Appendix C

Measurement of Soil Salinity in Wetlands: Methods and Seasonal Variability

Introduction

Soil salinity is a measure of soluble salts in the soil. Soils described as “saline” have accumulated free salts at or below the surface and are prevalent in the arid west due to the low amount of precipitation and high evapotranspiration rates. Saline soils can occur in terminal basins, such as Great Salt Lake and the Sevier playa, where water enters via streams and surface runoff but only leaves via evaporation, leaving salts behind. Saline soils also occur in desert playas that have shallow groundwater and little surface recharge; groundwater with associated dissolved salts is drawn towards the surface where the groundwater evaporates, leaving behind a salt crust. Natural accumulations of salts may be increased by human activities such as the use of road salts, runoff from impervious surfaces, and irrigation runoff from agriculture.

The level of soil salinity impacts the plant community that can inhabit a site. The presence of salts affects plant growth in various ways including interference in photosynthesis within the leaf and by reducing water uptake capacity of the plant from the soil. Some plant species are more tolerant of saline soils than others. Thus, soil salinity is a useful tool for understanding the association between plant communities and environmental constraints and for classifying sites into ecologically meaningful categories such as saline meadow and fresh meadow. Previous work suggests that salinity is an important classifier for understanding Utah’s wetlands (Keate, 2004; Menuz and others, 2016) and wetlands in the arid west are often dry, so a method to estimate salinity at sites without surface water is necessary. Furthermore, soil salinity can be used to help assess wetland condition. For example, a playa that appears physically undisturbed may in fact be in poor condition due to an increase in fresh water flushing out soil salts, which could make the site vulnerable to invasion by less salt-tolerant species.

The goal of this study is to develop a repeatable field method for measuring soil salinity that provides results comparable to more time and cost intensive methods that will allow us to better describe, classify, and assess wetlands in Utah. Soil salinity is determined by measuring electroconductivity (EC), which measures how much electricity moves through a solution; soils with higher salts have higher EC values. Two methods commonly used to measure soil EC are the saturated paste method (EC_e) and measuring the EC of a soil and water solution. Although the saturated paste method is more accurate, it is typically performed in a lab setting and is less practical as a field method. We examined variability between the two methods, within adjacent sample locations at a site, and in repeated measurements over the growing season.

Field Methods

We conducted an initial exploratory field sampling day to examine observer variability resulting from how we obtained soil samples and to refine the field method. We took all measurements using the $EC_{1:5vol}$ method, detailed below. We explored differences in results between homogenizing the entire pedon versus homogenizing a few small samples from different depths from the extracted soil pedon. We also examined differences in EC values from different soil pits less than 1-m apart, from different observers sampling the same pedon, and from different settling times after mixing with soil samples with water. Results from this initial exploration showed that there was less variability when observers homogenized the entire pedon rather than pinching off subsamples from it and less variability when observers each subsampled the homogenized pedon rather than collected data from soil pits close to one another. Settling time did not have a large effect on measured values, though we continued to record repeat measurements in subsequent testing.

We used a field method adapted from the Natural Resources Conservation Service (NRCS, 2001) method for field testing electrical conductivity using a 1:5 aqueous mixture by volume for subaqueous soils. We considered using a 1:1 mixture by volume but selected the larger ratio to make it easier to fully submerge handheld water quality meters in the supernatant. The greater water to soil ratio also allowed for more opportunity to obtain readings in highly saline soils, common in the Central Basin and Range ecoregion of Utah, by diluting the salinity and making it less likely that readings would be out of the meter's range. To obtain a soil sample, the top 15 cm of the soil was collected using a soil augur and placed into a plastic Tupperware container. At playa sites where a salt crust was present, observers made sure to include an amount of salt crust that matched the diameter of the augur because the crust was often destroyed by sampling. Observers removed rocks, coarse roots, and vegetation from the sample when present. The soil sample was placed in the Tupperware and homogenized by hand. One quarter cup of loose soil from the Tupperware was measured and added to a plastic mixing jar with 1.25 cups of distilled water. These volumes were adopted due to the availability of measuring cups in these sizes and to allow for plenty of supernatant in which to submerse the handheld EC meters. The mixing jar also contained a metal wire ball intended for use in mixing smoothie drinks that was used to help break down the soil and mix the solution. The mixture was shaken 25 times and allowed to settle. $EC_{1:5vol}$ measurements were taken five and ten minutes after mixing using a handheld multiparameter meter. If the two measurements differed by >250 uS, additional measurements were taken at 5-minute intervals until measurements differed by <250 uS. This 250 uS level of difference was arbitrarily chosen based on values obtained by different observers during the initial exploratory field day.

