Invader impacts on soil ecosystems—what every restoration practitioner should know

Ylva Lekberg
(ylekberg@mpgranch.com)

Photo: Sue Brown

Photo: Dean Pearson
• ~17,000 acre property in the Bitterroot Valley
• Research related to restoration ecology, invasion biology and plant-herbivore interactions
• Tracking spring and fall migrations of birds (mostly raptors)
• Long-term monitoring of songbirds as a response variable to assess restoration
• Educational outreach (~2000 visitors each year)
• Website (http://mpgranch.com)
Cheatgrass (*Bromus tectorum*)

Spurge (*Euphorbia esula*)

Knapweed (*Centaurea stoebe*)
• How is this spurge invasion different from a native prairie?
• Does it depend on the particular invader?
• Do species-specific effects influence the likelihood of restoration success?
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• Does it depend on the particular invader?
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✓ It’s very different in terms of productivity, nutrient cycles and microbial communities
✓ For some processes yes, for other processes invaders group together
✓ These invader-specific effects should guide restoration
How do these evolutionary naïve exotics outperform locally adapted native species?

- Summaries of invasion studies show that productivity can double with invasions globally (Liao et al. 2008, Vila et al. 2011)

![Graph showing productivity comparison between invaded and native patches.](#)

**Aboveground Net Primary Productivity (g m\(^{-2}\) yr\(^{-1}\))**

- **Invaded patches**
- **Native patches**

**Species:**
- Cheatgrass
- Knapweed
- Spurge
- Cinquefoil

*M* indicates a significant difference.*

**McLeod et al., J Ecol. 2016**

Morgan McLeod
Common gardens at MPG Ranch

Photo credit: Alan Ramsey
Invasive plants produce more biomass in common gardens

(N=5, mean +/- se; P<0.05)
What’s the potential role of soil microbes?

1 tsp of soil can contain:
- One billion bacteria
- Several yards of fungal filaments
- Thousands of protozoa
- 10-100 nematodes
Bacteria and fungi are involved in many nutrient transformations in soils.
How do we characterize microbes?
Brief method for community assessments

1. Take root or soil samples
2. Extract and amplify selected DNA (fungi/bacteria)
3. Sequence DNA using NGS
4. Match with curated databases
Invaders change bacterial communities in common gardens

McLeod et al. in review.
Exotics promote bacteria and change soil nutrient cycles

Ammonia oxidizing bacteria

\[ \text{NH}_4^+ \rightarrow \text{NO}_3^- \]

McLeod et al., J Ecol. 2016
Invaders can alter N-availabilities in common gardens

$P_{\text{Plant communities}} < 0.10$ both years
Soil legacy effects on subsequent growth

Leila Marsh
Biomass of natives differ depending on community.

- **Blanketflower**
  - Native: 100 mg plant⁻¹
  - Cinquefoil: 200 mg plant⁻¹
  - Cheatgrass: 300 mg plant⁻¹
  - Knapweed: 400 mg plant⁻¹
  - Spurge: 500 mg plant⁻¹

- **Bluebunch**
  - Native: 100 mg plant⁻¹
  - Cinquefoil: 200 mg plant⁻¹
  - Cheatgrass: 300 mg plant⁻¹
  - Knapweed: 400 mg plant⁻¹
  - Spurge: 600 mg plant⁻¹
....but cheatgrass outgrows them all, which may help explain invasion meltdown....
Invaders can promote productivity by increasing N-availability. Shifts in bacterial communities likely involved

For restoration practitioners:
• Know that nutrient availabilities are likely higher compared to the native communities.
• Consider how this may influence restoration success vs. invasion meltdown (apply saw dust or something that binds the N if manageable size?).
• Unknown: How long does the legacy persist?
What about other soil biota?
Mycorrhizal fungi
Myco – rhiza = Fungus root

Nutrients

Carbon
Arbuscular mycorrhizal fungi (AMF)

- AMF colonize 90% of all plant families
- “Plants don’t have roots, they have mycorrhizas”
- Fungi receive C from plant in exchange for nutrients and other services
- Due to the high abundance and location in the root-soil interface, AMF can influence ecosystem properties (carbon and nutrient cycling)
Mycorrhizal fungi can promote plant growth
....improve soil structure
.... and drought tolerance

