Evaluation of Soil Treatment Techniques on Remediated Brine Spill Sites in western North Dakota

Photo courtesy of Carmen Waldo

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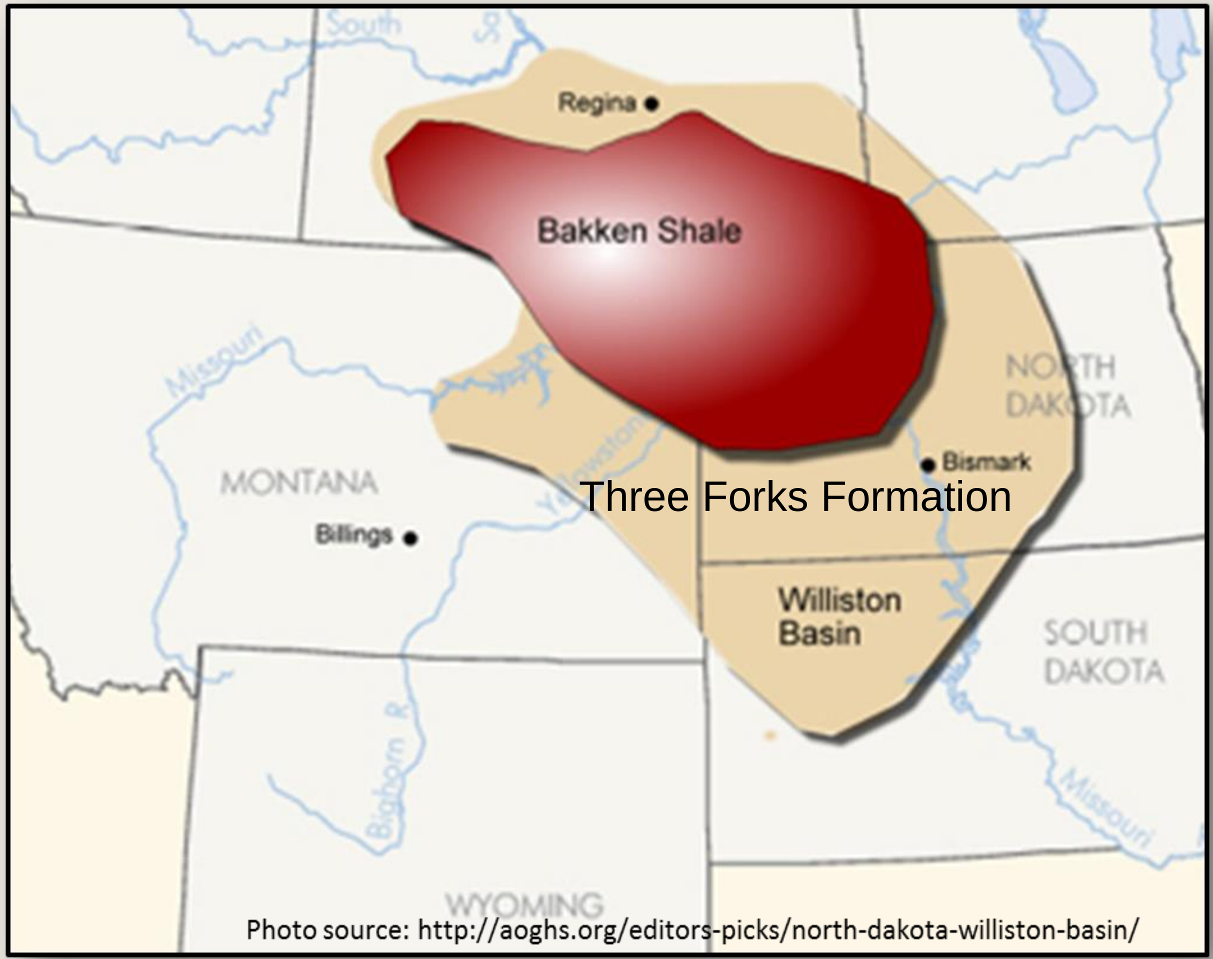
OIL PRODUCTION IN NORTH DAKOTA

- First oil boom 1950's[1]
- Second oil boom late 1970's[1]
- Third oil boom 2000's

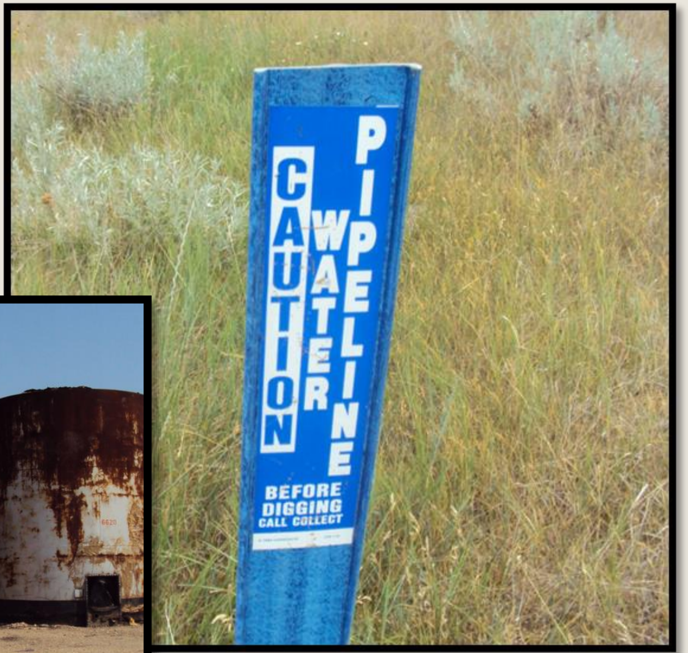
BAKKEN REGION

- Bakken & Three Forks Formation[1]
- Hydraulic fracturing
- North Dakota is the second largest oil producer in the U.S.



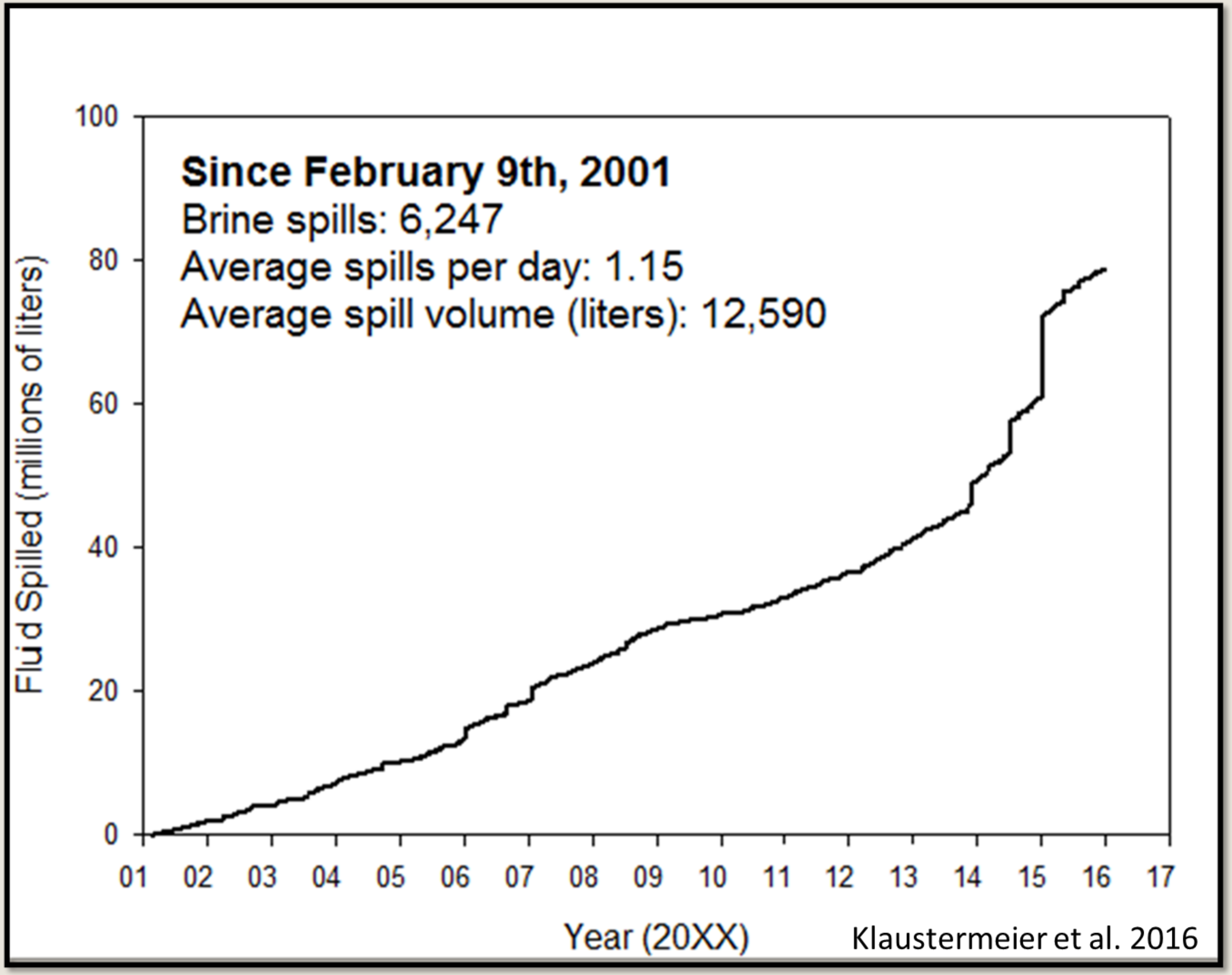
OIL-PRODUCED WATER (I.E. BRINE)

