Testing the effects of site selection and artificial shelters on native plant recruitment from seed in a degraded coastal sage scrub restoration

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Barriers to Restoration

• Competition with invasives

• Herbivory

• Lack of suitable habitat for plant establishment (nutrients, moisture, microclimate)

• Limited time and funding
Coastal Sage Scrub Restoration Experiment

Goal:
Improve cost-effectiveness in CSS restoration

Techniques and Emerging technologies:
1. Habitat suitability modeling
2. Tree shelters
3. Seeding of shrubs
Habitat Suitability Modeling

• Remote sensing tools (LiDAR, GIS) help identify topographic microclimates across large landscapes more suitable for critical plant life stages

• Can direct efficient use of resources
Habitat Suitability Modeling

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The role of site selection

Moderately steep, Pole-facing slopes:

• Lower incident solar \textit{radiation} and \textit{temperature}

• Reduced \textit{evaporation} and \textit{run-off}

• Increased soil \textit{moisture} and \textit{nutrients}

• \textbf{Less stressful} for seedlings, better establishment

Limits to habitat suitability models
Limits to habitat suitability models
Role of shelters

Role of shelters

• Anti-herbivory

Role of shelters

- Anti-herbivory
- Protection from chemical and physical weed management

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Beneficial microclimate:

- Solar radiation
- Wind and erosion
- Soil moisture
- Relative humidity

Role of shelters

• Anti-herbivory

• Protection from chemical and physical weed management

Shelter Limitations:

• Lack of non-forestry studies

• Direct-seeding results?

• Varying species interactions

Seeding

Benefits:

• Cost (propagation)
• Labor (transport and transplanting)
• Maintenance (irrigation)
• Nursery-borne pathogens (ex. *Phytophthora* sp.)
• Timing (flexible with seed storage)
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Tradeoffs:

- Lower success rate!!
  - Granivory and herbivory
  - Poor conditions
  - Slow growth/weed competition
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• Labor (transport and transplanting)
• Maintenance (irrigation)
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Tradeoffs:

• Lower success rate!!
  - granivory and herbivory
  - poor conditions
  - slow growth/weed competition

{Off-set by shelters?}
Different species – different life history traits

Amsinckia intermedia

Stipa pulchra

Diplacus longiflorus

Heteromeles arbutifolia
Different species – different life history traits

Amsinckia intermedia
Annual

Stipa pulchra
Perennial

Diplacus longiflorus

Heteromeles arbutifolia
Different species – different life history traits

- **Annual**
  - Shade-intolerant
  - *Amsinckia intermedia*

- **Partial shade**
  - *Stipa pulchra*

- **Perennial**
  - Shade-tolerant
  - *Diplacus longiflorus*

  - *Heteromeles arbutifolia*
Different species – different life history traits

- **Amsinckia intermedia**: Annual, Herbaceous, Shade-intolerant
- **Stipa pulchra**: Annual, Grass, Shade-intolerant
- **Diplacus longiflorus**: Annual, Shrub, Shade-intolerant
- **Heteromeles arbutifolia**: Perennial, Shrub, Shade-tolerant

- **Partial shade**
- **Shade-tolerant**
Different species – different life history traits

- **Amsinckia intermedia**
  - Herbaceous
  - Annual
  - Shade-intolerant
  - Obligate seeder

- **Stipa pulchra**
  - Perennial
  - Partial shade
  - Facultative seeder

- **Diplacus longiflorus**
  - Shrub
  - Long-lived seed
  - Obligate seeder

- **Heteromeles arbutifolia**
  - Shrub
  - Shade-tolerant
  - Obligate sprouter
Different species – different life history traits

Amsinckia intermedia
- Herbaceous
- Shade-intolerant
- Obligate seeder
- Trichomes

Stipa pulchra
- Shallow, fibrous roots
- Facultative seeder

Diplacus longiflorus
- Long-lived seed
- Drought deciduous

Heteromeles arbutifolia
- Obligate sprouter
- Sclerophyllous leaves
Question 1

*How do site selection and shelters affect abiotic factors important to plant recruitment?*

- Abiotic conditions will be less severe in High Suitability (HS) plots and Shelter treatments.
- Shelters will play a greater role in ameliorating abiotic conditions in harsher Low Suitability (LS) sites than the more moderate HS sites.
Question 2

How do site selection and shelters affect seed germination and seedling establishment patterns?