Three test areas around the eastern and northeastern shore of Great Salt Lake were selected for sampling, and three sites were sampled in each location. The test areas included Farmington Bay Waterfowl Management Area, the Great Salt Lake Shorelands Preserve, and a location on private property near Promontory, Utah, in a spring-dependent wetland along the historical shore of Great Salt Lake (hereafter "Promontory"). Sites within each test area were chosen to try to capture a range of soil salinity values based on *a priori* knowledge of typical soil salinity ranges found in vegetation communities (Menuz and Sempler, 2018). Sites ranged from meadows with shallow standing water densely vegetated with emergent sedge and grass species to dry unvegetated playas or playa-like sites dominated by halophytic perennial species or completely barren. For the sake of analysis, we classified all sites as either herbaceous or playa. Soil sampling locations at the three test areas varied spatially with community types and ranged from tens to hundreds of meters apart.

Each site was visited three times between May 29 and August 20, 2019, and GPS locations were recorded to ensure return to the same area for subsequent resampling. In addition to collecting the $EC_{1:5vol}$ data as described above, we recorded soil texture, soil moisture level (dry, moist, saturated, or standing water), and vegetation next to each soil pit at each site for each survey. During the first visit at each site, we dug two pits less than 1 m apart and performed the same sampling on both pedons; only one pit was dug per site on subsequent visits. During the second visit, we retained the soil sample for lab testing after 0.25 cup was removed for field testing. These samples were air dried in the office and sent to the Utah State University Analytical Laboratories for EC testing using the saturated paste method. We collected surface water EC measurements at the Promontory site from a springhead pool and outflow channel approximately 800 m downstream from the pool. These additional measurements were taken because the emergence point of a natural springhead and outflow channel that supported the test sites were very close to the sampling locations and presented a good opportunity to explore whether trends in groundwater mirrored trends in soil salinity over time in a relatively undisturbed area. All soil salinity sites at the Promontory area were within 100 m of the surface water in the spring outflow channel.

Data Analysis

We used linear mixed effects models to look at variability in EC measurements with settling time and across the growing season, using site location as a random effect and either settling time period (5, 10, or 15 minutes) or visit number (1, 2, or 3) as a fixed effect. For the analysis of settling time, we only used data from the first survey event as no 15-minute measurements were made during subsequent survey events. For all other analyses, we used the last EC measurement from each soil pit for analysis. All statistical analysis was conducted in R 3.5.3 statistical software (R Core Development Team, 2019).

To compare the $EC_{1:5vol}$ values with lab data, we first converted $EC_{1:5vol}$ units to decisiemen, and then to EC_e by using soil texture-specific factors from a New South Wales agriculture department publication describing methods to test soil salinity (New South Wales Agriculture, 2000), as suggested by NRCS staff Randy Lewis (personal communication, January 2019). All soils were textured in the field as silty clay, sandy clay, or clays; sandy and silty clays were classified as "light clays" and clays as "medium & heavy clays" texture groups as described by the New South Wales document. $EC_{1:5vol}$ values for light clays were converted to decisiemen and multiplied by 8.6, and values for medium and heavy clays converted to decisiemen and multiplied by 7 to convert them to EC_e. Pearson correlation and a linear regression model were used to examine the relationship between lab measurements and the converted field measurements.

We converted $EC_{1:5vol}$ to EC_e values and then assigned soil salinity classes to evaluate whether sites stayed in the same class across settling time, within adjacent soil pits, across methods, and across the three site visits. Soil salinity classes were adopted from NRCS (Scianna, 2002) and include five classes based on EC: Nonsaline 0-2, Very slightly saline 2-4, Slightly saline 4-8, Moderately saline 8-16, Strongly saline > 16 dSm^{-1}.