- Brine is a by-produce of oil and gas extraction
  - 90% sodium chloride (NaCl))[2]
- 1:1 brine to oil production ratio[3]
- Spills are a result of equipment failure[4]



JUSTIFICATION FOR REMEDIATION

- Non-remediated brine spills don't recover naturally
- Brine plume expansion[3]
- Remediation aims to remove or minimize the abiotic stressor



Klaustermeier et al. 2016

IMPACTS OF BRINE ON SOIL & VEGETATION

- Sodium (Na^+) disperses clay particles
  - Loss of soil structure
  - Clogs soil pores
- Ion toxicity
- Salts increase soil water osmotic potential

In situ

Chemically amended (Ca^{2+}) and subsequent leaching

Ex situ

Topsoil excavation with soil replacement

OBJECTIVES

- Evaluate *in situ* & *ex situ* remediation techniques:
  - Soil EC_e
  - Plant cover
  - Plant production

Chemical Amendment (*in situ*)

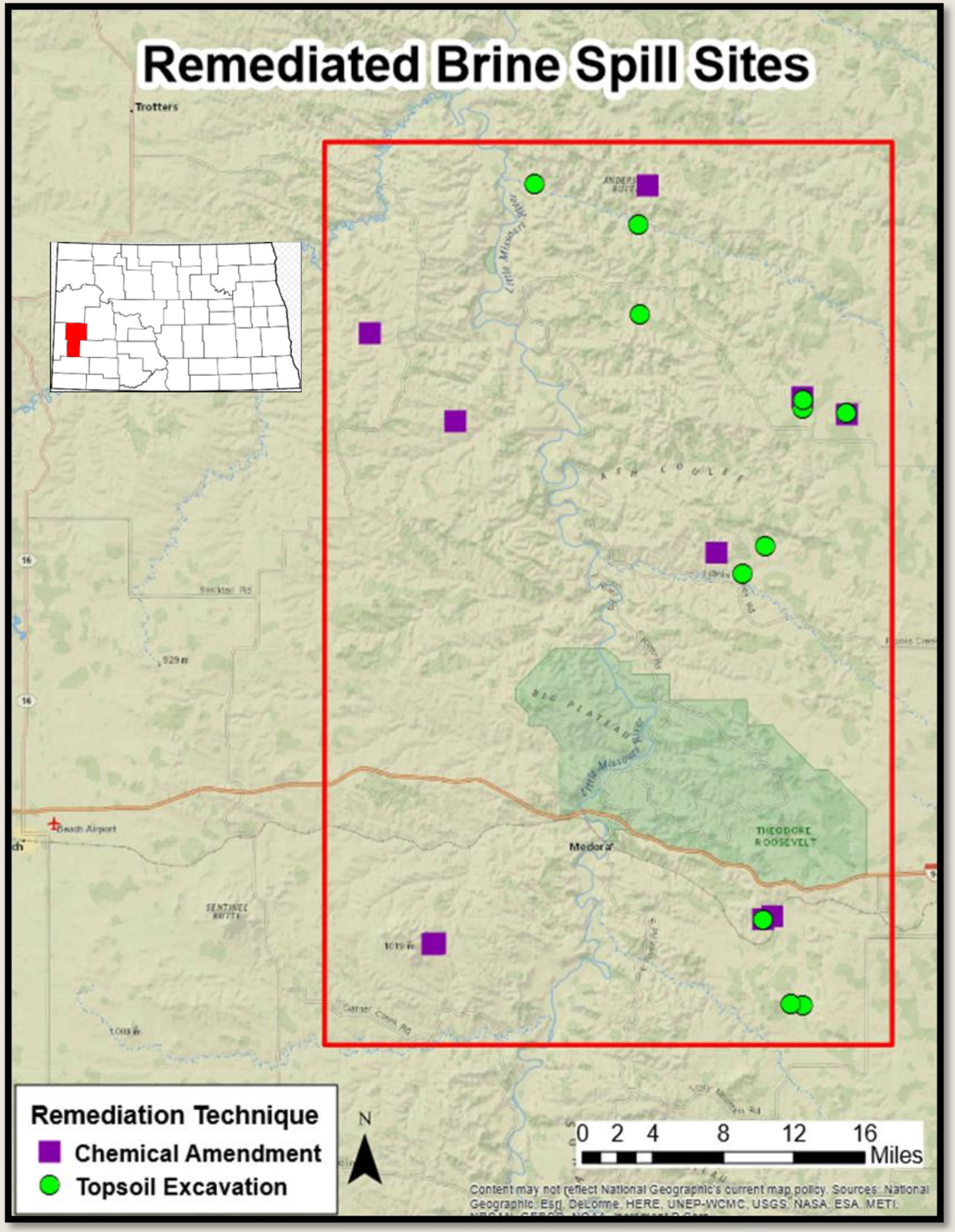
Topsoil Excavation (*ex situ*)

HYPOTHESIS

- We hypothesize no difference in soil and plant parameters between reference sites and respective remediation techniques

SITE SELECTION

- Little Missouri National Grasslands in western North Dakota
- 10 chemical amendment & 11 topsoil excavation
  - ➢ July-August 2015
- Paired-plot design
  - ➢ Reference vs. remediated