**Fig. 2.2** Plant growth of trifoliate orange inoculated with *Diversispora versiformis* (AMF) under well-watered (WW) and drought stress (DS)
Enhanced mutualism hypothesis (Reinhart and Callaway, 2004)

- Mycorrhizal-mediated increased competitive ability of invader

Spotted knapweed (*Centaurea stoebe*)
Degraded mutualism hypothesis (Vogelsang et al., 2005)

- Decreased competitive ability of mycotrophic natives
Do invaders shift mycorrhizal fungal communities and are shifts invader-specific?

Søren Rosendahl  
Sean Gibbons  
Philip Ramsey

Cheatgrass (*Bromus tectorum*)  
Leafy spurge  
Knapweed
Survey of six locations around Missoula

- Sampled roots from 6 locations per community
- Representative grasses and forbs collected from native communities
- AMF communities were characterized using molecular techniques
Fungal richness and diversity is higher with some invaders

<table>
<thead>
<tr>
<th>Plant community</th>
<th>n</th>
<th>AMF richness</th>
<th>Diversity (H)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Native mixed</td>
<td>6</td>
<td>13.0 (1.03)(^c)</td>
<td>1.85 (0.03)(^b)</td>
</tr>
<tr>
<td>Cheatgrass</td>
<td>5</td>
<td>14.6 (0.87)(^c)</td>
<td>1.49 (0.19)(^c)</td>
</tr>
<tr>
<td>Knapweed</td>
<td>6</td>
<td>24.2 (1.08)(^a)</td>
<td>2.27 (0.06)(^a)</td>
</tr>
<tr>
<td>Spurge</td>
<td>5</td>
<td>20.4 (1.47)(^b)</td>
<td>2.10 (0.10)(^{ab})</td>
</tr>
</tbody>
</table>

Lekberg et al., ISME 2013
Community composition shifts and is invader-specific
Invaders cause these shifts
Consistent, and invader-specific shifts in fungal abundance

- **Degraded mutualism hypothesis**
- **Enhanced mutualism hypothesis**

**Graph:**
- AM colonization (%)
- Bars for Native, Cheatgrass, Knapweed, Spurge
- Native: b
- Cheatgrass: c
- Knapweed: a
- Spurge: a

**Image:**
- Image of plants
- Micrograph of *Glomus diaphanum* with labeled structures:
  - Vesicles
  - Arbuscules
  - Spore? (20 µm scale bar)
Fungal abundance and richness change with invasions and depend on the invader. What are the consequences of this for restoration?
Invasion legacies on fungal colonization on blanketflower

Blanket flower was planted in all communities to assess differences in fungal communities among plots.
Root colonization follow the same pattern as abundances

- Shifts in AMF abundances caused by the invaders
- This translates to differences in AM colonization of native plant
- Could influence restoration of native communities
- How long does this legacy last?
Do you need to inoculate with mycorrhizal fungi?

- Should be the absolute last resort as it is expensive, may not work and introduce foreign fungi that are not locally adapted and may outcompete local fungi.
Are mycorrhizal fungi there?

- Measure root colonization of existing roots (Milltown floodplain)

- Measure the activity in the soil (requires a greenhouse)
How can inoculations be done?

Contains seeds and mycorrhizal fungi
Direct and indirect effects of herbicides

- Direct effects evaluated from responses in grass communities
- Indirect effects evaluated from responses in knapweed communities
Picloram change the plant community composition

Knapweed is replaced by bulbous bluegrass (*Poa bulbosa*)

This reduces AMF host quality

Which in turn reduces AMF abundance

Which in turn reduces AMF abundance

Sometimes you have to spray but know that there are consequences belowground when you do!

Summary

• Microbial communities differ among invaders, are invader-specific and predictable, and are caused by the invader
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• These shifts affect ecosystem processes

• These changes can result in strong legacy effects, but how long they last and implications for restoration is little known
Remember the belowground and you will be better off for it!
Questions?