Results

Variability in 5-minute intervals

Differences in EC measurements across the settling times were much smaller in the herbaceous sites than the playa sites with mean maximum differences of 62 uS in the former and 398 uS in the latter (figure C1). We observed no directional effect of settling time (5, 10, or 15 minutes) on field measurements of EC, as determined by mixed effects model results ($p = 0.84$). Three sites had values that decreased over time, five sites had values that increased over time, and one site had the lowest value during the second reading. Only one of the 36 sets of readings differed in the salinity class assigned to the site between the first and second reading (between very slight and slight); that set of readings only differed by 19 uS.

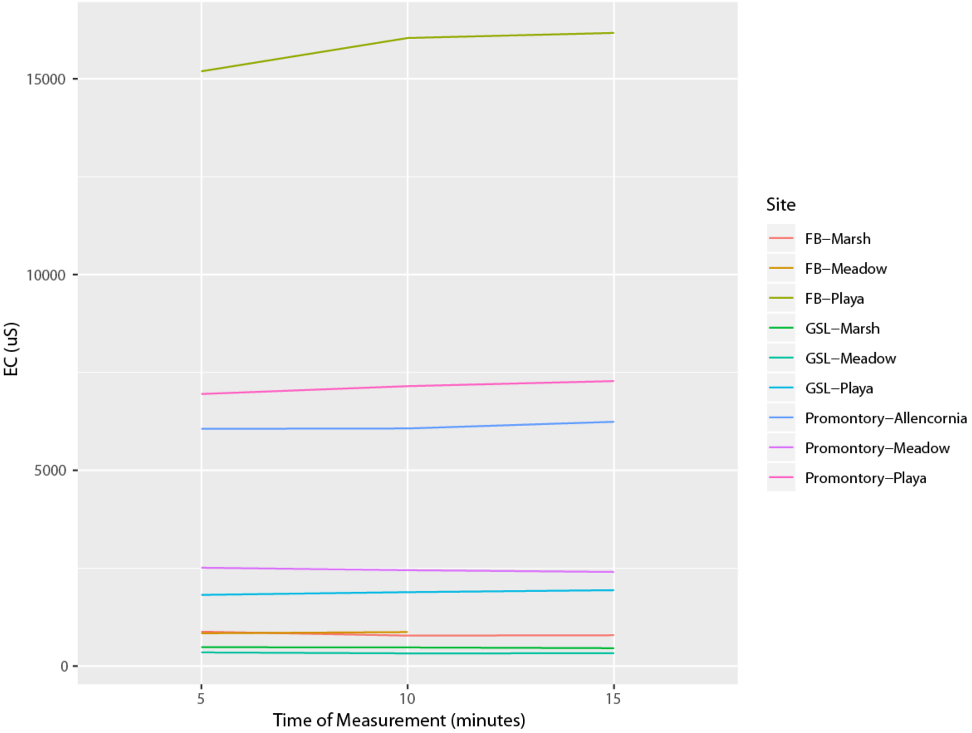

Figure C1. Electroconductivity measured at 5, 10, and 15 minutes after mixing. Colors indicate different sites. Site prefixes used are Promontory, FB=Farmington Bay Waterfowl Management Area, GSL=The Nature Conservancy's Great Salt Lake Shorelands Preserve. A fifteen-minute reading was not taken at the FB-Meadow site

Variability within site

Differences in soil salinity values between two adjacent soil pits sampled at the same time were higher at more saline sites. Mean absolute values of field measurements differed by 183 uS at herbaceous sites and by 2267 uS at playa sites. When soil salinity classes were assigned using converted EC_e values, three sites had adjacent pedons in different soil salinity classes, though no site showed a difference of more than one class. Sites that differed were all herbaceous sites, including two meadows and one marsh.

Method comparison

EC values collected using the field method were strongly correlated with the values obtained from the EC_e by saturated paste measured in the laboratory (table C1, $r = 0.98$, $p < 0.01$), and a linear regression model suggested converted $EC_{1:5vol}$ values were a good predictor of EC_e (figure C2, $r^2 = 0.96$, $EC_e = (2.85 * EC_{1:5vol}) - 8.74$. Visual examination of plotted values suggests potential for different relationships for high and low salinity sites, though this was not explored due to the low sample size. Additionally, all points plotted above a 1:1 line, indicating that converted field values always underestimated the saturated paste lab values. A confusion matrix showed that the field method resulted in the same salinity class as the lab method at six of nine sites (table C2).