Map Credit: Sarah Anderson

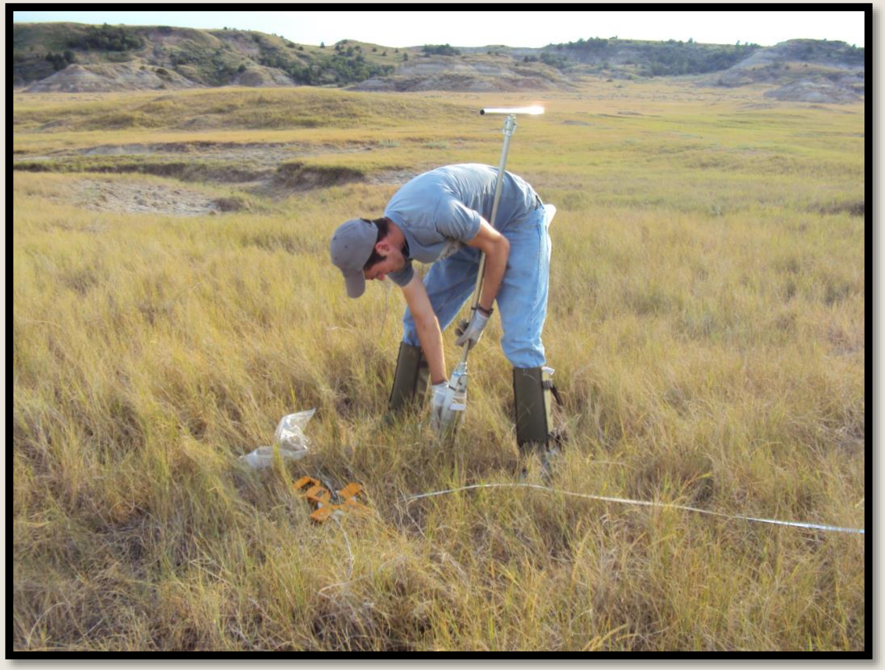
EXPERIMENTAL DESIGN

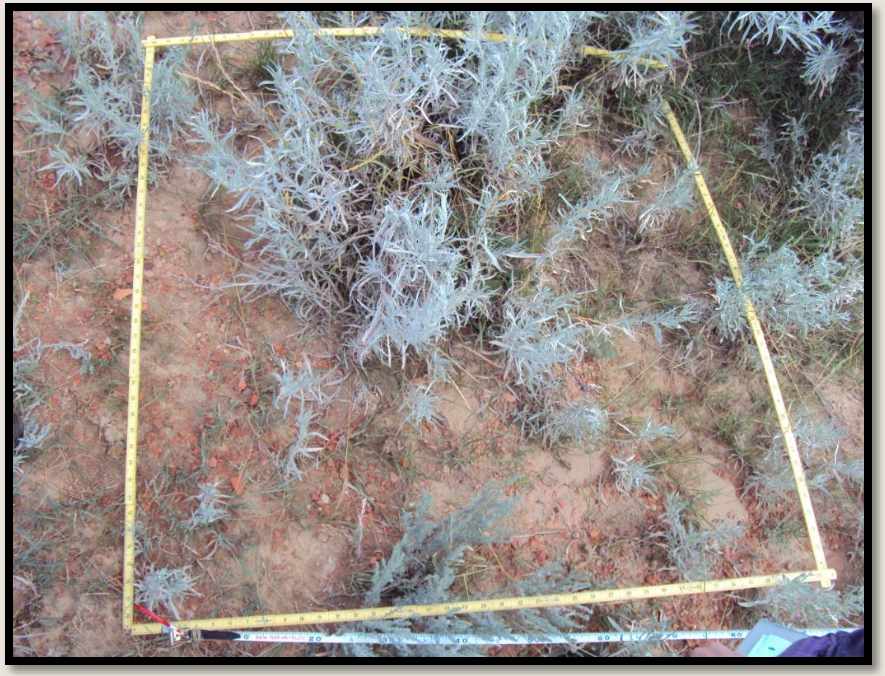
Reference

Remediated

MATERIALS & METHODS

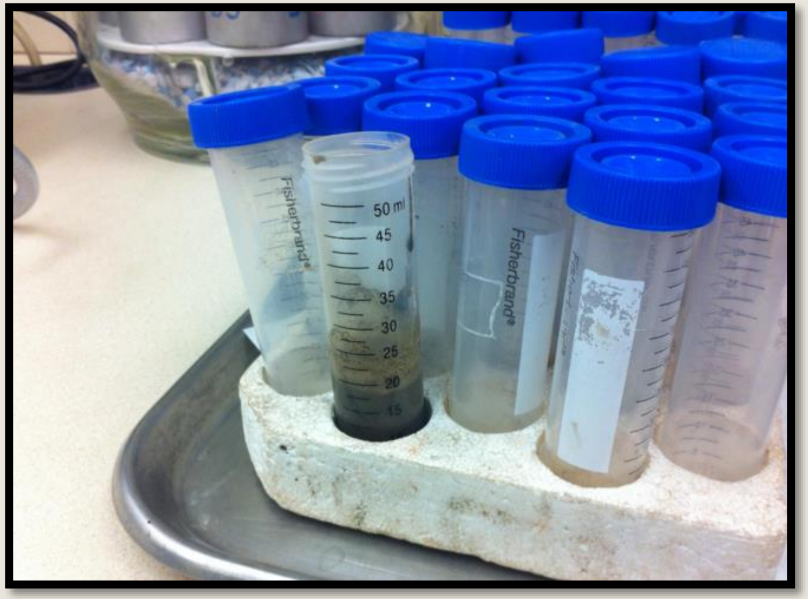
- Soil samples: 0-15, 15-30, & 30-60 cm
- Percent cover estimated (1x1m frame)
  - Modified Daubenmire (1959) cover class method
- Biomass: native and exotic functional plant groups

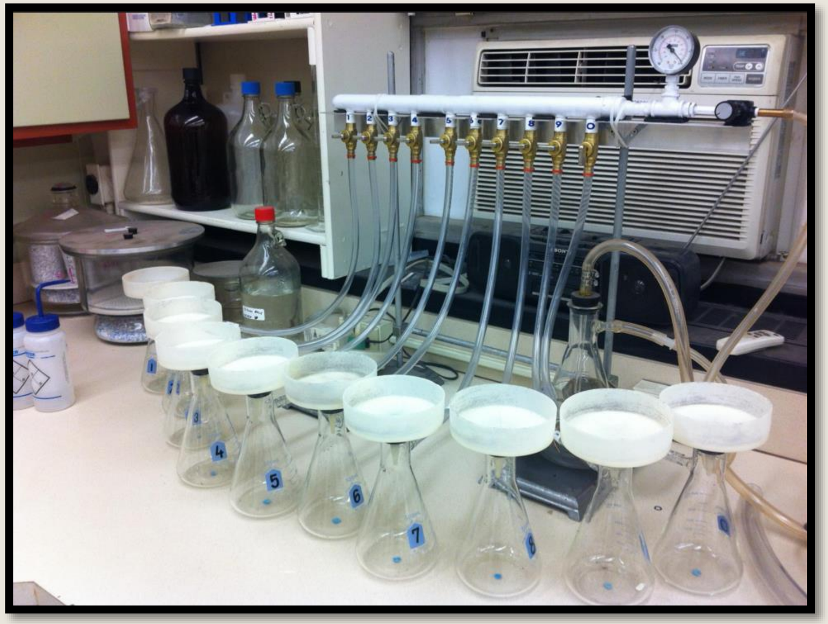




Statistical Analysis

- $EC_{1:1}$ converted to EC_e values[6,7,& 8]
  - t-tests (alpha 0.05)
- Biomass & Ground Cover
  - t-tests
- Plant Cover (PC-ORD 6.0®)
  - Diversity Indicies (t-tests)
  - Sørensen Dissimilarity Index (t-tests)
  - Nonmetric multidimensional scaling (NMS) ordination
  - PerMANOVA





