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SEED BANK VIABILITY OF INLAND SALINE WETLAND SITES IN AGRO-ECOSYSTEMS

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ABSTRACT—Wetland restoration typically includes modifications to soils, flora, and hydrology. Will the return of wetland hydrology to former saline wetlands create conditions suitable for wetland taxa, especially saline wetland indicator species? To answer this question we evaluated the potential restoration efficacy of historical saline wetland soils by re-exposing them to wetland hydrological conditions simulated in a greenhouse. Agricultural lands contained no saline indicator plants and limited wetland species, likely due to significant and long-term land alteration. Restored wetlands showed only a few additional wetland taxa, and seeds of saline wetland plants emerged from soils of only one restored site. Because land alteration threatens the seed bank status of current saline wetlands, potential restoration sites, and even historical saline wetlands under agricultural production in Nebraska, preservation of existing sites that currently have saline dynamics and affluent seed banks may be the only means for continued restoration.

Key Words: hydrology, inland saline wetland, Nebraska Eastern Saline Wetlands, seed bank, wetland restoration assessment

INTRODUCTION

Among wetland types, saline wetlands exhibit some of the most extreme environmental conditions. These conditions lead to intricate spatial and temporal relationships between halophytes, nonhalophytes, and soil ionic potential. Salinity has been shown to alter germination more than other abiotic factors such as temperature, soil moisture, and humidity. Thus salinity ultimately affects vegetation zonation (Wijte and Gallagher 1996; Noe and Zedler 2000). It also has been shown to limit soil microbial activity and colonization by mycorrhizal fungi, thereby ultimately aiding plant performance (Caravaca et al. 2005). Because of these overriding influences, saline wetland restoration becomes increasingly difficult and more reliant upon preserving existing sites where the necessary brines, hydroperiod, halophyte seed banks, and edaphic communities occur. In nonsaline wetlands, restoration success depends upon water level, hydroperiod, and hydrological character, especially with respect to seed bank status (Poiani and Johnson 1988; van der Valk et al. 1994; Hunt et al. 1999). Arguably, seed banks of restored wetlands may contain lower seed densities (Galatowitsch and van der Valk 1996) or higher seed densities than those found in naturally occurring seed banks (Baldwin and DeRico 1999). Thus, while seed densities may be linked to site context, characterizing seed bank quality and response are extremely important to help gauge the effectiveness of restoration efforts.

In Nebraska, inland saline wetlands occur primarily within Lancaster and Saunders counties, and especially near the municipal boundaries of Lincoln along Salt Creek and its tributaries. This wetland complex is characterized

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by saline soils predisposed to salt accumulation (Elder et al. 1965; Brown et al. 1980) and a renewable supply of brine from deep within Permian and Pennsylvanian geologic strata underlying the Cretaceous Dakota Aquifer (Harvey et al. 2002). Saline wetland indicator plant species include *Aster subulatus, Atriplex subspicata, Distichlis spicata, Iva annua, Ruppia maritima, Salicornia rubra, Scirpus maritimus, Suaeda depressa*, and *Typha angustifolia* (Ungar et al. 1969; Clausen et al. 1989; Gersib and Steinhauer 1991). A recent soil and hydrological assessment identified a total of 133 saline wetlands and 99 potential saline wetland sites within Lancaster and Saunders counties (Gersib and Steinhauer 1991). All sites are characterized by the same foundational soil, water, and vegetative features and by a dynamic spatial relationship with accumulating salts from underlying aquifers.

Historically, anthropogenic activity has eliminated the natural hydrology within a majority of these sites, as drainage for agricultural cropland, erosion, municipal expansion, and industrial commerce lowered water tables and altered topography. Crops grow poorly in these disturbed saline soils, and wetland plants often lack the necessary soil moisture to germinate. More recently, land developers have placed increasing pressure on saline watersheds around Lincoln. In freshwater wetlands, land disturbance has been shown to reduce seed density and seed bank viability (Wisheu and Keddy 1991). It is of interest to determine if similar effects occur in saline wetlands. If restoring hydrology to hidden seed banks proves an effective method for restoring saline wetland communities, existing seed banks will be an important factor for restoration efforts. Thus, knowledge of seed bank viability in remaining saline wetlands, current restoration sites, and even historical saline wetlands now under agricultural production can aid in mitigation activities, as well as our understanding of these unique ecosystems and their restoration. For this study, we sought to evaluate historical saline wetland soils by re-exposing them to extant wetland conditions, and to identify sites with viable saline wetland seed banks. This project was conducted in conjunction with the Nebraska Game and Parks Commission to evaluate potential future restoration sites.