- There will be higher germination for all species in shelters and HS sites
- Shelters will play a greater role in seedling survival in LS sites
- Shrub seedlings will show higher association with HS sites and shelters, while herbaceous species will be unaffected or perform better in open treatments
Restoration Experiment

- 2 years (2017-2019)
- Voorhis Ecological Reserve (Cal Poly Pomona)
- Degraded coastal sage scrub habitat
- Increase native cover within experimental plots
Habitat Suitability Model: Voorhis Ecological Reserve

Aspect + Slope = Habitat Suitability Model
Habitat Suitability Model: Voorhis Ecological Reserve

High Suitability:
- North-facing aspect
- 10-30% slope

Low Suitability:
- South-facing aspect
- >30% slope
Experimental Design

Two 10x5 m plots per block

Three-factors:
- **Suitability** (2 levels) [whole-plot]
- **Species** (4 levels)
- **Shelter** (2 levels) [factorial]

Replication:
- \( n=30 \) per Species, Suitability and Shelter treatment
- \( N=240 \) total subplots over 6 plots
Site Preparation

All non-natives hand-cleared before and throughout experiment
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All non-natives hand-cleared before and throughout experiment

Sensors measured hourly:
- Solar radiation
- Air and soil temperature
- Soil moisture
- Leaf wetness
+ Sediment erosion traps
Shelters

• Shelter experiment modeled after trial in Angeles National Forest (Beyers and VinZant, 2016)

• TreePro Tree Tubes (Lafayette, IN)

• 30cm tall by 10cm diameter

• Single-walled, translucent plastic

• Ventilation holes (halfway up to allow herbicide treatment at base)
Seeding

Seeds collected and cleaned

Seeds counted and sorted

Greenhouse trials

Seeds surface sown at a rate >100 seeds/m$^2$ and hand-tamped
Results: Abiotic
Results: Solar Radiation

Maximum Total Solar Radiation, Year 2
Results: Solar Radiation

Maximum Total Solar Radiation, Year 2
Results: Solar Radiation

Maximum Total Solar Radiation, Year 2
Results: Soil Moisture

Volumetric Water Content, Year 2
Results: Sediment erosion
<table>
<thead>
<tr>
<th>Block</th>
<th>Collection Date</th>
<th>Sediment Erosion (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td><strong>High</strong></td>
</tr>
<tr>
<td>1</td>
<td>Dec’18-Jan’19</td>
<td>13.42 ± 1.84</td>
</tr>
<tr>
<td></td>
<td>Feb-Mar’19</td>
<td>32.24 ± 10.92</td>
</tr>
<tr>
<td>2</td>
<td>Dec’18-Jan’19</td>
<td>5.17 ± 3.31</td>
</tr>
<tr>
<td></td>
<td>Feb-Mar’19</td>
<td>2.39 ± 0.94</td>
</tr>
<tr>
<td>3</td>
<td>Dec’18-Jan’19</td>
<td>50.99 ± 32.80</td>
</tr>
<tr>
<td></td>
<td>Feb-Mar’19</td>
<td>56.20 ± 42.66</td>
</tr>
</tbody>
</table>
Results: Seedlings
Results: Germination

- **Shelters** increased germination for all species
Results: Germination

- **Shelters** were more important for germination than Suitability

- **Amsinckia intermedia**
  - Shelters: +23%
  - Suitability: +3%

- **Diplacus longiflorus**
  - Shelters: +12%
  - Suitability: +2%

- **Heteromeles arbutifolia**
  - Shelters: +5%
  - Suitability: +2%

- **Stipa pulchra**
  - Shelters: +5%
  - Suitability: -4%
Results: Germination

- **Shelters** were more important for germination than Suitability
- **High Suitability** shelters had higher germination than Low Suitability shelters.
Results: Germination

- **Shelters** were more important for germination than Suitability

- **High Suitability** shelters had higher germination than Low Suitability shelters.
Results: Growth

Shelter plants significantly larger for *A. intermedia*, *D. longiflorus*, and *H. arbutifolia*
Results: Survival, Year 2
Results: Survival, Year 2
Results: Survival, Year 2

Shrub

- **D. longiflorus**
- **H. arbutifolia**

Herbaceous

- **A. intermedia**
- **S. pulchra**

Graphs show the proportion of surviving subplots over time. The graphs are labeled with different lines indicating high and low suitability, as well as presence or absence of shelter.
Results: Survival, Year 2

Shrub

<table>
<thead>
<tr>
<th>Species</th>
<th>Proportion of Surviving Subplots</th>
</tr>
</thead>
<tbody>
<tr>
<td>D. longiflorus</td>
<td>[Graph showing survival trends]</td>
</tr>
<tr>
<td>H. arbutifolia</td>
<td>[Graph showing survival trends]</td>
</tr>
</tbody>
</table>

Herbaceous

<table>
<thead>
<tr>
<th>Species</th>
<th>Proportion of Surviving Subplots</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. intermedia</td>
<td>[Graph showing survival trends]</td>
</tr>
<tr>
<td>S. pulchra</td>
<td>[Graph showing survival trends]</td>
</tr>
</tbody>
</table>

- **Suitability**
  - High Suitability
  - Low Suitability

- **Shelter**
  - No Shelter
  - Shelter
Conclusions and Recommendations

1. **Shelters** increased germination and survival, especially for shrubs

2. Shelters played a larger role than Suitability in seedling establishment and growth, but Shelters in **High Suitability** provided overall the best microclimate for seedlings
Conclusions and Recommendations

1. **Shelters** increased germination and survival, especially for shrubs

2. Shelters played a larger role than Suitability in seedling establishment and growth, but Shelters in **High Suitability** provided overall the best microclimate for seedlings.