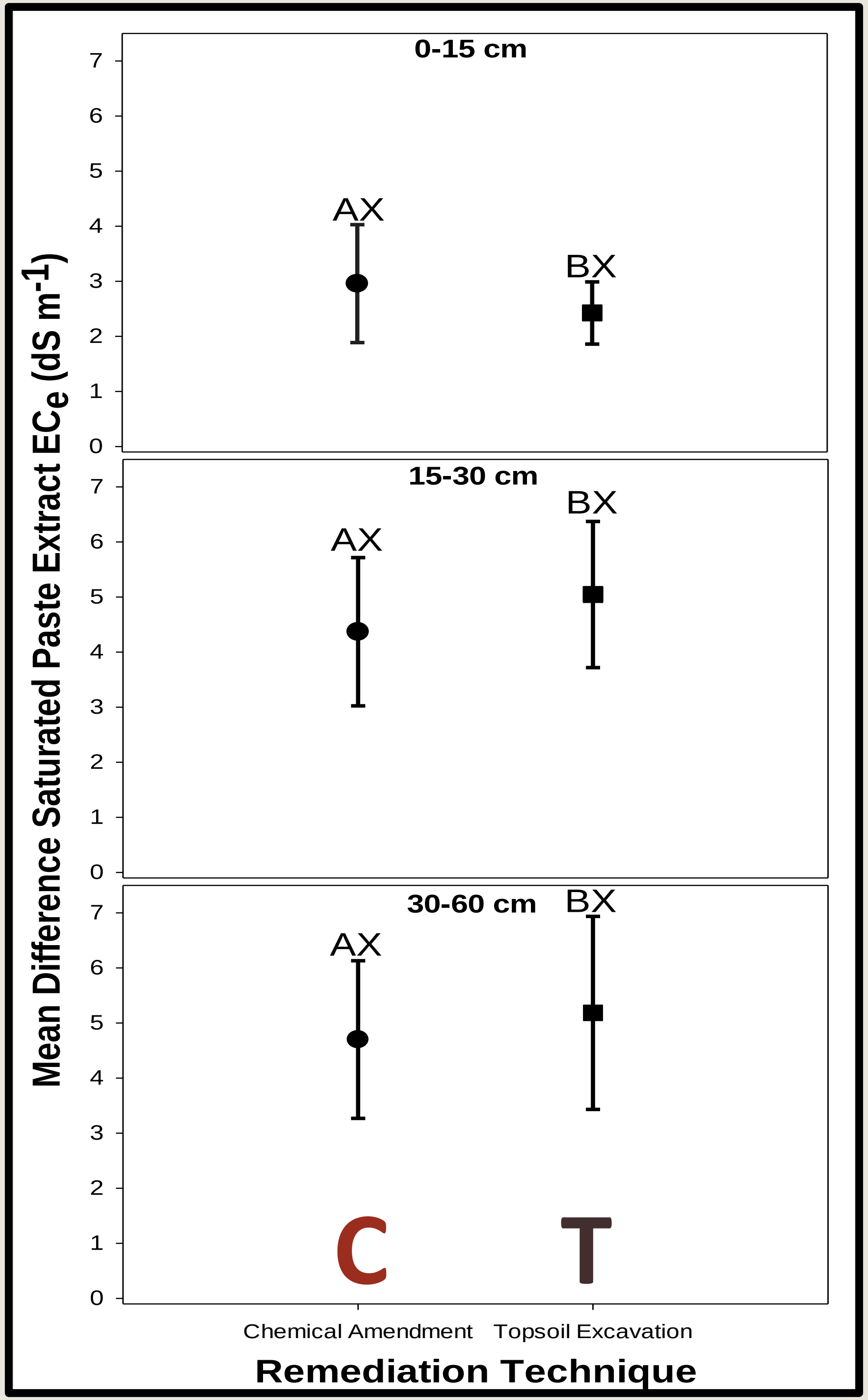
RESULTS

Soil

Vegetation

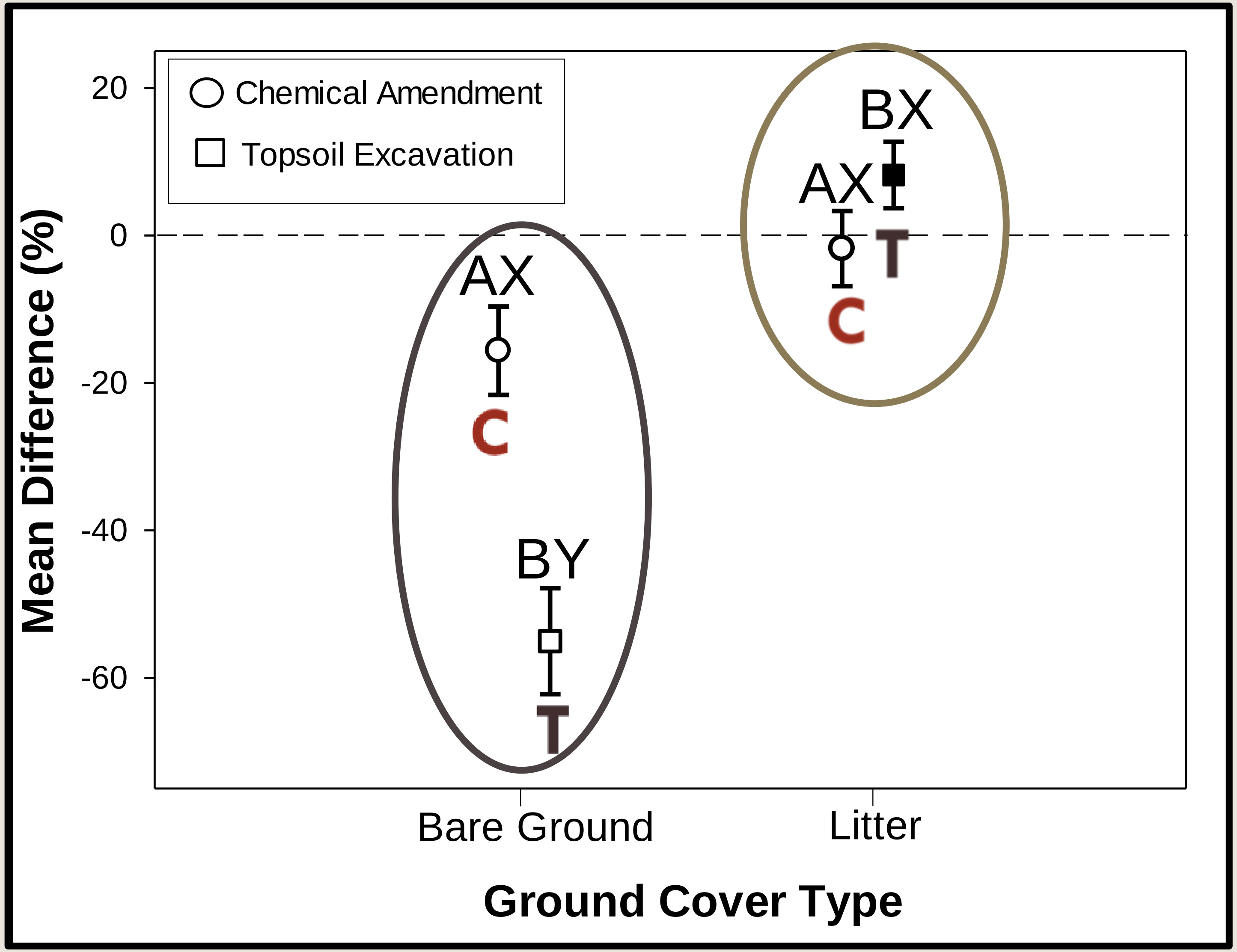
Soil EC_e

- $EC_e \neq 0$ ($p < 0.05$) at the three depths
  - ➢ Reference – Remediated = Difference (A's & B's)
  - ➢ Residual brine salts
  - ➢ Pockets of natural salinity
- EC_e chemical = EC_e topsoil ($p > 0.05$) to 60 cm
  - ➢ $\text{Remediated}_{\text{chemical}} - \text{Remediated}_{\text{topsoil}}$ = Difference (X's)