STUDY AREA

The study area was within Lancaster County, NE, primarily around the city of Lincoln (40°85′N, 96°75′W). Study sites were located predominantly north of Lincoln; however, some occurred south near the headwaters and first-order tributaries draining into Salt Creek (Fig. 1). Of the sites sampled, one landowner desired to remain anonymous (AA in Table 1)

Soil-sample survey sites were selected based on several criteria: accessibility, known historical use, and present wetland condition (i.e., relative level of disturbance). Accessibility was determined first by the presence of Salmo and Lamo soils in Lancaster County, and second by depending upon landowner permission to access sites. Known historical use was determined by soil survey characterization of saline soils and personal communications with landowners. Thus, those areas where large expanses of saline wetlands previously occurred were identified as primary sampling sites, while minor seeps were not used in this study. For a map of historical saline wetlands, see Farrar and Gersib (1991).

The final selection criterion was present wetland condition. This was determined by observable soil hydrological characteristics (ponding, clayey soils), indicator plant species, and the presence of obvious surface salt deposits. The sites were then characterized as either permanently altered (drained), altered but still hydrologically connected via surface water (ponding evident), or unaltered (restored or remnant wetland). Although restored wetlands may have previously been altered, they are relatively unaltered compared to agricultural lands. Unaltered sites were further classified by flooding frequency (f) as periodically flooded or dry for periods greater than one year ($f > 1$ year), flooded once annually ($f = 1$ year), or standing water present ($f < 1$ year). Of the 14 sites selected, six were altered, two were altered but still connected, and six were unaltered with flooding frequencies spanning all categories (two $f > 1$; three $f < 1$; one $f = 1$).

MATERIALS AND METHODS

We exposed soil samples to controlled environmental wetland) conditions to assess seed viability using the methods of previous wetland (Kadlec and Smith 1984; Galatowitsch and van der Valk 1996; Rossell and Wells 1999) and saline wetland (Noe and Zedler 2000) seed bank studies. We collected soil samples in December 2001 and January 2002 using an 8.3 cm diameter × 7.5 cm deep corer (ca. 400 cm^3 of soil). Three soil cores were sampled every 5 m following a 25 m transect perpendicular to the water's edge (or where water pooled), beginning at the shoreline. We combined cores in bags unique to site and location along the transect, and stored samples at ambient winter temperatures (-12°-0°C) until germination trials in mid-January. Prior to greenhouse trials we removed organic debris from samples and

