Multi-process control over ecosystem invasibility

SageSTEP Meeting
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Study Objectives

1. Describe the role of sagebrush as driver of herbaceous species abundance (Chapter 1)

2. Describe the role of sagebrush as a driver of community stability (Chapter 2)

3. Evaluate the relative importance of the causal network of factors and processes driving invasibility (Chapter 3)
Study Objectives

1. Briefly describe patterns of invasibility across the landscape.

2. Evaluate a multi-variate hypothesis of the causal network of factors and processes driving patterns in invasibility observed.
Objectives

Structural equation modeling

1. Evaluate processes by which cattle grazing influences invasibility
2. Control for confounding factors
3. Place the role of cattle grazing in context by assessing the relative importance of all factors and processes

• Conceptual *a priori* model of ecosystem invasibility
  - Developed by panel of ecologists with combined decades of experience & findings of many studies (causal mechanisms)
  - Represents prediction of system behavior based on the best available science
Study Design

• 75 study sites; 3 grazing allotments; sampled over 2 years
• Stratified random sampling design to capture:
  1. Sites ranging from lowest to highest levels of stress for 3 potential gradients (heat, water, and herbivory)
  2. As many different combinations of levels and 3 types of stress as possible

1. Water stress gradient-driven differences soil texture
   • Five different Ecological Site Descriptions
   • Finer-texture = lower water stress
   • Coarser-textured soils = higher water stress
   • Quantified: soil texture and depth

<table>
<thead>
<tr>
<th>Loam</th>
<th>Clay loam</th>
<th>Sandy Loam</th>
<th>North Slopes</th>
<th>South Slopes</th>
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</thead>
</table>

- North Slopes
- Loam
- Clay loam
- Sandy Loam
- North Slopes
- South Slopes
Study Design- Continued

2. Heat stress gradient
   - Driven by changes (aspect/slope)
   - **North-aspects** = low heat stress
   - **South-aspects** = high heat stress
   - **Flat** = intermediate heat stress
   - Quantified: potential heat loads

3. Herbivory stress gradient = driven by changes in cumulative cattle grazing levels
   - Plots range 100-3600m from nearest source water
   - Quantified: cow pie frequency and density, distance from water
Conceptual *a priori* model of ecosystem invasibility

- **Landscape Orientation**
  - 6 (-)
- **Cattle grazing disturbance**
  - 3 (-)
  - 2 (-)
- **Soil Physical Properties**
  - 7
- **Native Bunchgrass Community Composition**
  - 8
- **Native Bunchgrass Abundance**
  - 9
- **Safe Sites**
  - 12 (-)
- **Sagebrush Abundance**
  - 13 (-/+)
- **Precipitation amount & timing**
- **Ecosystem Invasibility**
  - 14

Numbers indicate the direction and strength of the relationship:
- (+) positive
- (-) negative
- (-/+ or +/-) mixed
Cattle grazing influences invasibility through four processes

1(-) Directly decreases invasibility by reducing cheatgrass abundance

1(+) Directly increases invasibility by dispersing seeds and increasing propagule pressure

2(-) Indirectly increases invasibility by decreasing biotic resistance because grazing reduces bunchgrass abundance and/or shifts bunchgrass community composition.

3(-), & 4 Indirectly increases invasibility by decreasing biotic resistance because grazing reduces bunchgrass abundance and/or shifts bunchgrass community composition.

Is biotic resistance just a function of abundance or are the composition of the bunchgrass community and the structure of the bunchgrass community also important?  

2(-) Indirectly decreases invasibility because trampling reduces biological soil crusts (BSC) and creates safe sites for cheatgrass establishment.