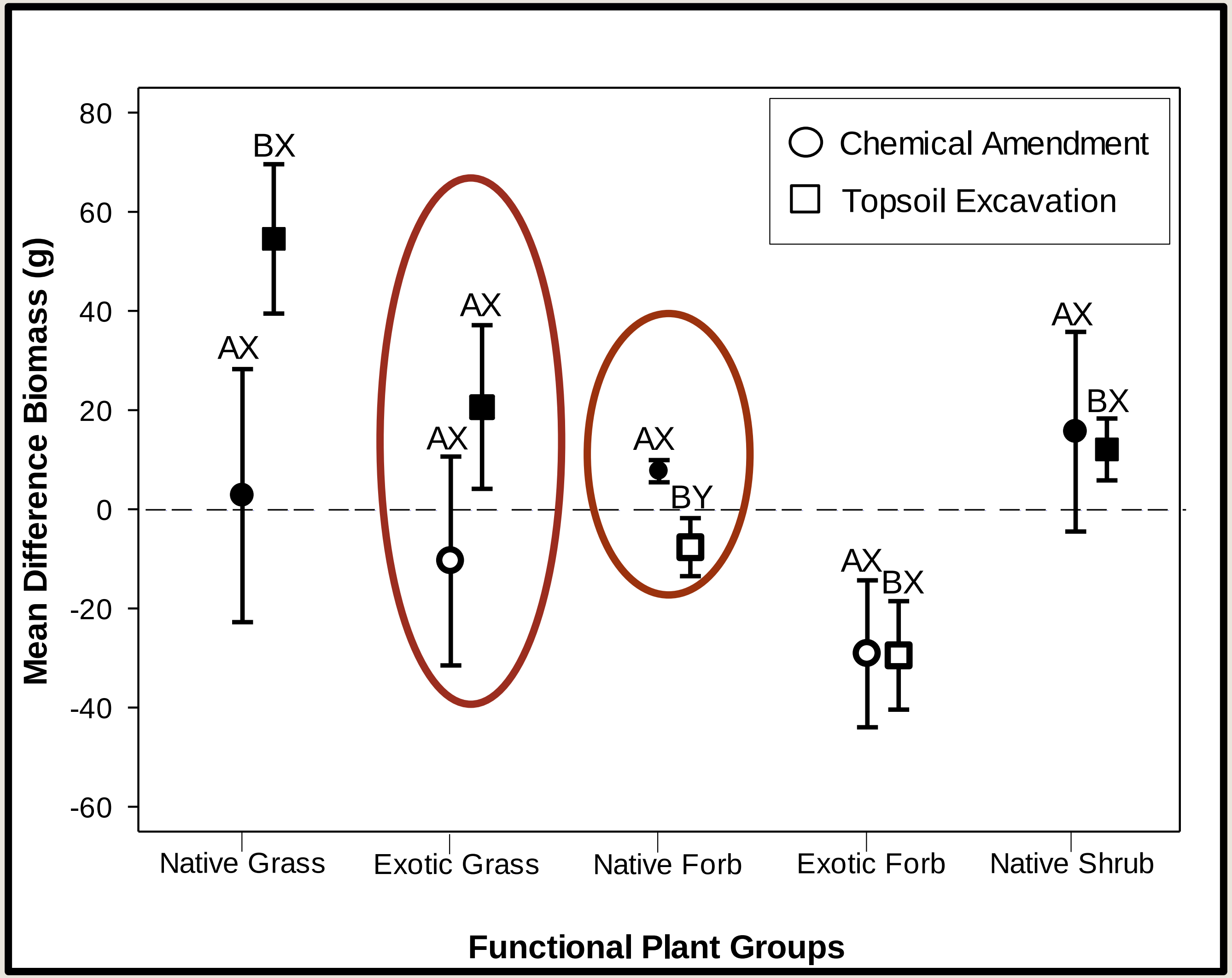
GROUND COVER

- Bare ground ($p < 0.05$)
  - REF ≠ REM
  - $REM_{chem} \neq REM_{top}$
- Litter ($p < 0.05$) ($p = 0.08$)
  - REF ≠ REM
  - $REM_{chem} = REM_{top}$



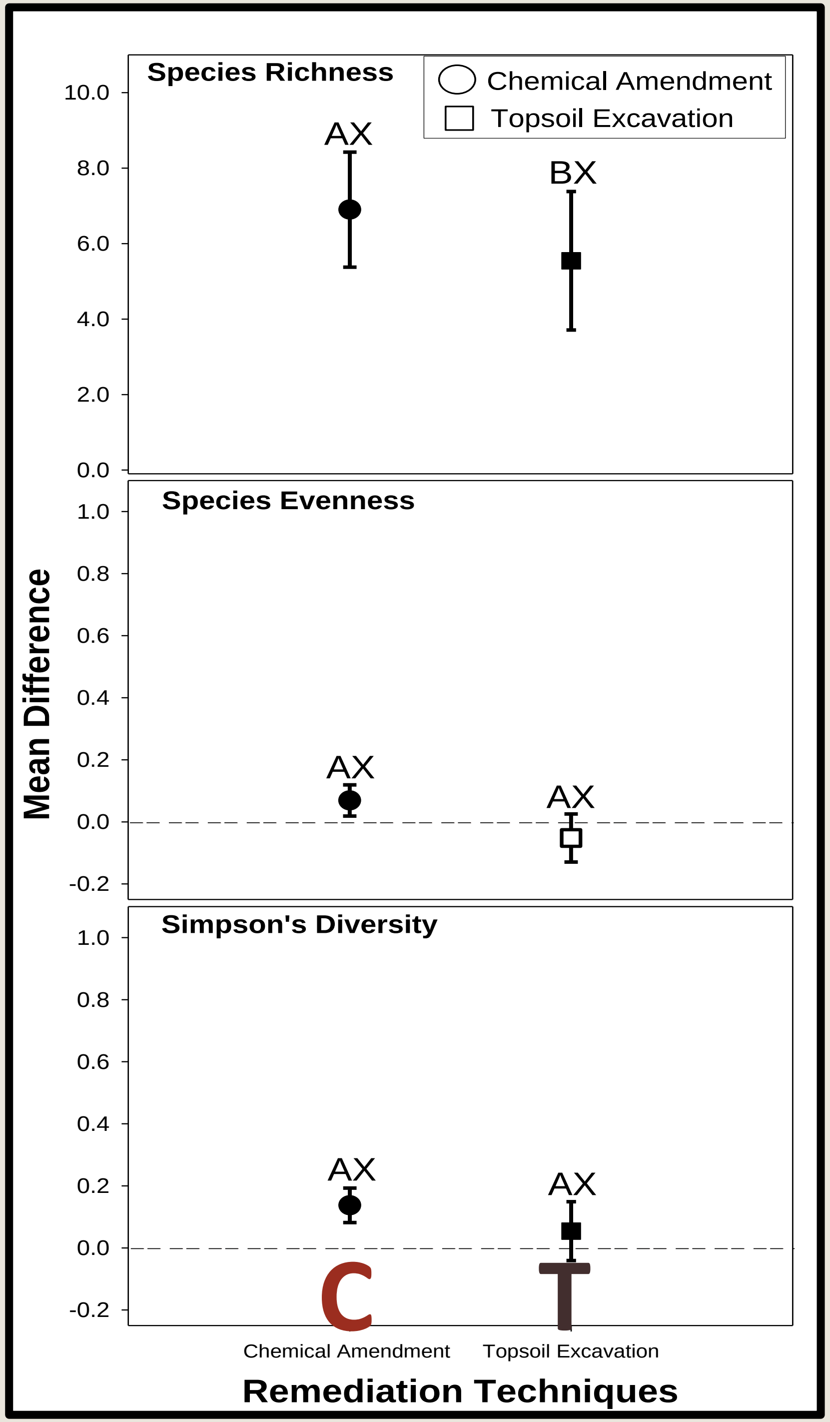
BIOMASS

- Native grass, native forb, exotic forb, native shrub ($p < 0.05$)
  - REF ≠ REM
- Exotic grass ($p \geq 0.05$)
  - REF = REM
- Native grass ($p = 0.09$), exotic grass, exotic forb, & native shrub ($p \geq 0.05$)
  - $REM_{chem} = REM_{top}$
- Native forbs ($p < 0.05$)
  - $REM_{chem} \neq REM_{top}$