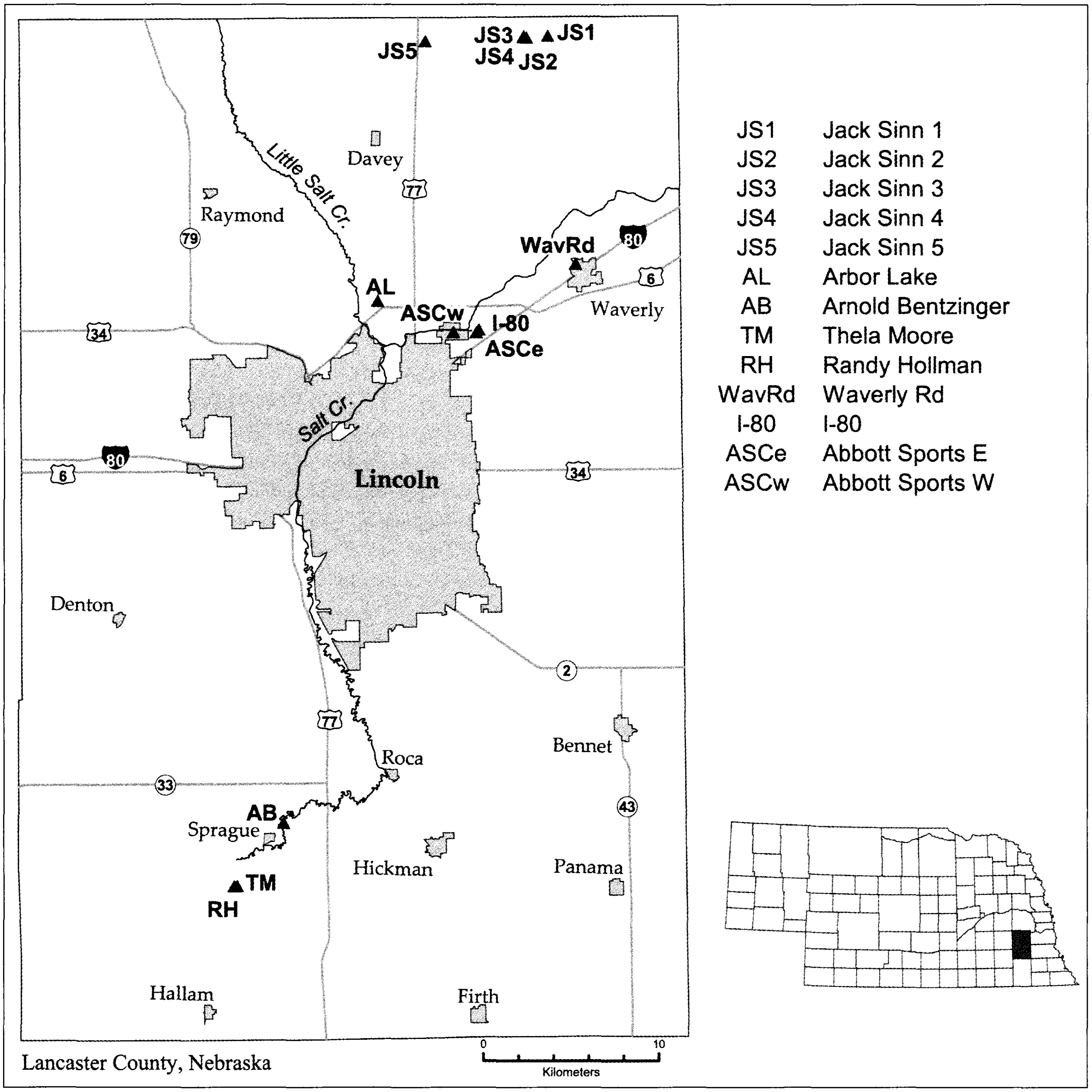

Figure 1. Map of Lancaster County, NE, showing location of soil sample sites near Lincoln, NE. One landowner desired to remain anonymous (AA; Table 2) and is not shown on the map.

thoroughly mixed each soil sample. The subsamples we tested were comprised of approximately 300 cm^3 of soil added to 300 cm^3 of sterilized sand in a 15 cm diameter plastic pot.

To correct for temperature gradients within the greenhouse, we blocked subsamples first by location along the transect, and second by treatment. Thus, each of the five transect locations received the same water treatments (flooded and moist). Pots within each water treatment (and transect location) were randomly assigned a soil subsample or 600 cm^3 sand (control) and placed in a plastic tub (33 x 30.5 x 15 cm). Sixteen pots (14 soil subsamples + 2 controls) were randomly distributed (3-4 pots per tub across 5 tubs) within each transect location (n = 5) for each water treatment (n = 2). Control pots were used to monitor seed crossover or contamination.