3. Erosion mitigation may be as or more important than creating a microclimate.
Conclusions and Recommendations

1. **Shelters** increased germination and survival, especially for shrubs and shade-tolerant species

2. Shelters played a larger role than Suitability in seedling establishment and growth, but Shelters in **High Suitability** provided overall the best microclimate for seedlings

Recommendations:

1. Diversify plant addition strategies between seeding and planting in shelters, especially for sensitive species and low suitability areas

2. Experiment with seeding more species in shelters, and share results!
Acknowledgments and Funding

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MENTORES

CNPS-San Gabriel Mountains Chapter Research Grant

Agricultural Research Initiative (ARI)
Questions?
# Results: Sediment Erosion

<table>
<thead>
<tr>
<th>Block</th>
<th>Plot Slope (°)</th>
<th>% Bare ground</th>
<th>Date</th>
<th>Sediment Erosion (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HS 20 LS 27</td>
<td>HS 37 LS 51</td>
<td>1</td>
<td>High 13.42 ± 1.84</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>32.24 ± 10.92</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td>Low 2,449 ± 1,875</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2,740 ± 1,941</td>
</tr>
<tr>
<td>2</td>
<td>22 25</td>
<td>55 82</td>
<td>1</td>
<td>5.17 ± 3.31</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>2.39 ± 0.94</td>
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<td></td>
<td></td>
<td>858 ± 538</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>285 ± 133</td>
</tr>
<tr>
<td>3</td>
<td>26 26</td>
<td>58 66</td>
<td>1</td>
<td>50.99 ± 32.80</td>
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<td></td>
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<td></td>
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<td>56.20 ± 42.66</td>
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<td></td>
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<td></td>
<td>592 ± 285</td>
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<td></td>
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<td>411 ± 199</td>
</tr>
</tbody>
</table>
Economics of Restoration

• Multi-billion dollar industry - at least $3 billion spent annually in US alone\textsuperscript{1,2}

• 40% of restoration projects include “active restoration”\textsuperscript{3} = $1.2 billion per year on native species addition in degraded habitats

• Survival rate is highly variable (by climate, plant community, etc.)

• Estimated $8,700 to $18,200 per acre to restore California CSS habitat\textsuperscript{1}

• Future: increased need for, and cost of, restoration in semi-arid landscapes
Precision Restoration

• Resource efficiency

• Uses ecological theory, remote sensing, and plant science/agriculture

• Precision agriculture integrates geospatial variability into crop management to develop specific microsite plans that optimally utilize resources\textsuperscript{4}

• Recently becoming a tool in restoration ecology\textsuperscript{5}
Results: Sediment erosion
Cost Model

Will keep detailed records of equipment and labor hours involved in all aspects of restoration project (not experimental design and abiotic data)

<table>
<thead>
<tr>
<th>Project Stage</th>
<th>Seeding Experiment</th>
<th>Restoration Planting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-restoration</td>
<td>- Seed collecting/order</td>
<td>- Nursery production (includes phyto-sanitation, plant material, soil, pots, labor)</td>
</tr>
<tr>
<td></td>
<td>- Pre-treatments</td>
<td>- Field preparation (weeding, herbivore exclusions)</td>
</tr>
<tr>
<td></td>
<td>- Weed treatment</td>
<td></td>
</tr>
<tr>
<td>Restoration</td>
<td>- Cost of shelters</td>
<td>- Outplanting labor</td>
</tr>
<tr>
<td></td>
<td>- Seeding labor</td>
<td>- Herbivory shelters</td>
</tr>
<tr>
<td>Maintenance</td>
<td>- Weeding</td>
<td>- Weeding</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Watering</td>
</tr>
<tr>
<td>Total</td>
<td>$ Total</td>
<td>$ Total</td>
</tr>
<tr>
<td>Cost Per Plant</td>
<td>$ Total</td>
<td>$ Total</td>
</tr>
<tr>
<td></td>
<td># of Plants</td>
<td># of Plants</td>
</tr>
<tr>
<td>% Survival</td>
<td># Added</td>
<td># Added</td>
</tr>
<tr>
<td></td>
<td># Surviving</td>
<td># Surviving</td>
</tr>
<tr>
<td>Cost Per Surviving</td>
<td>$ Total</td>
<td>$ Total</td>
</tr>
<tr>
<td>Plant</td>
<td>% Survival</td>
<td>% Survival</td>
</tr>
</tbody>
</table>
Results: Temperature

15°C = critical for most seed germination
Results: Survival
Coastal sage scrub

- Altered disturbance regimes → Type Conversion
- 10-15% of historic range; once 2.5% of land area in California (Westman, 1981)
- 71% occurs on private lands (Davis 1994)
Future Directions

• Large-scale shelter seeding study in Angeles National Forest (direct-sowing and outplanting 5 chaparral species) in High and Low Suitability

• Look into weed management with Shelters: herbicide applications, and weed distribution/composition in suitability classes and shelters