Table C1. Raw EC$_{1:5vol}$ values at each site during three visits. Site Name prefixes used are Prom=Promontory, FB=Farmington Bay Waterfowl Management Area, GSL=The Nature Conservancy's Great Salt Lake Shorelands Preserve. The first date of each 2-day sampling run is used for each sampling event. Values with gray shading indicate sites which remained in the same soil salinity class during all visits. Letter codes in parentheses indicate soil salinity class based on converted dS values: SlS=slightly saline, VsS=very slightly saline, MS=moderately saline, StS=strongly saline.

Site Name	**May-29 (uS)**	**July-01 (uS)**	**August-20 (uS)**	**Converted field EC July - 01 (dS^{-1})**	**ECe lab results (dS^{-1})**
Prom-Spring[1]	12380	7600	11630	NA	NA
Prom-Stream[1]	12160	7040	12000	NA	NA
Prom-Allencornia	6240 (StS)	2990 (StS)	9330 (StS)	25.7	59.6
Prom-Meadow	2406 (StS)	1742 (MS)	2230 (StS)	15.0	16.1
Prom-Playa	7280 (StS)	4020 (StS)	7330 (StS)	34.6	95.6
FB-Marsh	790 (SlS)	426 (VsS)	809 (SlS)	3.0	4.9
FB-Meadow	870 (SlS)	584 (SlS)	1688 (MS)	4.1	5.5
FB-Playa	16170 (StS)	5830 (StS)	10280 (StS)	40.8	113.0
GSL-Marsh	460 (VsS)	364 (VsS)	775 (SlS)	2.5	3.9
GSL-Meadow	330 (VsS)	326 (VsS)	441 (VsS)	2.3	3.8
GSL-Playa	1940 (MS)	2030 (MS)	4200 (SS)	14.2	25.6

[1] EC value from waterbody, not 1:5 soil sample.

Table C2. Confusion matrix showing differences in soil salinity classification between field EC1:5vol measurements converted to ECe values and direct laboratory ECe via saturate paste values. Ranges for each class are in (dS m-1).

		Laboratory Soil Salinity Class				
		Nonsaline (0-2)	Very slightly saline (2-4)	Slightly saline (4-8)	Moderately saline (8-16)	Strongly saline (>16)
Field Soil Salinity Class	Nonsaline	0	0	0	0	0
	Very slightly saline	0	2	1	0	0
	Slightly saline	0	0	1	0	0
	Moderately saline	0	0	0	0	2
	Strongly saline	0	0	0	0	3

Variability across the growing season

A linear mixed model showed soil salinity varied significantly ($p < 0.05$) over the course of the study period, with nearly every site showing a similar pattern of decrease in soil salinity in the middle of the season (July 1) before returning to previous or greater levels of salinity (figure C3, table C2). The scale of decrease during the second visit was much greater in the playa sites than the herbaceous sites, with one playa site decreasing by 8445 uS between the first and second visit. Surface water sites at Promontory showed a similar trend to terrestrial playa sites, with a large decrease during the second visit. Two herbaceous sampling sites showed a continuous increase in soil salinity; one site increased only 160 uS over the entire sample period, whereas the other increased 16 uS between the first and second visit, then by 2201 uS between the second and third visits. When field EC measurements were converted to soil salinity classes, all playa sites were classified as strongly saline during each visit, but only one herbaceous site was classified as the same salinity class at each visit. Disagreements in soil salinity class were never more than one class and only occurred at one of the visits.