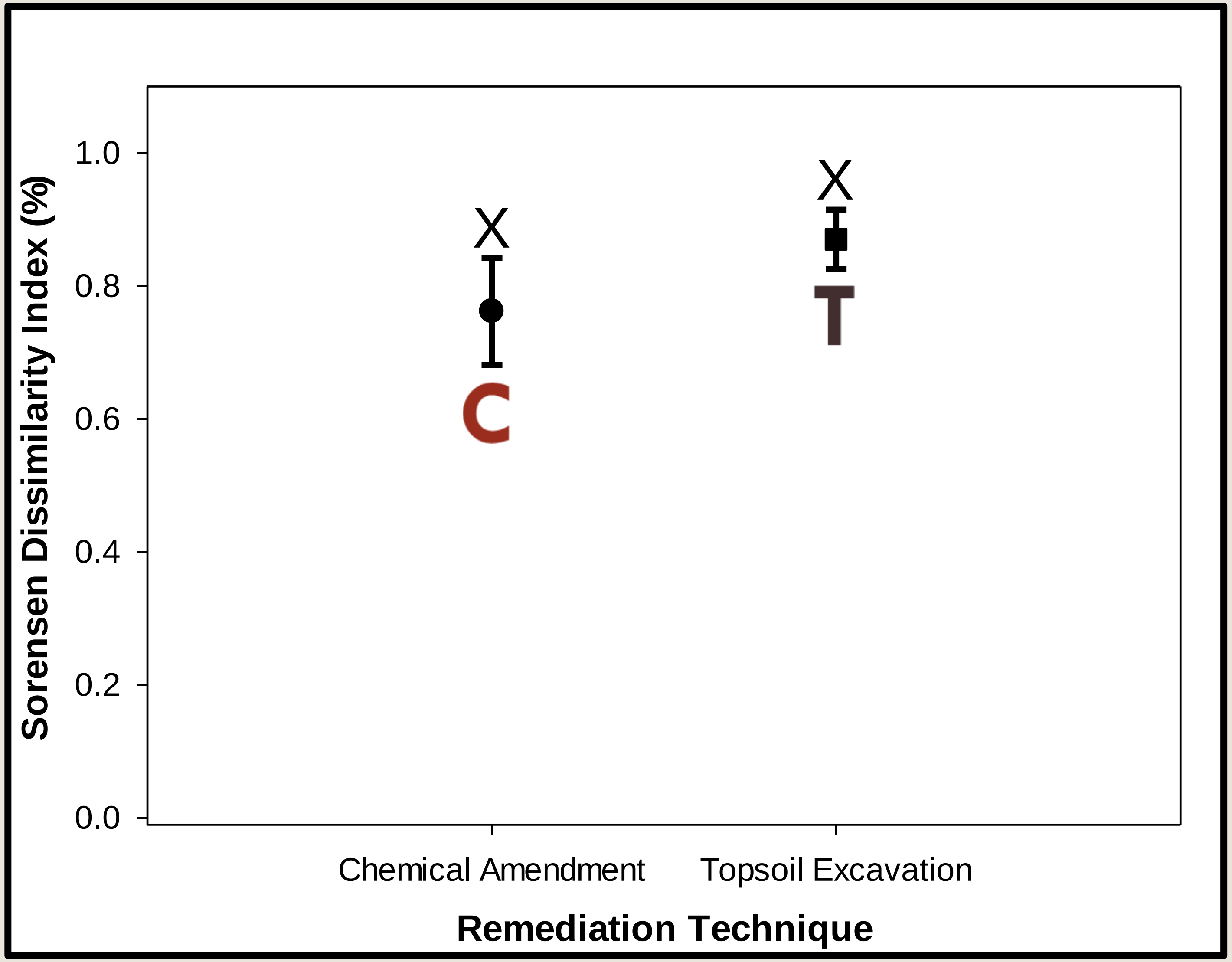
Diversity Indicies

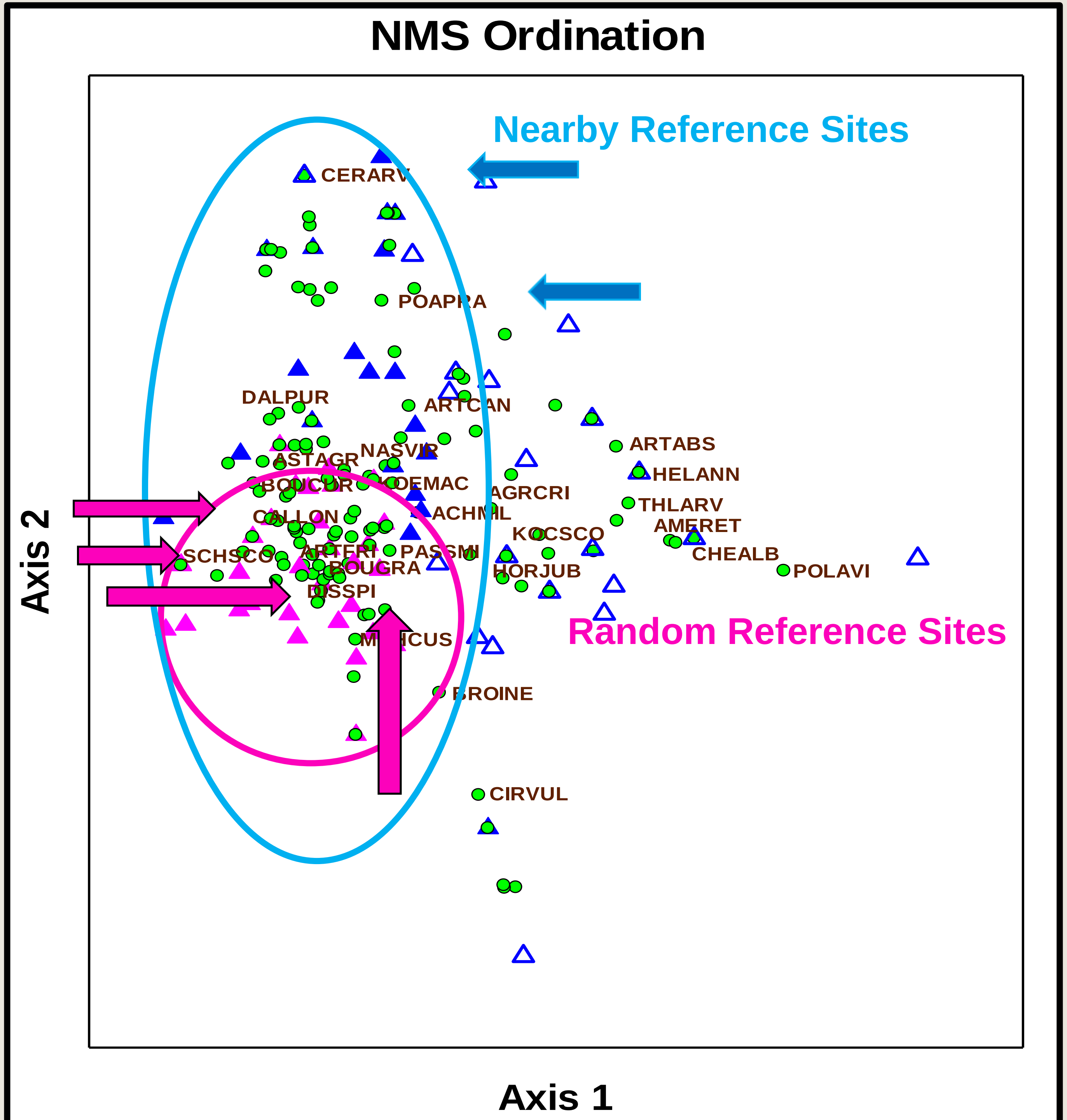
- **<u>Species Richness</u>** (number of species in a given area)
  - ➢ REF ≠ REM ($p < 0.05$)
  - ➢ $REM_{chem} = REM_{top}$ ($p \geq 0.05$)
- **<u>Species Evenness</u>** (relative abundance of species within a local area) ($p \geq 0.05$)
  - ➢ REF = REM
  - ➢ $REM_{chem} = REM_{top}$
- **<u>Simpson's Diversity</u>** (characterizes biodiversity within a community) ($p \geq 0.05$)
  - ➢ REF = REM
  - ➢ $REM_{chem} = REM_{top}$



Sørensen Dissimilarity Index

- The Sørensen Dissimilarity Index ($p \geq 0.05$)
  - ➢ $REM_{chem} = REM_{top}$
- Vegetation on remediated sites are still recovering

