		8.5	-10.7	-10.3	-12.6	-6.3

Table 6. Chemical characteristics of the saturation extracts of the soil samples at Plan de Callén (PC), Central Ebro Valley, Spain.

	<i>n</i>	aver.	min.	max.
EC	32	10.1	3.3	27.6
SAR	32	125	33	311
Na ⁺	32	104	31	311
pH	17	9.70	9.27	10.30

n = number of computed samples;

aver. = the mean for electrical conductivity (dS m⁻¹) and Na⁺ (meq L⁻¹), and the median for SAR and pH.

Fig. 1.

Fig. 1. The locations of the four saline wetlands (AN, PC, AL, and AG) studied in the Central Ebro Valley, Spain. Irrigated land is in light green. The coordinates (Datum WGS84) are AN: 42° 12.1' N, 0° 31.8' W; PC: 41° 58.6' N, 0° 22.5' W; AL: 41° 57.7' N, 0° 23.5' W; AG: 41° 25.9' N, 0° 6.4' W. The image is the SPOT5 mosaic in natural color taken in 2009 (IGN, Instituto Geográfico Nacional).

Fig. 3. ECe100 at AN3 and AN4 (augerings and pit). The solid circle indicates a sampling depth of 65 cm. Samples collected in 1979-1980 and in 1999-2000 are indicated by dashed lines and solid lines, respectively.

Fig. 4. SAR100 and ECe100 at Paúl de Anzano. Samples collected in 1979-1980 and in 1999-2000 are indicated by dashed lines and solid lines, respectively. The arrows mark the temporal succession of the samplings. The numbers are the day number in a sampling campaign. The solid circle indicates a sampling depth of 65 cm.

Fig. 5. ECe100 at sites AL1, *Suaeda vera*, and AL2, *Salicornia ramosissima*, at Paúl de Almuniente, a wetland in the Central Ebro Valley, Spain. A pit (AL0) was sampled below *S. vera* and mosses, and an augering site (ALx) located between AL1 and AL2. Samples collected in 1979-1980 and in 1999-2000 are connected by dashed lines and solid lines, respectively. Dates printed vertically indicate two samplings.

Fig. 6. ECe100 and SAR100 of soils sampled in 1979-1980 at AL1 (*Suaeda vera*) and AL2 (*Salicornia ramosissima*), sampling sites at Paúl de Almuniente, a wetland in the Central Ebro Valley, Spain. The number is the day in the sampling campaign. The site ALx, located between AL1 and AL2, was sampled in 1985, and the site AL0, with *S. vera* and mosses, in 1979. Dashed arrows mark the temporal succession of the sampling campaigns: from 1979-1980 to 1985, and then to 1999-2000.

Fig. 7. ECe40 calculated from soil samples taken by auger at the four sites at Saladar de Agustín, a wetland in the Central Ebro Valley, Spain, and day in the sampling campaign. Samples collected in 1979-1980 and in 1999-2000 are connected by dashed lines and by solid lines, respectively.

Fig. 8. Boxplots of the SAR measurements from 122 auger samples collected at all sampling sites in Saladar de Agustín (AG), a wetland in the Central Ebro Valley, Spain, and for these samples grouped by site (AG5, AG6, AG7, and AG8) and campaign (1979-1980, and 1999-2000). Asterisks indicate outliers; n = number of samples in each boxplot.

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760 Fig. 9. ECe values of 20-cm-thick synthetic layers of the soils at each of the four
wetlands studied in the Central Ebro Valley, Spain. A total of 258 synthetic values were
calculated from the soil samples collected from the 52 augerings, only; n is the number of
generated ECe values in each of the synthetic layers

765

Fig. 10. Median ECe (left) and median Cations (right) for 20-cm-thick synthetic layers of
the soils at the four wetlands studied in the Central Ebro Valley, Spain.

770

Fig. 11. ECe for 20-cm-thick synthetic layers calculated from samples collected with auger at two sites (AN3 and AN4) on six days at Paúl de Anzano, a wetland in the Central Ebro Valley, Spain.

Fig. 12. ECe for 20-cm-thick synthetic layers calculated from samples collected with auger at two sites (PC1 and PC2) at Plan de Callén, a wetland in the Central Ebro Valley, Spain.

Fig. 13. ECe for 20-cm-thick synthetic layers calculated from samples collected with auger at two sites (AL1, AL2) at Paül de Almuniente, a wetland in the Central Ebro Valley, Spain.

805

Fig. 14. Synthetic ECE profiles created based on the soil samples from the 23 auger holes drilled at the sites AG5 to AG8 which were on a 270-m transect in Saladar de Agustín, a wetland in the Central Ebro Valley, Spain.