Impacts of Brine on Soil and Vegetation in the Bakken Region of Western North Dakota

Hannah Tomlinson, Aaron Klaustermeier, Ryan Limb, Aaron Daigh, & Kevin Sedivec

School of Natural Resource Sciences, North Dakota State University, Fargo, North Dakota

Introduction

Justification

The Bakken shale formation encompasses two-thirds of western North Dakota (ND) (Fig. 1). Brine contamination is an environmental concern where oil production occurs[1] (Fig. 2). Electrical conductivity (EC) measures the electrical current generated by soluble salt ions in the soil, eg., Na^+, Cl^-. An EC greater than 4 dS m^{-1} indicates salinity problems. In the absence of remediation techniques, salts from spills can remain in the soil profile for decades, significantly reducing soil and plant productivity. Spill sites will remain barren until the chemical stressor is reduced or removed.

Fig. 1: Bakken Shale Formation stretches 300,000 sq. mi. beneath three U.S. states and two CA provinces

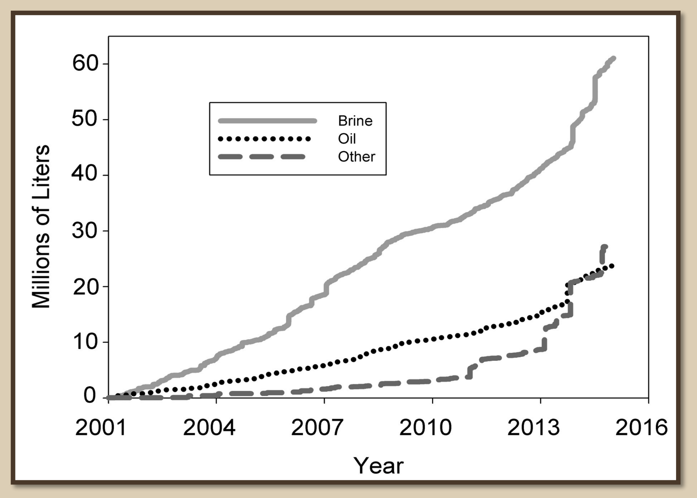

Fig. 2: North Dakota Department of Health Spill Report Database since 2001

Objectives

- Collect and analyze soil and plant data to create a baseline for remediating land affected by brine spills
- Describe implications of non-reclaimed spill sites

Hypotheses

- EC will decrease starting from center of spill, moving outward toward the spill boundary
- Bulk density will decrease along the EC gradient
- Plant community dynamics will change along the EC gradient

Materials and Methods

- Sampled seven non-reclaimed brine spill sites in Bottineau and Burke County, ND, 2014 (Fig. 3a)
- Collected soil and vegetation data along transects originating from center of spill, moving outward toward the spill boundary using a 1x1 m frame (Fig. 3b)
- Collected composite soil samples at three depths (0-15,15-30, and 30-60 cm)
- Analyze soil samples for EC 1:1, EC 1:5, and Saturated Paste Extract EC (EC_{SE})[3]
- Collected bulk density samples at the 0-15 cm depth
- Estimated plant cover using a modified Daubenmire (1959) cover class method
- Statistical analyses - SAS 9.3

Fig. 3a: Non-reclaimed brine spill site near Bentinck, ND, jar of brine after five years in left-hand corner