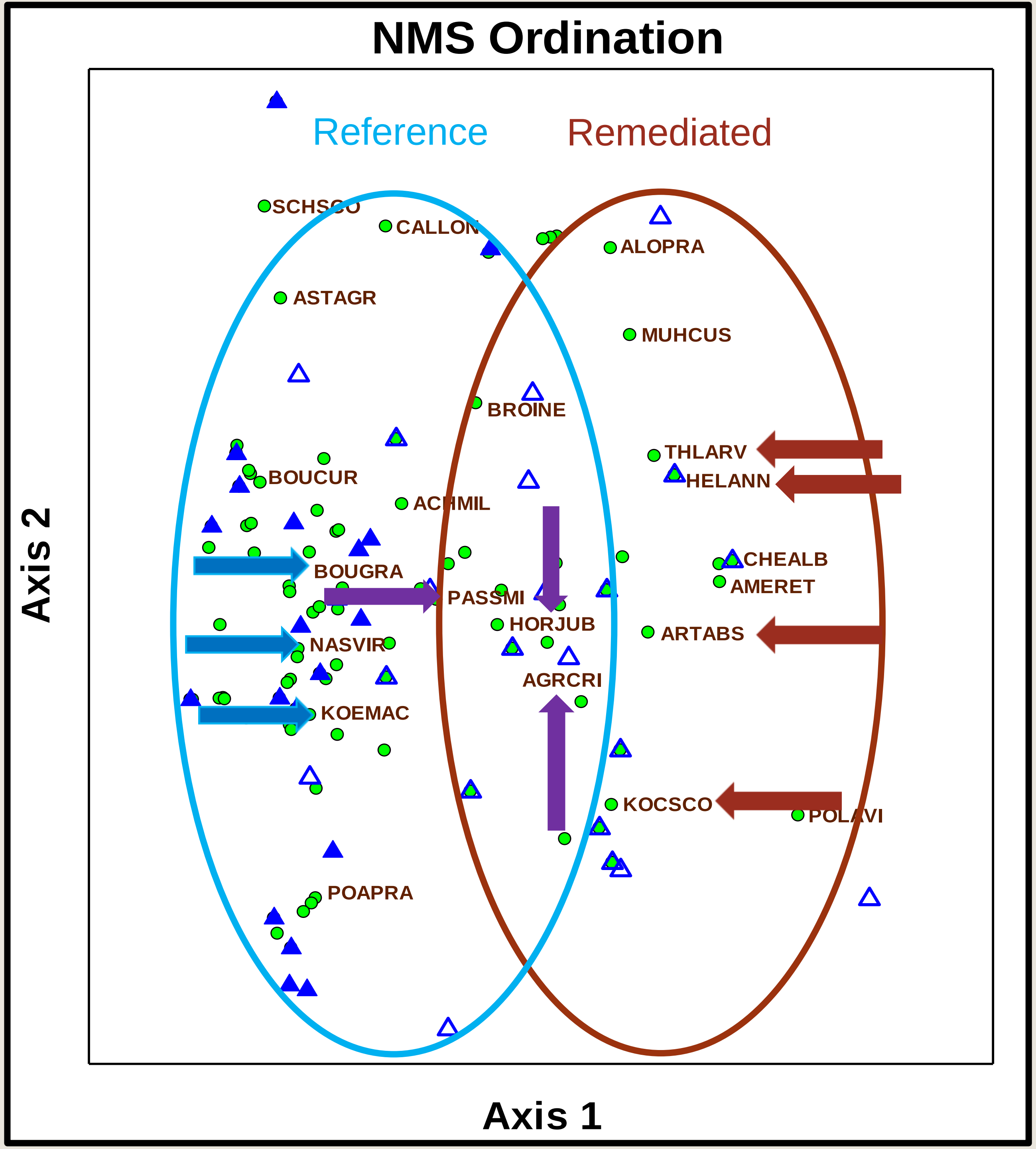




NMS Ordination
Nearby Reference Sites
Random Reference Sites
Axis 1
Axis 2
CERARV
POAPRA
DALPUR
ARTCAN
NASVIR
ASTAGR
ARTABS
HELANN
KOEMAC
AGRCRI
THLARV
ACHMIL
CALLON
AMERET
KOCSCO
SCHSCO
ARTFRI
PASSMI
CHEALB
POLAVI
HORJUB
BOUGRA
DISSPI
BROINE
CIRVUL

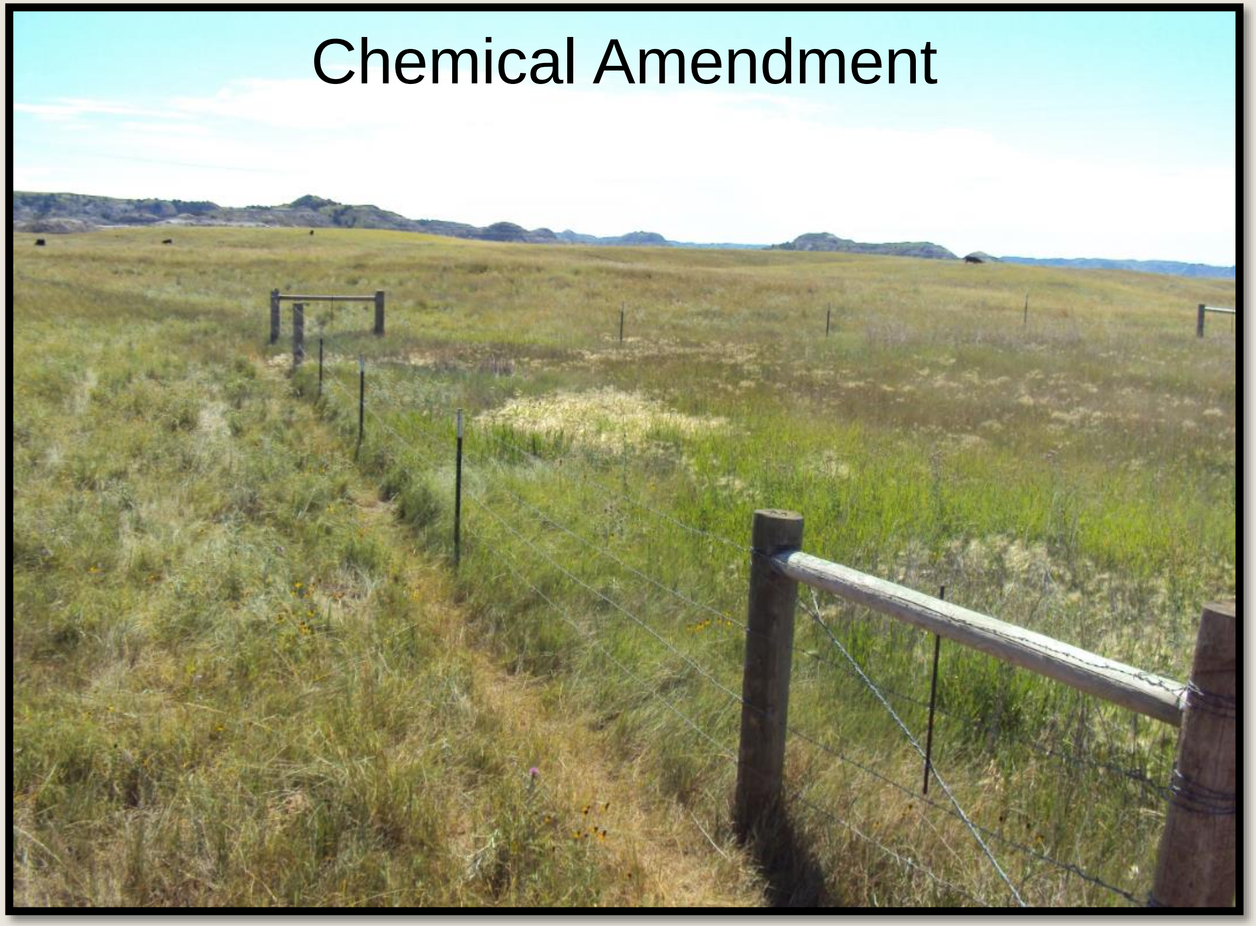
NMS ORDINATION

- Remediated brine spill sites are significantly different from reference sites ($p < 0.05$)
- Reference sites were more associated with native species
- Ruderal and exotic plant species are more associated with remediated brine spill sites



