Ecological Remote Sensing of Invasion By Perennial Pepperweed

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Outline

1. Introduction to *Lepidium*
2. Mapping *Lepidium* distribution with hyperspectral remote sensing
3. Modeling potential *Lepidium* distribution
4. Monitoring *Lepidium* spread
5. Detecting and explaining *Lepidium* phenological variation
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Lepidium latifolium

- Dramatically spread across the western US over the past decade.
- Invades wetland & riparian areas; tolerates salinity.
- Displaces natives; forms monocultures.
- May alter biogeochemical cycles.
- Spreads vegetatively; produces seeds prolifically.
Lepidium latifolium

- Cal-IPC A-list exotic pest plants
- CDFA B-list noxious weed

Understanding the habitat requirements, spread characteristics, and phenology of *Lepidium* can inform management in space and time.
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Hyperspectral Image Data

- HyMap airborne hyperspectral image data:
  - Spectral resolution - 128 15-20nm bands in the visible and reflected IR
  - Spatial resolution - 3m

Graph showing reflectance against wavelength (nm) for Lepidium and Green vegetation.
Study Sites

- Rush Ranch
- Cosumnes River Preserve
- Bouldin Island
Hyperspectral *Lepidium* Detection

- Reflectance Image
- Spectral Physiological Indexes
  - MNF Transform
  - MTMF Products

Field Data → Spectral Physiological Indexes

25 CART models

Lepidium Infestation Map

Andrew & Ustin, *In Press*
LiDAR

- Light Detection and Ranging
- Active sensor
  - Emits pulses of EMR
  - Calculates surface height from time of pulse return

- Uses
  - High-resolution DEM
  - Channel detection
  - Vegetation height
  - Vegetation structure
  - Etc.
Benefits of high-resolution LiDAR DEM:

- Only spatial elevation products available that adequately capture fine-scaled topography that is ecologically very important in wetlands.
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Potential *Lepidium* Distribution

- 12.6 ha current distribution
- 219 ha potential distribution
- 25% of Rush Ranch invasible
- Only 5% of suitable habitat is currently occupied
- Omission = 13.6%
### Potential Lepidium Distribution

#### Variable Importance

<table>
<thead>
<tr>
<th>Variable</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance to upland</td>
<td>44%</td>
</tr>
<tr>
<td>Distance to channel</td>
<td>26%</td>
</tr>
<tr>
<td>Elevation</td>
<td>9%</td>
</tr>
<tr>
<td>Aspect</td>
<td>3%</td>
</tr>
<tr>
<td>Slope</td>
<td>2%</td>
</tr>
<tr>
<td>Profile convexity</td>
<td>1%</td>
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<tr>
<td>Plan convexity</td>
<td>1%</td>
</tr>
<tr>
<td>Longitudinal convexity</td>
<td>1%</td>
</tr>
<tr>
<td>Cross-sectional convexity</td>
<td>1%</td>
</tr>
<tr>
<td>Minimum curvature</td>
<td>1%</td>
</tr>
<tr>
<td>Maximum curvature</td>
<td>1%</td>
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</tbody>
</table>

R: D_channel
G: Elevation
B: D_upland
Distance to channel includes relevant topographical information, especially relative elevation.

Sample LiDAR returns of a channel cross-section.
Distance to channel includes relevant topographical information, especially relative elevation.

Marsh-wide relationship between distance to channel and elevation:

\[ R^2 = 0.49 \]
There is the potential for considerable spread of *Lepidium* at Rush Ranch.

*Lepidium* selects habitats that minimize the stress associated with wetlands.

- Marshland-upland margin - increased terrestrial influence.
- Along channels - relatively high ground → avoid inundation and anoxia stress.
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**Lepidium Spread - Bridge Site**

- Increased 2.6x in 5 years.
- **Dispersal distances**
  - 2004-2005: 15 ± 18m, max = 78m
  - 2005-2006: 5 ± 5m, max = 25m
  - 2006-2007: 6 ± 3m, max = 20m
  - 2007-2008: 5 ± 4m, max = 31m
Lepidium Spread - Western Mesic Site

- 30-fold increase in area.
- Dispersal distances
  - 2004-2005: 53 ± 46m max = 215m
  - 2005-2006: 16 ± 15m max = 123m
  - 2006-2007: 11 ± 11m max = 71m
  - 2007-2008: 5 ± 5 max = 57m
Lepidium Spread - Levee Site

- Doubled in area.