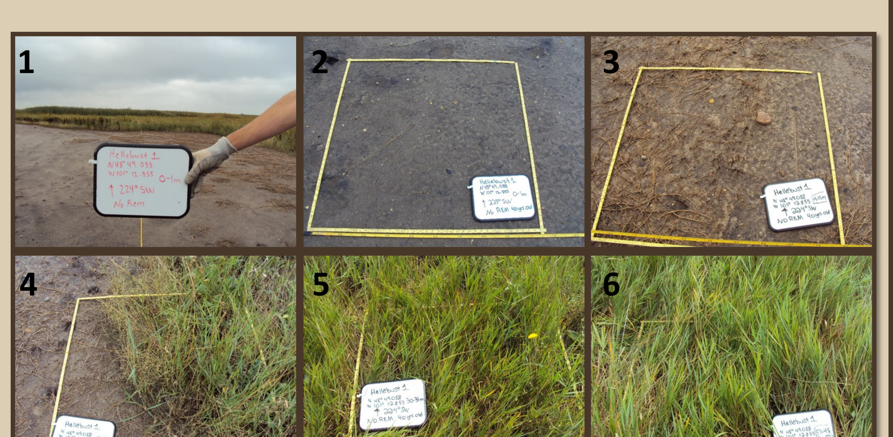

Fig. 3b: Gradient frame pictures from center of spill (1), moving outward toward the spill boundary (6)

Results & Discussion

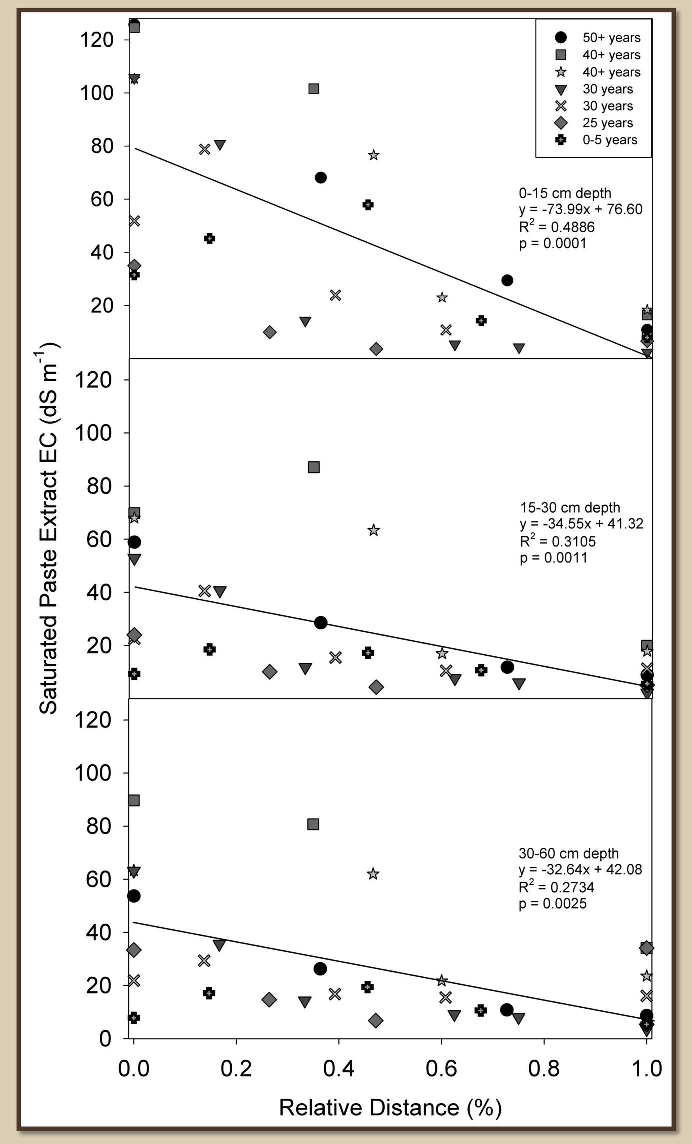

Fig. 4: EC_{SE} levels at 0-15, 15-30, and 30-60 cm depths for seven non-reclaimed brine spills in western ND

Fig. 6: BD holes on brine spill site in western ND

Soil Properties

- EC 1:1, EC 1:5, and EC_{SE} were highly correlated ($R^2 \geq 0.90$; $p<0.05$)
- EC_{SE} decline paralleled the increase in vegetation ($p<0.05$) (Fig. 4)
- EC_{SE} were highest in the 0-15 cm depth
- Age of spill was not a contributing factor for EC_{SE}
- Bulk density (BD) decreased with relative distance ($p<0.05$) (Figs. 5 & 6)
- Soil compaction reduces water infiltration and restricts root growth (BD >1.6 g/cm^3)

