Determining the scale of local adaptation: What can we learn from a large-scale reciprocal transplant study of an important restoration grass species?

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What is local adaptation?

Germino et al. 2019, *Ecological Applications* 29: e01842
How prevalent is local adaptation?

<table>
<thead>
<tr>
<th>Study</th>
<th>Freq. of LA (^ bounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leimu and Fischer 2008</td>
<td>71%</td>
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<td>Hereford 2009</td>
<td>71%</td>
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<tr>
<td>Oduor et al. 2016 - Native</td>
<td>55%</td>
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<tr>
<td>Oduor et al. 2016 - Invasive</td>
<td>45%</td>
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<tr>
<td>Baughman et al. 2019 - GB Surv.</td>
<td>67%</td>
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<tr>
<td>Baughman et al. 2019 - GB Rep.</td>
<td>90%</td>
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</tbody>
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How do we measure local adaptation?

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1. Differences among populations in fitness-related traits


Schemske and Bradshaw 1999, *PNAS* 96: 11910-11915
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1. Differences among populations in fitness-related traits
2. Correlations between these trait values and environmental or other habitat-related variables

AKA: Transfer function
One* garden, many sources


How do we measure local adaptation?

Signatures of local adaptation:

1. Differences among populations in fitness-related traits
2. Correlations between these trait values and environmental or other habitat-related variables
3. Higher fitness of local over nonlocal populations in the local environment

AKA: Response function
One* source, many gardens


Restoration in the Great Basin of the United States

• The Great Basin is a large area: 550k km² – 75% controlled by the Federal Government

• Extremely topographically variable (750-4000 m) - ranges in aridity from salt desert to montane forest (50-600 mm)

• Severely threatened by fire – driven by invasive annuals and climate change – fire return intervals shifted from 100-150 y to 30-50 y, and even 7-11 y in some locations

• Bureau of Land Management spends over $600m per year on post-fire restoration – mostly in the Great Basin
Seed sourcing in the Great Basin

Jones and Larson 2005,
USDA Forest Service
Proceedings RMRS-P-38
Seed sourcing in the Great Basin
Seed sourcing in the Great Basin

Squirreltail

Snake River wheatgrass

Thickspike wheatgrass

Basin wildrye

Western wheatgrass

Bluebunch wheatgrass
Seed sourcing in the Great Basin
Seed sourcing in the Great Basin – *Elymus elymoides*

Ott et al. unpublished data
Bluebunch wheatgrass – important restoration species

St. Clair et al. 2013, Evolutionary Applications 6: 933-948
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Bluebunch wheatgrass – Reciprocal transplant study
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Kas Dumroese, Jeremy Pinto, Jessica Irwin, Chris Poklemba, Matt Fisk, Jameson Rigg, Alexis Malcomb, Katherine Prive, Nancy Shaw, Berta Youtie, Jeff Ott, Bobby Benson, Kimberly Stocks, Matt Germino, Jill Pavlik, Lia Leibman, Chris Link, Charlie Abeles, Andrea Balch, Allison Busier, Tessa Bartz and many more!
Bluebunch wheatgrass – Reciprocal transplant study

• 2 experimental regions (transects)
• 15 common garden sites – 8 in the northern transect, 7 in the southern transect
• 38 natural populations planted across all sites within each transect (78 total), as well as 3 commercial germplasms (not discussed here)
• Over 15,000 experimental plants were installed
• Site monitoring began in 2015 and continues for 14 of the 15 original sites
• Data in this talk will focus on 2017, the last year where all original measurements were taken
Bluebunch wheatgrass – Reciprocal transplant study

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Massatti et al. 2018, Evolutionary Applications 11: 2025-2039
Bluebunch wheatgrass – Variation between gardens
Bluebunch wheatgrass – Variation between gardens
Bluebunch wheatgrass – Variation between gardens
Bluebunch wheatgrass – Evidence of local adaptation

Size

Reproduction

Survival

Local

Derived local

4/7

3/5

5/6

2/7

4/5

3/3

4/5

3/3

3/3
Bluebunch wheatgrass – Evidence of local adaptation

Northern gardens

Size

PC 1 difference

R² = 0.3093

Reproduction

PC 1 difference

R² = 0.2463

Survival

PC 1 difference

R² = 0.3101

Southern gardens

Size

PC 1 difference

R² = 0.0077

Reproduction

PC 1 difference

R² = 0.1557

Survival

PC 1 difference

R² = 0.0375
Bluebunch wheatgrass – Scale of local adaptation

Northern gardens

- Size PC 1 difference
  -3.3%/std

- Reproduction PC 1 difference
  -1.3%/std
  -2.3%/std

- Survival PC 1 difference
  -4.1%/std

Southern gardens

- Size PC 1 difference
  -4.6%/std

- Reproduction PC 1 difference
  -5.7%/std
  -3.3%/std

- Survival PC 1 difference
  +4.2%/std
Bluebunch wheatgrass – Summery

- How well did the gardens capture climatic variation? - Quite well! However, they do not precisely match representative seed zones. Also, not all climate space of the populations was covered by gardens.
Bluebunch wheatgrass – Summery

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• Is there local adaptation? – Yes. Though it is weak on a per garden basis and there is some maladaptation as well.
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• Are there any patterns to local adaptation? Yes! While there was evidence that local did better, mostly populations from hotter and drier conditions than a given garden did worse. The signal was neutral to mixed for populations from cooler and wetter conditions.
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• What is the scale of adaptation? A range 1.3-5.7% loss in relative fitness occurred for every standard deviation of climatic distance from garden conditions, which was generally worse for plants from hotter and drier conditions. This allows managers to estimate risk of maladaptation.
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• Overall, this study shows that it is possible to determine the scale of local adaptation and determine the risk of maladaptation to current and changing climates. For species of high restoration importance we should not use “rules of thumb.”
Implications for common garden study design

- Literature suggests that 50 populations and 20 garden sites are sufficient for high quality modeling
- But! If sites are well distributed climatically, then number could be reduced further
- Bluebunch wheatgrass study, with 2 replicated “transects” indicates that 7-8 sites and ~38 populations are sufficient for high quality modeling
- How can this be implemented?

Wang et al. 2010, Ecological Applications 20: 153-163
Douglas' dusty maiden (*Chaenactis douglasii*)

Hoary tansyaster (*Dieteria canescens*)

Tapertip hawksbeard (*Crepis acuminata*)

Showy fleabane (*Erigeron speciosus*)

Showy goldeneye (*Heliomeris multiflora*)

Globemallow (*Sphaeralcea grossulariifolia*)

Yellow beeplant (*Cleome lutea*)

Silverleaf phacelia (*Phacelia hastata*)

Thickleaf penstemon (*Penstemon pachyphyllus*)

Nettleleaf horsemint (*Agastache urticifolia*)

2018 2019 2020+
Implications for common garden study design - forbs

![Map of study locations with markers for different locations.](image)

- **Glass Butte**
- **Orchard**
- **Richfield**
- **Paine Gulch**
- **Duck Valley**
- **Twin Creeks**
- **Plymouth**
- **Duck Valley**
- **Orchard**
- **Paine Gulch**
- **Twin Creeks**
- **Glass Butte**
- **Plymouth**
- **Reno**

![Scatter plot showing mean annual precipitation and temperature.](image)

- **Mean Annual Precipitation (mm)**
  - 5
  - 150
  - 550
- **Mean Annual Temperature (°C)**
  - 5
  - 7
  - 9
  - 11
Implications for common garden study design - forbs
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Transfer functions only

Transfer and response functions

Per garden X species cost

Time to completion for 7 species
Thank you!