TABLE 1
GERMINATION CONDITIONS AND VEGETATIVE ASSOCIATION FOR PLANT SPECIES LIST FOR CENTRAL PLAINS

Number in Table 2	Species	Common name	Treatment[a]	Land indicator[b]	Association[c]
1	*Amaranthus* sp.	Pigweed	M	U	FAC+
2	*Ambrosia psilostachya* DC.	Western ragweed	M	U	FAC
3	*Atriplex subspicata* L.	Spearscale	M	S	FACW
4	*Bidens frondosa* L.	Beggartick	M	U	FACW
5	*Brassica* spp.	Mustard	M	U	U
6	*Capsella bursa-pastoris* (L.) Medic.	Shepherds purse	M	U	FACU
7	*Conyza canadensis* (L.) Cronq.	Horseweed	M	U	FACU
8	*Erigeron philadelphicus* L.	Common fleabane	M	U	FAC
9	*Helianthus annuus* L.	Annual sunflower	M	U	FACU
10	*Latuca* sp.	Prickly lettuce	M	U	FACU, FAC+
11	*Oxalis stricta* L.	Wood sorrel	M	U	U
12	*Panicum dichotomiflorum* Michx.	Fall panicum	M	U	FAC
13	*Phyla lanceolata* (Michx.) Greene	Fogfruit	M	W	OBL
14	Poaceae spp.	Grasses	M	U	FAC, FACU, FACW, OBL, U
15	*Polygonum arenastrum* Bor.	Knotweed	M	U	U
16	*Rorippa* sp.	Mustard	M	U	FAC, FACW, OBL
17	*Rumex patientia* L.	Patience dock	M	W	
18	*Salicornia rubra* A. Nels.	Saltwort	M	S	OBL
19	*Suaeda depressa* (Pursh) S. Wats.	Seablite	M	S	FACW
20	*Taraxacum officinale* G.H. Weber	Dandelion	M	U	FACU
21	*Thlaspi arvense* L.	Pennycress	M	U	NI
22	*Veronica peregrina* L.	Speedwell	M	U	OBL
23	*Viola* sp.	Wild violet	M	U	FAC, FACU, FACW
24	*Ammannia coccinea* Rottb.	Toothcup	M, F	W	OBL
25	*Bacopa rotundifolia* (Michx.) Wettst.	Disk water hyssop	M, F	W	OBL
26	*Cyperus acuminatus* Torr. & Hook.	Taperleaf flatsedge	M, F	W	OBL
27	*Echinochloa crusgalli* (L.) Beauv.	Barnyard grass	M, F	W	FACW
28	*Eleocharis lancelolata* Fernald. (or *obtusa* [Willd.] J.A. Schultes)	Spikerush	M, F	W	FACW, OBL
29	*Eleocharis* spp.	Spikerush	M, F	W	FACW, OBL
30	*Juncus* spp.	Bulrush	M, F	W	FAC, FACW, OBL
31	*Lindernia dubia* (L.) Pennell	False pimpernel	M, F	W	OBL
32	*Polygonum hydropiperoides* Michx.	Swamp smartweed	M, F	W	OBL
33	*Ranunculus scelerata* L.	Celery buttercup	M, F	W	OBL
34	*Typha* spp.	Cattail	M, F	W	OBL
35	*Chara* sp.	Muskgrass	F	W	OBL
36	*Lemna minor* L.	Duckweed	F	W	OBL
37	*Sagittaria graminea* Michx.	Arrowhead	F	W	OBL

[a] Treatments indicate germination conditions: M = moist; F = flooded.

[b] Land indicator status denotes soils where the plant species typically occurs: U = upland; S = saline; W = wetland.

[c] Vegetative association is from the national list of plant species for the Central Plains, Region 5 (Reed 1988). Likelihood of appearance (in percent) is in parentheses. OBL = obligate wetland or almost always under natural wetland conditions (>99%); FACW = facultative wetland or usually found in wetlands (occasionally not) (67%-99%); FAC = facultative or equally likely to occur in wetlands or nonwetlands (34%-66%); FACU = facultative upland or usually found in nonwetlands (67%-99%) but occasionally found in wetlands (1%-33%); UPL = obligate upland or occurs in a wetland in another region but almost always occurs in nonwetlands in Region 5 (>99%); + and – denote higher and lower end of category, respectively.

