Applying Remote Sensing Metrics to Quantify Invasive Annual Plant Distributions and Map Potential Fire Hazard Across Mojave Landscapes

JANELLE DOWNS, JERRY TAGESTAD, VALERIE CULLINAN, KYLE LARSON

Pacific NW National Laboratory, Richland Washington
Fire Science Management for the Mojave Ecoregion—Barstow, CA, June 11, 2014
Invasive Species Detection and Fire Hazard: Objectives

- Develop and evaluate models to predict relative abundance of nonnative annuals using environmental attributes and remotely sensed data
- Construct relationship between measured cover and biomass that could be related to potential fire risk
- Provide model and tools to evaluate and compare relative fire hazard for Mojave
Invasive Species Detection and Fire Hazard Analysis

MODIS weekly NDVI composite images:
- From 2000-2014
- USGS eMODIS product
- 250 m pixel

Utilize weekly MODIS NDVI data to describe phenology and relative productivity; develop models for current and past distribution of nonnative annuals.

Develop landscape models to assess relative annual fire hazard.
Data > Field Plot Measurements

- 600 plot locations
- Collected during 2 campaigns (2009 & 2011)
- 50-meter plot size
- Cover measured for all species in subplots
- Biomass collected in a subset of the 2011 plots

<table>
<thead>
<tr>
<th>Plotcode</th>
<th>X</th>
<th>Y</th>
<th>AlnannfbTotal</th>
<th>AlnAnnfb+erocic</th>
<th>broarv</th>
<th>brorub</th>
<th>brotec</th>
<th>hordsp</th>
<th>schara</th>
<th>SchismusTotal</th>
<th>vulbro</th>
<th>Alnanngr Total</th>
<th>erocic</th>
<th>Alnbiefb Total</th>
<th>AlnperfbTotal</th>
<th>AlnpergrTotal</th>
<th>baresoil</th>
<th>litter</th>
</tr>
</thead>
<tbody>
<tr>
<td>66SER11</td>
<td>667</td>
<td>150</td>
<td>0.0</td>
<td>2.3</td>
<td>0.0</td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
<td>2.3</td>
<td>2.3</td>
<td>0.0</td>
<td>0.0</td>
<td>75.3</td>
</tr>
</tbody>
</table>
Phenological signatures or “Phenometrics”

Calculated for the hydrologic year between beginning of October and end of following September

Peak NDVI —
Maximum weekly NDVI during the growing season.

Start of Season (SOS) —
Weeks during which green-up is detected

End of Season (EOS) —
Week or month where senescence is nearly complete
Vegetation response to rainfall differs by zone

Mean NDVI and Cumulative Seasonal Precipitation for Creosote High Winter/High Summer Precipitation Class

Mean NDVI and Cumulative Seasonal Precipitation for Creosote Low Winter/Low Summer Precipitation Class

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965
Data > Field Plot Measurements

- More than 600 plot locations
- Collected during 2 campaigns (2009 & 2011)
- 50-meter plot size
- Cover measured for all species in subplots
- Biomass collected in a subset of the 2011 plots

<table>
<thead>
<tr>
<th>Plotcode</th>
<th>X</th>
<th>Y</th>
<th>AlnammTotal</th>
<th>AlnAnnfb+erocic</th>
<th>broarv</th>
<th>brorub</th>
<th>brorub</th>
<th>hordsp</th>
<th>schara</th>
<th>SchismusTotal</th>
<th>vulbro</th>
<th>Alnanng_Total</th>
<th>erocic</th>
<th>Alnblf6b_Total</th>
<th>Alnperfb_Total</th>
<th>Alnperg_Total</th>
<th>baresoil</th>
<th>litter</th>
</tr>
</thead>
<tbody>
<tr>
<td>66SER11</td>
<td>667150</td>
<td>3902163</td>
<td>0.0</td>
<td>2.3</td>
<td>0.0</td>
<td>0.1</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
<td>2.3</td>
<td>2.3</td>
<td>0.0</td>
<td>0.0</td>
<td>75.3</td>
<td>1.7</td>
</tr>
</tbody>
</table>
Data—NDVI Signatures For Field Locations with >25% Cover NIA and <5% Cover NIA

NDVI signatures for plots in Blackbrush in the Moderate Winter/Moderate Summer Precipitation Class
Noisy data smoothed via Savitsky-Gorlay filtering
Detecting and Mapping Nonnative Annual Species