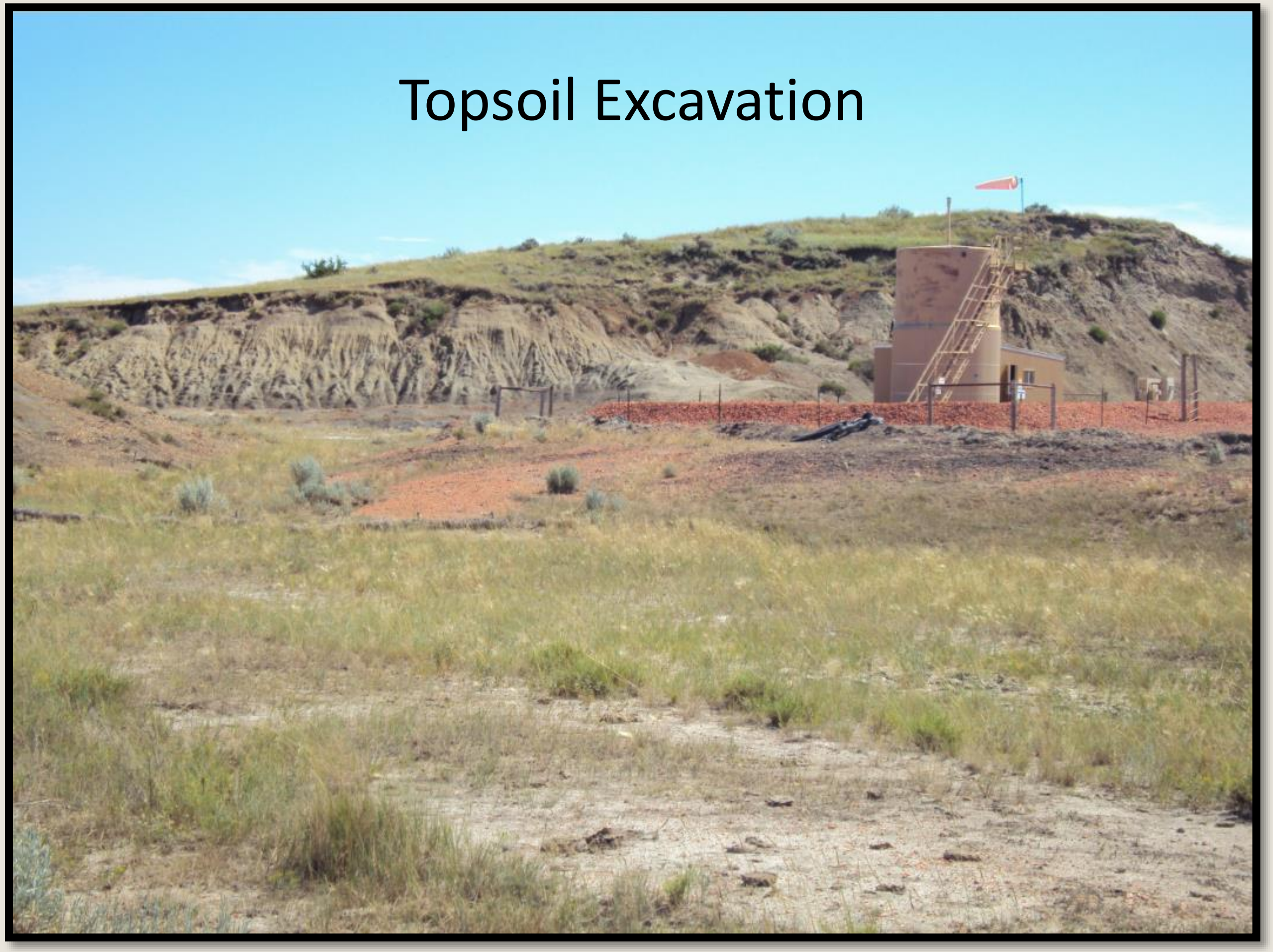
DISCUSSION

- Remediation ($CaCl_2$) lowered EC_e to allow revegetation[9]
- Native plant establishment higher on remediated than non-remediated spill[9]
- Foxtail barley, western wheatgrass, *Kochia scoparia*, Annual sunflower, & curly cup gumweed naturally revegetate oil contaminated sites[10]



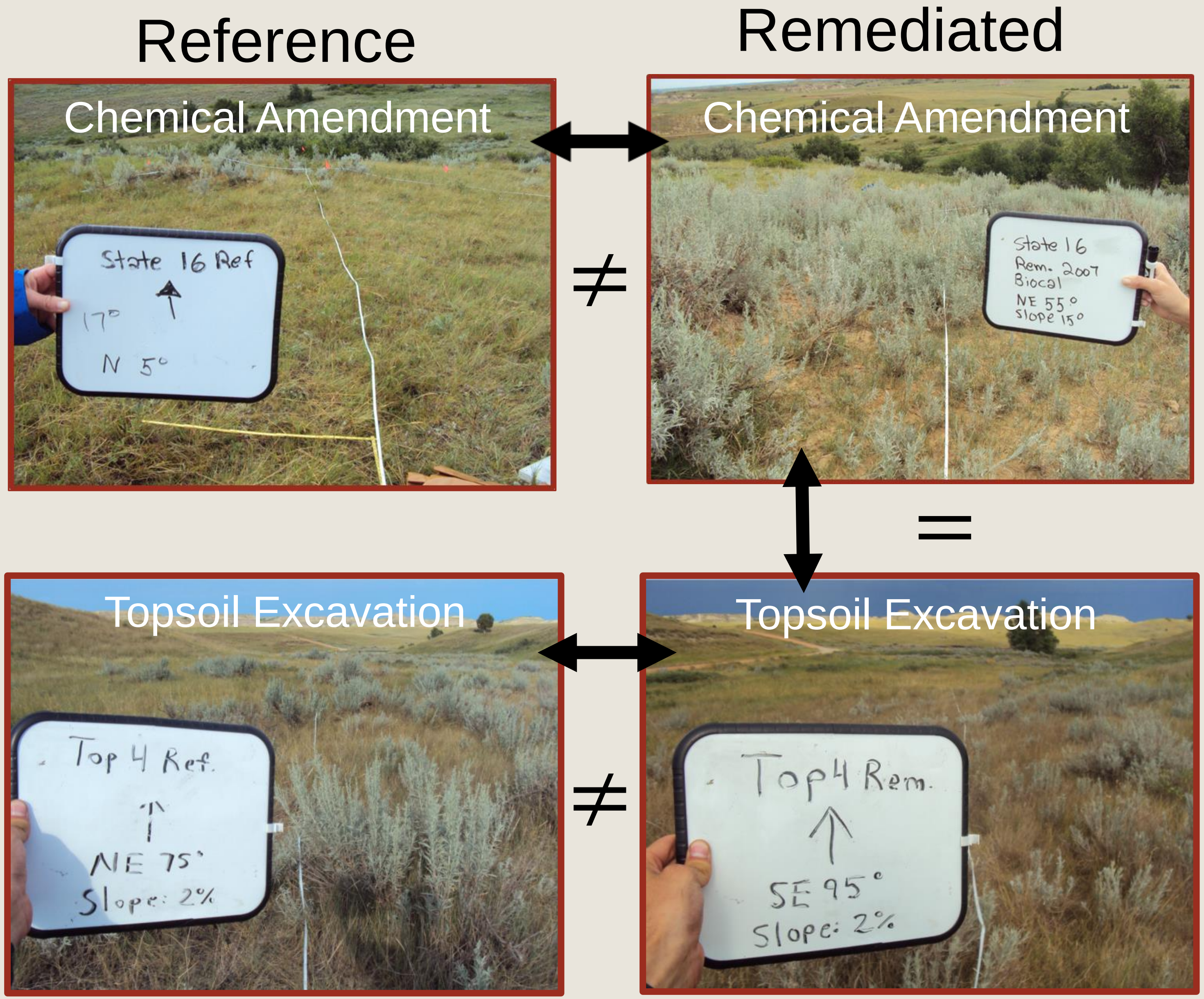
DISSCUSSION CONTINUED

- No soil or plant community data on topsoil excavation sites
- No significant difference in EC_e between remediation techniques
- Topsoil excavation is expensive



CONCLUSIONS:
CHEMICAL VS. TOPSOIL

- EC_e & vegetation significantly different between reference & remediated sites
- No significant difference in EC_e between remediation techniques
- Bare ground more prevalent on topsoil excavation sites
- Spills sites undergoing succession

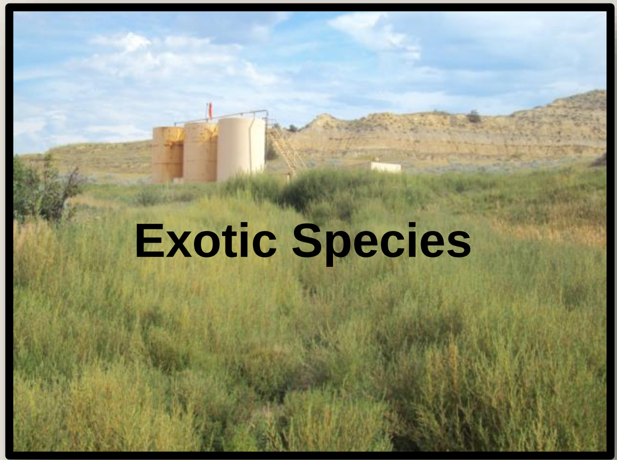


MANAGEMENT STRATEGIES

- No remediation technique is perfect
    - Chemical: brine salts migrate with soil water
    - Topsoil: Exotic seed bank & potentially different soil composition
- Attainable plant composition objectives

MANAGEMENT STRATEGIES

- Exotic species are opportunistic
- Native halophytes
  - Plant roots uptake salt ions[11]
  - USFS seed mix: western wheatgrass, green needlegrass, praire sandreed, & Canada wild rye[12]
- Remediation is a slow process



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THANK YOU!

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