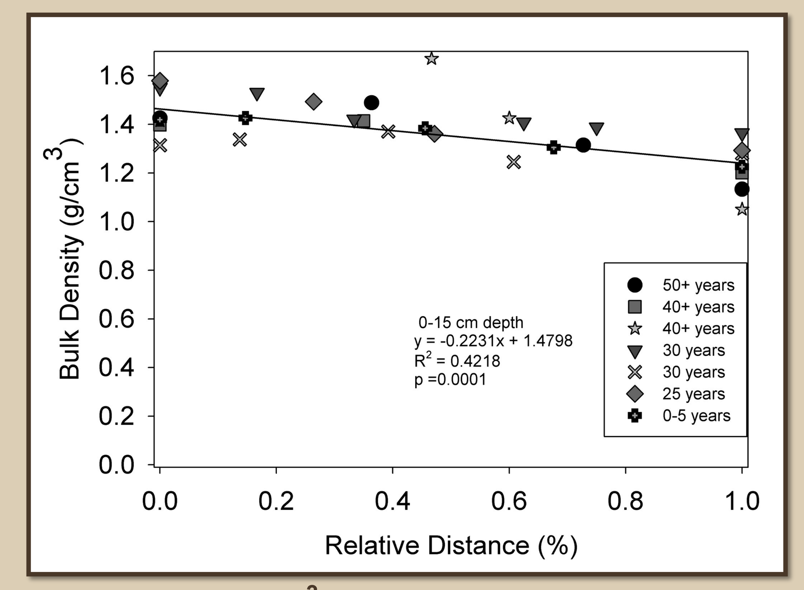

Fig. 5: BD (g/cm^3) for the 0-15 cm depth on seven non-reclaimed brine spill sites in western ND

Plant Cover

- Plant diversity and evenness were positively correlated with a decrease in EC_{SE} ($p<0.05$) (Fig. 7)
- Inflation of plant diversity and evenness occurred due to weedy halophytic species
- Salts decrease soil water potential energy resulting in plant root desiccation
- Salts near the soil surface reduce the number of available "safe-sites" for seed germination and establishment[4] (Fig. 8)