Can size of and connectivity between basal gaps be used as an indicator of increased resource availability and increased risk of invasion?
Methods-SEM

• Select observed variables to measure the conceptual variables = “indicator variables”
  – Ecosystem invasibility = cheatgrass cover
  – Bunchgrass community composition = ordinated the bunchgrass cover data and used the axes as indices
  – Community structure = proportion of transects covered by large basal gaps (>200cm) between perennial vegetation

• Measure of spatial aggregation; size of and connectivity between basal gaps
  – Safe sites = BSC cover and % bare soil cover
Patterns of Invasibility

State 1
Intact phase
understory
dominated by
native species

State 2
Understory
dominated by
non-native species
and Poa secunda

State 3
Understory
dominated by
non-native species
and E. elymoides

State 4
Annual non-native
grassland

↑ cattle grazing
size & connectivity between basal gaps

25% of study sites
(Phase-at-risk)

21% of study sites
(intact 1 & 2)

23% of study sites
(state 2)

31% of study sites
(intact 1 & 2)

↑ heat stress
↑ BSC cover

↑ water stress
↑ bare soil
↑ size & connectivity between basal gaps

Decreasing resilience to disturbance and stress and decreasing resistance to non-native invasions
Chi-square = 11.73 (p = 0.59)

Landscape Orientation

Heat loads

Cattle grazing disturbance

Distance from Nearest water

Sand

Soil Physical Properties

Axis 1
R² = 0.37

Axis 3
R² = 0.05

Bunchgrass community composition

Safe Sites

BSC cover
R² = 0.23

% bare soil
R² = 0.50

Invasibility

Cheatgrass cover
R² = 0.72

% of large basal gaps between perennial vegetation
R² = 0.72

Community structure

Native bunchgrass cover
R² = 0.35

Bunchgrass abundance

Chi-square = 11.73 (p = 0.59)
Conclusions-The Linchpin

- Structure of the bunchgrass understory community was the linchpin
- Increases in the size of and connectivity of basal gaps between bunchgrasses = increase in invasibility
- Increases in the spatial aggregation of vegetation and connectivity between gaps is associated with a loss of resilience
- Main mechanism of invasion is how species abundance is distributed in the community
Conclusions-Biotic resistance plays a pivotal role

- Resistance from resident bunchgrass and biological soil crust (BSC) communities is critical to limiting the magnitude of invasion.

- BSC probably limit the availability of safe sites for cheatgrass establishment by impeding root penetration and growth.

- Abundant and spatially dispersed bunchgrass populations reduce cheatgrass dominance by reducing resource availability.

- Combination of three species especially important:
  - Bluebunch wheatgrass and Thurber’s needlegrass—deep rooted, active late spring
  - Sandberg’s bluegrass—shallow-rooted, late winter and early spring

- This combination of species maximizes interactions with cheatgrass in time and space.
Conclusions—thresholds are context dependent

- Landscape orientation and soil physical properties set the stage for invasion

- Determine inherent resilience of a site to disturbance

- Mosaic communities that differ in the cumulative levels of disturbance or stress they can withstand before crossing threshold

- South-facing slopes, flat terrain, and coarser-textured soils are the least resilient to disturbance and least resistant to invasion

- Mechanism
  - Lower productivity
  - Larger and more connected basal gaps
  - Greater amounts of bare soil
Conclusions - Role of cattle grazing in context

• Statistically controlled for confounding factors; understand their importance

• Cattle grazing increased the magnitude of cheatgrass invasions

Mechanisms

1. Grazing reduced native bunchgrass abundance
2. Trampling reduced biological soil crust cover
3. Grazing shifted composition of bunchgrass community

• Reduced biotic resistance to invasion
• No evidence that cattle grazing reduced cheatgrass abundance or increased propagule pressure
General Conclusions & Management Implications

If the goal is to maintain and restore resilience:

1. Maintain and restore abundant, diverse, and spatially dispersed bunchgrass communities
   - Limit the size of and connectivity of gaps
   - Maximize overall resource capture and interactions with cheatgrass in time and space

2. Maintain and reduce cumulative stress levels to prevent communities from crossing thresholds
   - Recognize thresholds are context dependent and manage stress levels to protect the least resilient sites within a management unit
   - Heat and water stress may increase under climate change
   - Cattle grazing can be adaptively managed

3. Maintaining and reducing cumulative cattle grazing levels may represent one of the most effective means of passively restoring resilience