Detecting and differentiating fungal infection and drought stress in temperate oaks using leaf hyperspectral reflectance

Beth Fallon, Anna Yang, Cathleen Nguyen, Isabella Armour, Anna Schweiger, Jenny Juzwik, Rebecca Montgomery, John Gamon, Phil Townsend, Jeannine Cavender-Bares
Detecting threats to biodiversity


[Image: Map of the United States with number of oak species per ecosubregion. Bar charts showing number of species in genus Quercus, Pinus, Acer, Carya, and Juniperus in the U.S. and Mexico. Bar charts showing proportion of total basal area in naturally assembled forests in the U.S. and Mexico for Quercus, Pinus, Pseudotsuga, Abies, and other species.]
Detecting threats to biodiversity

Oak declines in abundance
Detecting threats to biodiversity

Oak declines in abundance

Oak wilt

Fei et al. 2011 *For Eco & Mgmt*; Juzwik et al. 2011 *Plant Disease*
Oak wilt

*Bretziella fagacearum* (frmr: *Ceratocystis*)

Oak wilt xylem staining

Northern pin oak

Morton Arboretum

fungal mats in infected trees

Beer et al. 2017 *MycoKeys*; Juzwik et al. 2011 *Plant Disease*; Koch, Quiram, & Venette 2009 *Urb For & Urb Green*
Oak wilt

*Bretziella fagacearum* (frmr: *Ceratocystis*)

Oak wilt xylem staining

**Morton Arboretum**

fungal mats in infected trees

bur oak

c. Brian Schwingle

Beer et al. 2017 *MycoKeys*; Juzwik et al. 2011 *Plant Disease*; Koch, Quiram, & Venette 2009 *Urb For & Urb Green*
Oak wilt treatment

Plow line treatment to disrupt root connections

Cedar Creek Ecosystem Science Reserve

Koch, Quiram, & Venette 2009 Urb For & Urb Green
Early or advanced detection

*Xylella fastidiosa*, a plant bacterial disease in olive groves in Spain and Italy

Hyperspectral and thermal imagery can be used to diagnose plants that are visually asymptomatic

Zarco-Tejada et al. 2018. *Nature Plants*
Hyperspectral reflectance

- Reflectance due to spongy mesophyll
- Chlorophyll absorption
- Water absorption

Wavelength (μm)

Visible

Near-Infrared

Shortwave Infrared

Humboldt State: http://gsp.humboldt.edu/OLM/Courses/GSP_216_Online/lesson2-1/vegetation.html
Early or advanced detection

- Symptomatic oak wilt northern pin oak trees can be accurately differentiated from healthy pin oaks.
Accurate detection

- Variation in symptoms and similarity to other diseases may complicate diagnosis
Accurate and advance detection

• Distinguish oak wilt-affected trees from other diseases or drought symptoms?
• Can we detect in advance of tree death?
Methods: Hyperspectral reflectance
Seedling experiment

https://creativemarket.com/provector/895677-Vector-oak-tree-silhouette
Seedling experiment

bur oak (Quercus macrocarpa, white)

Bur oak blight

Oak wilt

Drought

northern pin oak (Quercus, ellipsoidalis, red)

Oak wilt

Drought

N = 127, ~18/treatment

Bretziella fagacearum

Tubakia iowensis
Seedling experiment

• Leaf-level measurements from inoculation to 60 days post

Noun Project, (c) Ema Dimitrova; Alice Noir; Icon Island; Manohara
Visual symptoms

Oak wilt
Visual symptoms

Bur oak blight
Visual symptoms

Drought
Visual Symptoms

- Symptoms of leaf fungal disease appear within 10 days
Visual Symptoms

- Oak wilt symptoms appear more rapidly in red oaks than white.
Spectra

![Graph showing reflectance vs. wavelength (nm) for different conditions: control, drought, oak wilt, and bur oak bl.](image-url)
Spectra are different between treatments

![Graph comparing median reflectance differences between treatments](image)

Spectral differences 9 weeks into experiment
Models for diagnosis

[Diagram showing spectral reflectance and absorptions in different wavelength bands, indicating chlorophyll absorption, water absorption, and reflectance due to spongy mesophyll.]

Modified from Humboldt State: http://gsp.humboldt.edu/OLM/Courses/GSP_216_Online/lesson2-1/vegetation.html
Diagnosing disease

- Treatments are detectable before most symptoms appear

```
<table>
<thead>
<tr>
<th>Proportion of all samples correctly classified</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLS-DA</td>
</tr>
<tr>
<td>Time since inoculation (days)</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>20%</td>
</tr>
</tbody>
</table>
```

Model accuracy:
- Pin oaks: 20%, 40%, 60%
- Bur oaks: 20%, 40%, 60%

Graph shows:
- Pin oaks: Model accuracy increases over time.
- Bur oaks: Model accuracy plateaus.
Diagnosing disease

- Systemic effects (healthy or drought-treated) were most accurately classified in red oaks from leaf level spectral measures.
Diagnosing disease

• In white oaks, where disease spread is slow, the dramatic symptoms of leaf fungal disease are the most detectable.

- control
- drought
- oak wilt
- bur oak bl.

![Graph showing treatment prediction accuracy over time since inoculation (days) for different conditions: control, drought, oak wilt, and bur oak bl.](bur_oak)
Plant water status

- Drought treatments reduced plant water access, oak wilt-treated plants maintained access to water
Leaf-level measurements and compartmentalization

- Disease compartmentalization can affect our ability to diagnose disease at the leaf level

Beier et al. 2017 *For Path*
Leaf level != whole plant

- Leaf level measurements can capture whole plant stresses (or situations in which all leaves are equally affected)
- May not capture responses which may be compartmentalized within the plants
Diagnosing disease: scaling up
Whole plant measurements

- Scaling up (in progress!): Compare whole plant canopy spectral reflectance to leaf level responses.
- Explicitly measure visually “healthy” and symptomatic leaves throughout disease progression
Whole plant disease detection

![Graph showing reflectance vs wavelength for different conditions]

- Control
- Drought
- Oak wilt
- Bur oak bl.
Whole plant disease detection

![Graph showing treatment prediction accuracy for pin oak and bur oak over time since inoculation.](image)

- **Pin oak**: Treatment prediction accuracy increases with time since inoculation, with different treatments showing varied trends.
- **Bur oak**: Treatment prediction accuracy generally decreases with time since inoculation, with specific conditions like control, drought, oak wilt, and bur oak bl. showing distinct patterns.

Day 23

Treatment prediction accuracy

Time since inoculation (days)
Conclusions

• Leaf level detection with hyperspectral data significant but limited – complicated by heterogeneity of symptoms in plant
• Whole plant detection hopeful…ongoing
• Stand and landscape level very promising