Tubs were filled with deionized (DI) water 4-6 cm above the soil surface for flooded trials and to the soil surface for moist trials. We did not use saline water (to test different concentrations of salinity) because of limitations in time and space. Including a salinity gradient as treatments (e.g., 0, 100, 250, 500 µS/cm) would increase the total experimental units by a factorial. Water infiltrated through perforations in the lower pot surface to allow for upward saturation in a manner mimicking groundwater inflow. Flooded samples that yielded large floating organic debris (nonseeds such as wood chips, dried plant material, etc.) were subsequently sieved after the initial flooding. For both water treatments, soils remained undisturbed after the initial watering.

We checked pots daily for seed germination and added DI water when necessary to maintain the desired tub water depth for the duration of the study (about four months). We selected the four-month evaluation period because previous studies have shown upwards of 90% emergence within the first three to four months (Pederson 1983; Galatowitsch and van der Valk 1996). Thermometers were placed in tubs to measure temperatures across the greenhouse to observe thermal gradients, if present. Tub salinity, pH, and temperature were measured twice throughout the experiment using a YSI-85 multifunction meter (YSI Environmental, Yellow Springs, OH) to monitor changes in hydrological conditions. We allowed plants to grow until we could identify them to the lowest practicable taxon and then removed the plant. Species densities were not recorded; therefore, no quantitative comparisons of species richness can be made.

RESULTS

Fewer flooded pots showed emerged seedlings (73%) than pots subjected to moist conditions (86%). More plant taxa germinated under moist treatments (23 species) and different, albeit fewer, species germinated under submerged conditions (Table 1). Saline indicator plant species (*Atriplex subspicata, Salicornia rubra, Suaeda depressa*) germinated only under moist conditions, whereas nonsaline wetland taxa (e.g., some *Typha, Eleocharis, Sagittaria*) germinated under both moist and flooded conditions. Germination did not occur in sand-filled control pots; however, algae eventually appeared in most flooded control pots. These algal blooms (unidentified species) covered the water surface in flooded conditions for the duration of the experiment, potentially delaying if not inhibiting seed germination. Also, some plants (*Polygonum, Bidens, Latuca*) grew to sizes that potentially shaded seedlings within the same pot before they reached sufficient size for identification.

All sampled agricultural fields had partially viable wetland seed banks indicated by germination of at least one wetland species, even when only upland vegetation was observed in the field. Two agricultural sites located closest to either a stream (RH) or with a constructed wetland on the property (TM) showed greater wetland flora richness (Table 2). All fields had been altered or permanently drained, except RH and TM, where ponding after rain events or permanent ponds occurred, respectively. Disturbed roadsides had wetland species during sampling, which were again noted in the germination trials (Table 2). Turfgrass field sites were entirely monospecific with no evidence of wetland species, yet these sites showed the highest wetland plant diversity under greenhouse conditions among all sites tested, including restored and current wetlands.

Restored wetlands at Jack Sinn WMA were tested to evaluate the current seed bank and to determine if additional seeding was necessary. All restored wetlands had wetland flora, including the saline indicator saltgrass (*Distichlis spicata*). Germination data revealed one additional saline indicator species (*A. subspicata*) from only one site (JS1), a wetland species (*Typha*) common to all sites, and several upland and wetland taxa across all restored wetlands. Only three restored sites (JS2, JS3, and JS5) had additional wetland species (e.g., *Eleocharis, Lemna, Ammania*), yet several upland species (e.g., *Panicum, Amaranthus, Ambrosia*) were observed both in the field and in the greenhouse. Arbor Lake WMA is a saline wetland with distinctive indicator species (*Salicornia rubra, Suaeda depressa*) that also appeared in greenhouse trials.