- Dispersal distances
  - 2004-2005: 8 ± 8m, max = 43m
  - 2005-2006: 17 ± 19m, max = 123m
  - 2006-2007: 9 ± 8m, max = 51m
  - 2007-2008: 14 ± 11m, max = 57m
Spatial Variation in Spread

Bridge

Linear spread, + 2000m²/year

Western Mesic

Logistic growth increased 380-460% in exponential stage

Levee

Linear spread, + 4000m²/year
Annual Variation in Spread

- Greater spread in wet springs

- Importance of long time series

$R^2 = 0.504$

$p = 0.003$
Conclusions - Monitoring Spread

- *Lepidium* spreads extremely quickly when colonizing a site.
- Eradication should focus on satellite populations.
- *Lepidium* spreads steadily at established sites.
- *Lepidium* spread may be influenced by annual precipitation.
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Identification of phenologic stages
Rush Ranch

June 2006

Early flowering
Peak flowering
Fruiting
Identification of phenologic stages
Cosumnes River Preserve

June 2005

Vegetative
Flowering
Senescent
Significant terms:
- distance to channel
- slope
- longitudinal convexity
- distance to upland
- eastness
- profile convexity
- distance to edge
- \( d_{\text{channel}} \times d_{\text{upland}} \)
- \( d_{\text{channel}} \times d_{\text{edge}} \)
- elevation \times slope
- slope \times minimum curvature
- plan convexity \times d_{\text{edge}}
- longitudinal convexity \times eastness
- \( d_{\text{upland}} \times eastness \)
- profile convexity \times eastness

Environmental controls of phenology
Rush Ranch

\( R^2 = 0.33 \)
Environmental controls of phenology
Cosumnes River Preserve

$R^2 = 0.56$

Significant terms:
- elevation
- slope
- maximum curvature
- distance to tree
- elevation * distance to tree
- elevation * maximum curvature
- distance to edge
At both sites, more advanced phenology associated with:

- Interior of patches (intraspecific competition)
- Lower convexities
- Shallower slopes
- Higher elevations (drier)
Interannual phenologic variation
Cosumnes River Preserve

5 phenological trends identified (p < 0.0001, repeated measures MANOVA).

Interpretations confirmed by inspecting mean spectra.
Interannual phenologic variation
Cosumnes River Preserve

All trajectories except 3 were strongly related to hydrological variables.

- Total/springtime precipitation (P1, P2)
- Water year/springtime mean discharge of Cosumnes River (D1, D2)
- N days (water year/springtime) with sufficient discharge to inundate floodplain (F1, F2)

<table>
<thead>
<tr>
<th>R²</th>
<th>P1</th>
<th>P2</th>
<th>D1</th>
<th>D2</th>
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<tr>
<td>All</td>
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<td>.70</td>
<td>.68</td>
<td>.42</td>
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</tr>
</tbody>
</table>
Conclusions - Phenology

- *Lepidium* exhibits substantial spatial and interannual variation in phenology.
- 33-56% of the spatial variation is explained by environmental variables.
  - Unexplained variation? Missing variables (e.g., soils data)? Genetic?
- Interannual variation is strongly related to weather/hydrology but also to specific site conditions.
Phenology Relevance

Practical:
- Phenology influences detection. Both field and image surveys most successfully detect flowering *Lepidium*.
- Effectiveness of control varies with phenology.
- These results can inform management scheduling.

Ecological:
- Variation in phenology (either plastic or genetic) may contribute to invasion success and habitat breadth.
- Summer-active phenology of *Lepidium* may contribute to invasiveness in Mediterranean climates.
Conclusions

- Remote sensing provides accurate, rapidly repeatable maps of *Lepidium*.

- Uses of remotely sensed *Lepidium* maps:
  - Inform management
  - Drive predictive distribution modeling
  - Monitor spread - estimate population parameters and their spatial & temporal variability
  - Detect and explain phenological variation
  - Etc.
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