Fig. 8: Visible salt crust from brine spill in western ND

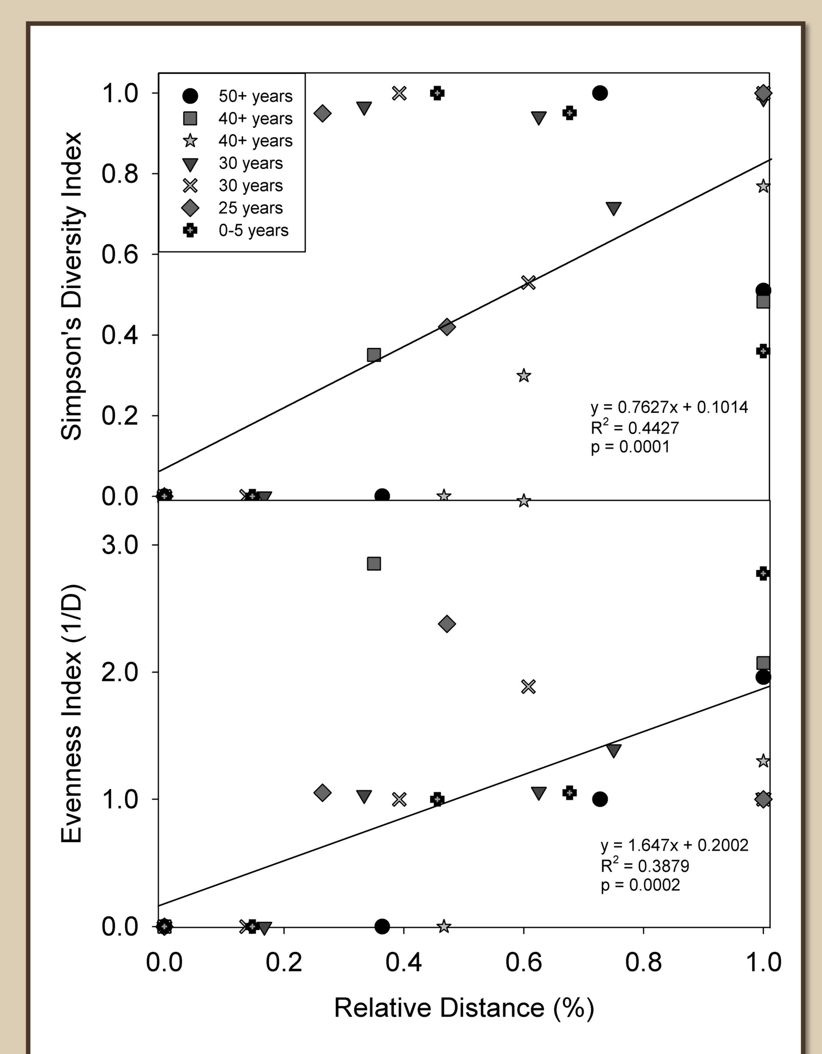

Fig. 7: Simpson's diversity and evenness indices for seven non-reclaimed brine spill sites in western ND

Conclusions

- Brine contamination is an anthropogenic disturbance that stalls natural successional processes (Fig. 9)
- The "do nothing" approach will not restore brine spill sites to pre-spill conditions on a practical time scale
- Briske et al. (2006) refers to this threshold category as property extinction
- Water scarcity in western rangelands limit salts from leaching to lower depths, inhibiting germination and propagation of plant roots
- Weedy halophytic species occupy a niche at the edges of brine spill sites (Fig. 10)
- Brine spills are a novel disturbance resulting in a novel ecosystem
- Trajectories of remediation amendments may present challenges and opportunities to develop a framework for the recovery of this system[6]

Fig. 9: 2014 photo of a 50+ year old non-reclaimed brine spill site in western ND

Fig. 10: *Kochia scoparia* growing on the edges of a remediated brine spill site in western ND

Implications for Remediation

- Resalinization can occur in dry conditions, reducing efficacy of remediation methods
- Calcium (Ca^{2+}) amendments for leaching sodium (Na^+) may be coupled with organic materials to help alleviate the effects of soil compaction[7,8]
- In situ remediation maintains soil integrity and reduces weedy introductions via soil seed bank
- Desirable halophytic species such as *Pascopyrum smithii* (western wheatgrass), *Puccinellia nuttalliana* (Nuttall's alkaligrass), and *Sporobolus airoides* (alkali sacaton) are a low cost, in situ remediation option
- Data are a precursor for 2015 greenhouse study and baseline for measuring remediation success

Acknowledgements: Our thanks to the Northwest Landowners Association for helping us find suitable sites for our research. Funding provided by the North Dakota Industrial Commission and Energy & Environmental Research Center.

Literature Cited:

[1] Keiffer C.H., and I.A. Ungar. 2002. Germination and establishment of halophytes on brine-affected soils. Journal of Applied Ecology 39: 402-415

[2] Richards, L. A. (ed). 1969. Diagnosis and improvement of saline and alkali soils. USDA Argic. Handbook No. 60, U.S. Government Printing Office, Wash., D.C.

[3] Daubenmire, R.F. 1959. Canopy coverage method of vegetation analysis. Northwest Science 33:43-64.

[4] Harper et al. 1961. The evolution and ecology of closely related species living in the same area. Evolution 15:209-227

[5] Briske et al. 2006. A unified framework for assessment and application of ecological thresholds. Rangeland Ecology Management 59: 225-236

[6] Suding et al. 2004. Alternative state and positive feedbacks in restoration ecology. Ecology and Evolution 19: 46-53

[7] Ashworth et al. 1999. A comparison of methods for gypsum requirement of brine-contaminated soils. Canadian Journal of Soil Science 79: 449-455

[8] Zhang et al. 2008. Enhanced bioaugmentation of petroleum-and-salt-contaminated soil using wheat straw. Chemosphere 73: 1387-1392