Conductivity measurements revealed highly variable salinities (from 40 to 1210 µS/cm) depending on the tub sampled; therefore, there was a high diversity in salinity across the sampled field sites. The pH was more consistent between treatments, with flooded pots ranging from 7.3 to 8.3 (mean ± standard error, or se; 7.8 ± 0.3) and moist pots ranging from 7.1 to 8.0 (7.5 ± 0.3). One month later, pH tended to be higher for both flooded and moist conditions, although not significantly ($P > 0.1$). Salinity decreased overall by the second measurement, despite increases observed in a few tubs. Tubs containing soils from Arbor Lake WMA or Jack Sinn WMA (locations with active saline seeps and decreased disturbance) showed high salinities in one or more pots, while tubs containing predominantly agricultural site soils, roadside easement soils, or both showed relatively lower salinities.

TABLE 2
LOCATIONS AND DESCRIPTIONS OF FIELD SITES
For site key, see Fig. 1. For species germinated key, see Table 1.

Site (see Fig. 1)	West longitude	North latitude	Description[a]	Type germinated[b]	Type observed[b]	Species germinated (see Table 1)	Land use characteristic[c]
AA	NA	NA	Agricultural field	W, U	U	8, 14, 32, 34	Altered, salt present
AB	96.44.477	40.38.297	Agricultural field	W, U	U	1, 14, 23, 34	Altered
ASCe	96.36.765	40.53.285	Agricultural field	W, U	U	7, 12, 14, 15, 22, 24, 31, 34	Altered
ASCw	96.37.314	40.53.372	Agricultural field	W, U	U	6, 8, 10, 11, 14, 20, 24, 25, 27, 28, 30, 31, 34, 35, 37	Altered
RH	96.46.834	40.36.701	Agricultural field	W, U	W, U	5, 8, 14, 21, 22, 24, 26, 29, 33, 34, 36	Altered, ponding
TM	96.46.116	40.36.767	Agricultural field	W, U	W, U	2, 8, 13, 14, 16, 21, 26, 28, 29, 31-34	Altered but connected, ponding
I-80	96.36.178	40.53.795	Disturbed roadside	W, U	W, U	8, 14, 24, 26, 29–31, 34	Altered but connected, ponding
WavRd	96.32.468	40.55.735	Disturbed roadside	W, U	W, U	14, 21, 24, 26, 27, 29, 30, 33, 34	Altered, salt present, ponding
JS1[d]	96.33.736	41.02.810	Restored wetland	S, W, U	W, U	3, 14, 34	Unaltered, $f > 1$
JS2[d]	96.34.006	41.02.525	Restored wetland	W, U	W, U	12, 14, 28, 30, 34, 36	Unaltered, $f < 1$
JS3[d]	96.34.671	41.02.777	Restored wetland	W, U	W, U	14, 24, 26, 28, 29, 34	Unaltered, $f < 1$
JS4[d]	96.34.658	41.02.641	Restored wetland	W, U	W, U	14, 17, 34	Unaltered, salt present, $f = 1$
JS[d]	96.38.637	41.02.061	Restored wetland	W, U	W, U	1, 2, 4, 9, 14, 17, 21, 30, 34	Unaltered, salt present, $f > 1$
AL[d]	96.40.716	40.54.272	Natural wetland	S	S, W, U	18, 19	Unaltered, indicators present, salt present, $f < 1$

[a] Field site descriptions generically describe the current land use or disposition of the soil. All sites were located on soil types where saline wetlands may be found (see Study Area).

[b] Species types that germinated belonged to one of three land indicator categories: S = saline, W = wetland, U = upland. For all agricultural fields (and the natural wetland), species types that germinated differed from species types observed.

[c] Flooding (f) frequency: $f > 1$ denotes flooded or dry for periods greater than one year; $f < 1$ denotes standing water present; and $f = 1$ denotes flooded once annually.

[d] *Distichlis spicata* L., a wetland, saline indicator plant species, was observed at all Jack Sinn (JS) WMA sites and at Arbor Lake (AL) WMA, although germination trials either did not produce viable specimens, or the grasses germinated were unidentifiable and included in Poaceae sp

DISCUSSION

This study was designed to evaluate historical saline wetland seed banks as potential restoration sites. Tests from our 14 sites revealed vegetation that would likely occur if wetland conditions returned. The results indicated that, of the sites included in this study, no agricultural or private lands contained saline wetland indicator species in their seed banks. Additionally, the majority of these sites contained limited wetland species overall (e.g., *Typha* spp., *Polygonum hydropiperoides*). Land alteration over the past 50 years has apparently eliminated viable seeds, since these sites existed as saline wetlands prior to agricultural or municipal development. Of the restored wetlands examined, only one exhibited a saline indicator species in addition to a few other wetland taxa.