- Vegetation data from 515 field locations assigned categories relevant for predicting fire risk
  - Low nonnative annual cover (≤ 10%)
  - Intermediate (10% to 40%)
  - High (> 40%)
- 25% of dataset withheld for validation
- Discriminant models
  - Standardized variables
  - By precipitation regimes and precipitation regime x vegetation association.
- Predictor variables:
  - Cumulative winter precipitation, monthly precipitation
  - Start of season (SOS) NDVI
  - Peak NDVI
  - Slope between SOS and Peak NDVI
Detecting and Mapping Nonnative Annual Species

- Relate measured nonnative annual cover to biomass measures
- N=128, $R^2 = 0.82$

<table>
<thead>
<tr>
<th>Fine Fuel Thresholds (a)</th>
<th>Log10 (biomass+1)</th>
<th>Cover = 0.0474*biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 kg/h</td>
<td>2.30103</td>
<td>9.48</td>
</tr>
<tr>
<td>1000 kg/h</td>
<td>3</td>
<td>47.4</td>
</tr>
</tbody>
</table>

(a) based on values from Rao et al. (2010), Brooks et al. (2007), Brooks (1999), and Brooks (2002).

$$y = \frac{b_{max} \cdot X}{K_d + X}$$

$$\text{arcsine}(\sqrt{\text{TotalAlienAnnualCover}})$$

$$\log_{10}(\text{Biomass} + 1 \text{ (kg/hectare)})$$
## Model Testing and Validation

<table>
<thead>
<tr>
<th>Model</th>
<th>Veg+Precip Classes</th>
<th>Modeled Sample Size</th>
<th>Validation Sample Size</th>
<th>Modeled Correct Classification</th>
<th>Modeled Maximum Error Size</th>
<th>Modeled Percent errors &gt; 5</th>
<th>Validation Maximum Error Size</th>
<th>Validation Percent Errors &gt; 10</th>
<th>1-Percent Errors &gt; 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>100, 300, 412 &lt; 1720 m +10(412)</td>
<td>38</td>
<td>22</td>
<td>86.8 (50% for 412)</td>
<td>9.96 (13.8 for 412)</td>
<td>8% (30% for 412)</td>
<td>4.7</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>M2</td>
<td>202, 205, 208, 210, 211</td>
<td>25</td>
<td>11</td>
<td>96</td>
<td>7.4</td>
<td>4%</td>
<td>37.4</td>
<td>27%</td>
<td>73%</td>
</tr>
<tr>
<td>M3</td>
<td>204 &lt; 896 m</td>
<td>39</td>
<td>17</td>
<td>76.9</td>
<td>25.2</td>
<td>8%</td>
<td>47.1</td>
<td>24%</td>
<td>76%</td>
</tr>
<tr>
<td>M4</td>
<td>204 &gt;= 896 m</td>
<td>44</td>
<td>8</td>
<td>77.3</td>
<td>10.7</td>
<td>7%</td>
<td>7.1</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>M5</td>
<td>403, 404, 406, 407, 410, 411</td>
<td>36</td>
<td>12</td>
<td>75.0</td>
<td>14.8</td>
<td>17%</td>
<td>35.6</td>
<td>17%</td>
<td>83%</td>
</tr>
<tr>
<td>M6</td>
<td>401, 405</td>
<td>57</td>
<td>23</td>
<td>82.5</td>
<td>30.2</td>
<td>12%</td>
<td>11.3</td>
<td>9%</td>
<td>91%</td>
</tr>
<tr>
<td>M7</td>
<td>412 &gt;= 1720 m</td>
<td>33</td>
<td>8</td>
<td>75.8</td>
<td>11.9</td>
<td>9%</td>
<td>8.1</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>M8</td>
<td>402 &gt;= 1200 m</td>
<td>62</td>
<td>15</td>
<td>75.8</td>
<td>36.6</td>
<td>8%</td>
<td>32</td>
<td>13%</td>
<td>87%</td>
</tr>
<tr>
<td>M9</td>
<td>402 &lt; 1200 m</td>
<td>40</td>
<td>11</td>
<td>82.5</td>
<td>22.5</td>
<td>13%</td>
<td>31.8</td>
<td>27%</td>
<td>73%</td>
</tr>
</tbody>
</table>
Example of Model Results for 2010-2011 Growing Season

- Represents two precipitation regions
  - High Winter/Low Summer
  - Low Winter/Low Summer
- 88% correct classification based on limited validation dataset
- Represents 57% of the study area
- Weighted mean classification accuracy = 75% for initial discriminant models
Model Development

- Model based primarily on 2009 and 2011 field data
- Further data collection occurred during 2012 and 2013 for development and validation
  - Dry years – little growth of invasive annuals
- Existing models not robust