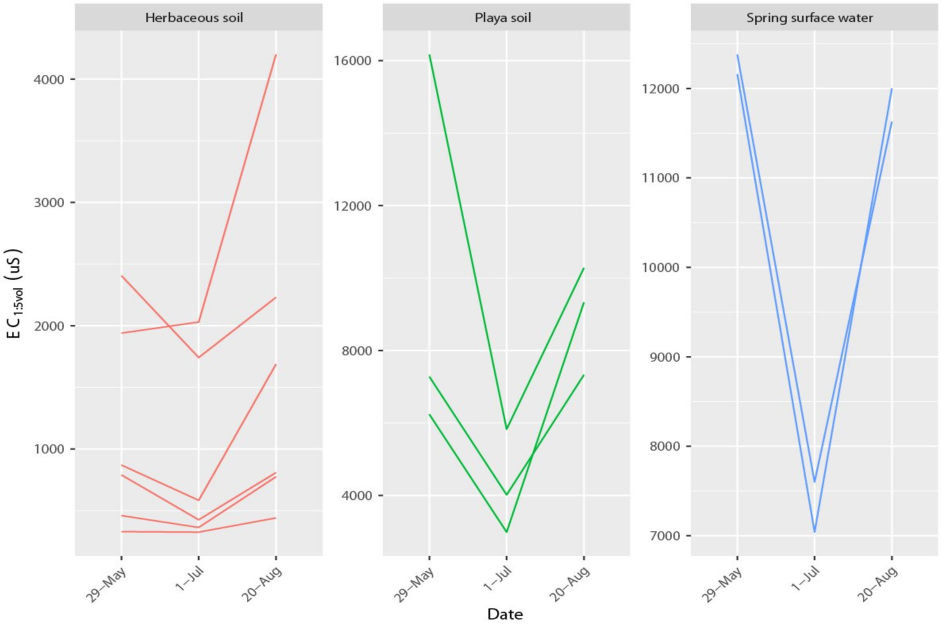

Figure C3. Salinity field values (uS) over three site visits. $EC_{1:5}$ was measured at herbaceous and playa sites in three test areas and salinity of surface water was measured at the spring and stream sites at Promontory.

Discussion

We believe that the $EC_{1:5vol}$ field method generates soil salinity measurements that are useful for comparing relative soil salinity among sites. As in other studies (Sonmez and others, 2008; Aboukila and Norton, 2017), correlation and regression suggest a strong relationship between field $EC_{1:5vol}$ and EC_e measurements and support the use of $EC_{1:5vol}$ as a predictor of EC_e. However, further investigation using a larger sample size and better representation of salinity classes would be useful to refine conversion factors specific to the region and determine if and how the relationship between methods varies among ranges of soil salinity. For example, $EC_{1:5vol}$ and EC_e values appear to be closer to a 1:1 relationship at low salinity levels, whereas strongly saline sites seem to have a different relationship (figure C2). A study by He and others (2013) examining the relationship between EC_e and $EC_{1:5vol}$ found improved r^2 values by using separate models for soils above and below 4 dS m^{-1}. Additionally, other conversion factors based on soil texture were found in a literature search, though none were regionally relevant, and further investigation is likely to suggest different conversion factors more appropriate for the Great Salt Lake region.

We believe that the decrease in soil salinity observed across most sites during the second visit was due to seasonal lag of groundwater additions. This theory is supported by the concurrent decrease in surface spring water EC at the Promontory site. The 2018–2019 winter was a very wet year in northern Utah, and the decrease in EC may represent a delayed pulse of groundwater flowing from high to low elevation which temporarily diluted free salts and led to a decrease in both spring surface water and soil EC. As this pulse of fresher water dissipated later in the season, evapotranspiration rates again increased above inputs of fresh groundwater, drawing moisture out of the soil and increasing salt concentrations.

Within-site variability was sometimes high, both spatially as found in the adjacent soil pits and across the growing season. However, sites generally maintained their relative rankings and frequently stayed within the same salinity class. Playa sites had the largest absolute value of differences between measurements, but also always stayed within the same soil salinity class and were readily distinguishable from herbaceous sites. High variability at playa sites may be due to a steep salt concentration gradient that increases toward the soil surface, variability in the amount of surface salt crust included in the sample by the observer, and the difficulty of mixing dense clay soils so that salt crusts and the sample itself are evenly homogenized.

We have three recommendations for collecting and using the soil salinity data. First, the methods of soil sample collection, homogenization, and measurement are adequate for obtaining estimates of soil salinity in the field, including the short settling time. Second, expect considerable variability within wetland survey locations. For this study, each site had homogenous vegetation, though in reality wetland assessment areas can be composed of multiple distinct patches of vegetation. It may be necessary to obtain soil salinity measurements from multiple soil pits at complex assessment areas to better characterize conditions at those sites. Third, sites should not be assigned salinity classes based solely on soil salinity measurements due to the variability found within sites and across time, particularly at herbaceous sites. Rather, the salinity data can be used in conjunction with other site information to help classify sites into broad ecological types, such as saline versus fresh meadow. Furthermore, it may be more useful to use the salinity values for analysis rather than salinity classes since herbaceous wetlands tend to fluctuate between salinity classes.

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