Multiple indicator species occurred only in the natural saline wetland (AL). Similarly, Seabloom and van der Valk (2003) evaluated restored prairie wetlands after five years and found not only fewer wetland taxa than in natural wetlands, but those restored wetland species represented only a subset of the natural wetland species richness. Thus, restored saline wetlands may need an introduction of indicator species to bring about a desired saline wetland flora. More importantly, if restored wetlands lack seed banks of indicator species, preserving existing saline wetlands may be the only means to protect the inland saline wetlands in Nebraska.

Vegetation is only part of a successful saline wetland restoration. Vegetation can be reintroduced or naturally reestablished with a return of wetland hydrology, and hydrological conditions can be partially reinstated through removing or filling drain tiles and ditches (Farrar and Gersib 1991), regulated flooding, and additional land alteration. Soil salinity, however, is a major limiting factor in the preservation of saline wetlands. Salinity has been shown to alter germination and the edaphic (soil) microorganism communities (Ungar 1996; Caravaca et al. 2005). The appropriate soil ionic potential must be present as a requirement for germination and growth of many saline wetland plant species (Kadlec and Smith 1984; Wijte and Gallagher 1996; Noe and Zedler 2000, 2001). Leached and drained agricultural soils removed from the natural seep of saline groundwater lack historic salinity levels. Only restored wetlands displayed measurable amounts of surface salts. Nevertheless, we do not currently know the precise saline soil requirements for establishing the ionic conditions necessary for saline ecosystem dynamics. Consequently, there is no established methodology for renewing saline wetlands where they once existed or for creating new ones.

The source of the salinity, once thought to be the Dakota sandstone aquifer, is now believed to originate below the Dakota from older bedrock within Pennsylvanian strata (Harvey et al. 2002). Current studies are reevaluating the source of salinity for these unique wetlands. Knowing the origin of the salinity is crucial; however, utilizing the salinity to reinstate historical wetland characteristics is more complex. Groundwater salinity levels are above levels tolerable to all but a few highly adapted plants (Harvey et al. 2002). Thus, using groundwater in restoration efforts becomes problematic. Present saline soil conditions exist based on a hydrologic regime created over millennia. Land alterations and soil inundation alone cannot restore saline wetlands to historical states, as the process is dependent upon saline influx.

Ionic gradients have been shown to affect germination, seasonal growth, and fecundity patterns of plant species associated within these saline ecosystems (Kadlec and Smith 1984; Ungar 1996; Noe and Zedler 2001). Because saline ecosystems depend on the interaction of several key components, there are no easy recipes for restoring and maintaining the flora. This ultimately complicates any restoration process. Therefore, researchers should conduct additional germination studies at more sites and especially within restored habitat to better understand saline wetland plant requirements and their relationship to sources of salinity.

Inland saline wetlands pose unique opportunities for research, education, aesthetic appreciation, and experience managing the interface between nature and man. Currently, steps have been taken to preserve the eastern saline wetland complex near Lincoln, NE, including the creation of a city task force and established mitigation guidelines emphasizing in-kind wetland banking (Taylor and Krueger 1997). Of the species endemic to the saline wetland complex, saltwort (*Salicornia rubra* A. Nels) is now state protected, whereas the Salt Creek tiger beetle (*Cicindela nevadica lincolniana* LeConte) is both state and federally protected. Remaining wetland sites are found in areas where the necessary geologic and hydrologic conditions still exist anthropogenically unaltered, but these sites are outside the range where endangered species protection exists. Many historical sites have lost these characteristics, and thus, restoration clearly depends on the preservation of seed banks in extant saline wetlands (for seed source) and on further study of the reintroduction of these unique habitats.

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