- Step back to drawing board
  - More complex models?
  - More data?
  - Logistics for incorporating current data and complex models into accessible information in timely manner
- What other metrics or modeling approaches can we use to evaluate potential fire hazard
Conceptual Model for Preseason Assessment of Fire Hazard

\[ \text{Hazard} = P(\text{Ignition}) \times P(\text{Burn}) \]

- **Ignition**
  - Human Sources
    - Distance to Road or Road Density
  - Natural Sources
    - Lightning Density

- **Burn**
  - Fuel
    - Fuel type
      - Perennial woody
      - Herbaceous
    - Fuel load
  - \( \Delta \text{WPPT} \)
  - \( \Delta \text{NDVI} \)

\( \Delta \text{NDVI} = \text{peak NDVI in current year } (i) - \text{median of peak NDVI}_{2000-2010} \)

Mean \( \Delta \text{WPPT} = \text{Winter precipitation for current year} - \text{median winter precipitation}_{1971-2010} \)
Use the database of fire starts for 1980 to 2012

81% of fire **starts** occur <1000 m from a road

52% human-caused, 33% natural, 15% unknown caus

Inverse relationship between all fire types and distance from road is function of road density in Mojave.

Relationship for human-caused fires.
Mean $\Delta$NDVI for Burned Areas 2000-2010

$\Delta$NDVI = peak NDVI in current year (i) – median of peak NDVI$_{2000-2010}$
Mean \( \Delta WPPT \) for Burned Areas (2000 – 2010)

\[ \text{Mean } \Delta WPPT = \text{Winter precipitation for current year} - \text{median winter precipitation}_{1971-2010} \]
Subsampling by Vegetation Type within Burns

- **Class 1** – low elevation
  - Creosote, Salt Desert Shrub and Mojave Scrub Shrub

- **Class 2** – mid elevation
  - Blackbrush, Sagebrush

- **Class 3** – higher elevation
  - Juniper, Pinyon Pine, Chapparal

65% of fires occurred in Blackbrush and Creosote vegetation types for the entire fire record.
Preseason Fire Hazard

- Use precipitation zones as strata to divide region into sampling areas
- Using 10-year record of data:
  - Fire history (Burned/Unburned)
  - $\Delta$NDVI
  - $\Delta$WPPT
  - Ignition variables
  - Vegetation Type
- Apply logistic regression to derive parameter estimates to predict probability of fire hazard in that season
Preseason Fire Hazard: Logistic Regression Model

- **Sampling Strategy**
  - Stratified by:
    - Precipitation Zone
    - Vegetation Type
    - Year
  - Sampled 1,000 fires and 1,000 non-fires from each Precipitation Zone – Vegetation Type combination

- **Final Model**
  - Logistic Regression
  - Variables included:
    - Distance to Road
    - Lightning Density
    - Delta winter precipitation
    - Delta NDVI
    - Dwppt^2
    - Lightning Density^2
  - Parameters estimated using 20X cross-validation.
Preseason Fire Hazard: Logistic Regression Model

- Model generates predicted probability of fire for each pixel (for each year or future year)
- More complicated models considered with little to no improvement in classification accuracy
- Classification Accuracy
  - Accuracy = 77.8%
  - False Positives = 6.3%
  - False Negatives = 15.8%
Mojave Fire Management Portal linked through California Fire Science Consortium

- Project Products/Information
- Dynamic Satellite Data
- Models
- Data Access
- Collaboration
- Customization
- Visualization
- Prediction
- Dynamic Data and Maps
- Web Portal
- Hazard Maps
- Web GIS
- Information (Handbook & Publications)
- Phenology

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Mojave Fire Management Portal linked through California Fire Science Consortium

- Project Products/Information
- Dynamic Satellite Data
- Models
- Data Access
- Collaboration
- Customization
- Visualization
- Prediction
- Dynamic Data and Maps
- Web Portal
- Hazard Maps
- Web GIS
- Information (Handbook & Publications)
- Phenology

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965
http://gisx.pnl.gov/Mojave

Predictive Tools for Managing Altered Fire Regimes
Caused by plant invasions in the Mojave Desert

Easting
(313199 - 831599)

Northing
(3722754 - 4222220)

Bolded Lines are Displayed

Zoom

Projection (WGS84 UTM 11n) x: 646998.94 y: 3799207.38 (meters)
Model Index {row: 1712, col: 1445}

Week Number for Hydrologic Year Oct – Sept
Predictive Tools for Managing Altered Fire Regimes
Caused by plant invasions in the Mojave Desert

Projection (WGS84 UTM 11n) x: 411883.82 y: 3859559.56 (meters)
Model Index {row: 1470, col: 505}
Week Number for Hydrologic Year Oct. – Sept.: 26