Resilience and regeneration after wildfire in dry mixed-conifer forests of the U.S. northern Rockies

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Balsamroot in bloom, Frank Church-River of No Return Wilderness, ID; June 2012 © Phil Higuera
Increase in the **frequency** of large wildfires in the western US (Westerling et al. 2006, 2008), **largest** wildfires are getting **larger** (Dennison et al. 2014)

**Earlier snowmelt** and warmer **spring temperatures** will continue increasing vulnerability to fires (Westerling et al. 2006)
Large disturbances shape ecosystem structure & function for decades to centuries. Changes in frequency, size, or intensity can alter ecosystem resilience.

- State change post-fire to non-forested vegetation (Savage & Mast 2005, Odion et al. 2010)
- Shift post-fire species assemblages (Johnstone et al. 2010)
Large disturbances shape ecosystem structure & function for decades to centuries. Changes in frequency, size, or intensity can alter ecosystem resilience.

Two measures of forest resilience:
- Are trees regenerating where they existed prior to the fire?
- Does the species composition remain the same?
Larger, more frequent fire especially a concern in dry mixed-conifer forests of the western U.S... Combined effects of 20th century management have led to changes in: 

- species composition,
- stand density,
- and fuel loading
Traditional paradigm (adopted in part from SW U.S.)...

- Fuel loading
- Fire intensity & severity (e.g., Dillon et al. 2011)
- Forest resilience

Dry mixed-conifer forests of Northern Rockies...

- Fuel loading (Keeling et al. 2006)
- Fire intensity & severity (Dillon et al. 2011)
- Forest resilience
Research Objective

Quantify variability in post-fire regeneration as a function of wildfire patch metrics and biotic and abiotic environmental conditions
Sampling Design

Site Selection

Northeast

Southwest
Hypotheses

**Burn severity:** Higher burn severity may alter post-fire microenvironment and eliminate seed sources (e.g., Savage & Mast 2005)

**Patch size:** Isolation of live seed sources can limit seed dispersal into burned areas (e.g., Donato et al. 2009, Haire & McGarigal 2010)

**Topography & Microhabitat:** Regeneration will be limited on warmer, drier south facing slopes and at low elevations (Dodson & Root 2013)
Sampling Design

Variables

- **Burn Severity** (Categorical)
- **Elevation** (Continuous)
- **Aspect** (Continuous - Bounded [0 360])
- **Slope** (Continuous - Bounded [0 90])
- **Latitude** (Continuous)
- **Distance to seed source** (Continuous; ≤ 500 m)
- **Stand basal area** (Continuous)
- **Understory vegetation cover** (Continuous: %)
- **Canopy cover** (Continuous: 0 – 100%)

Derived Variables

- **Time since fire** (Continuous)
- **Heat Load Index** (Continuous)
## Results

### Conifer species composition

<table>
<thead>
<tr>
<th>Time</th>
<th>Conifer Density (trees ha(^{-1}))</th>
<th>Conifer Species Composition* (Mean % of plot density ± 2 SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Douglas-fir</td>
</tr>
<tr>
<td>pre - 2000 fire</td>
<td>361 ± 61</td>
<td>38.9 ± 3.4</td>
</tr>
<tr>
<td>post - 2000 fire</td>
<td>7047 ± 1714</td>
<td>35.3 ± 4.3</td>
</tr>
<tr>
<td>pre - 2007 fire</td>
<td>421 ± 48</td>
<td>32.7 ± 3.9</td>
</tr>
<tr>
<td>post - 2007 fire</td>
<td>8153 ± 2006</td>
<td>24.1 ± 4.4</td>
</tr>
</tbody>
</table>

*NP indicates that mature trees of that species were not found on any sites post-fire

** pre-fire measurements are of mature trees

*** post-fire measurements are of seedlings

---

Douglas-fir (*Pseudotsuga menziesii*)

Ponderosa pine (*Pinus ponderosa*)

Lodgepole pine (*Pinus contorta*)

Grand fir (*Abies grandis*)
Results

Exploratory Data Analysis

![Graph showing seedling density (tr/ha) vs. distance to seed source (m) with different fire severity categories: Unburned, Low, Moderate, High.](image)

- Seedling density decreases as the distance to the seed source increases.
- Inset graph shows a closer view of the seedling density near the seed source.

- See inset for detailed view.
Statistical Analysis

Logistic Regression & Count Models

Do different processes matter for different species?

1. Logistic Regression (binomial distribution)

   - All Species
   - Douglas-fir
   - Ponderosa pine
   - Lodgepole pine
   - Grand fir

Seedlings Present or Absent?

Fire occurs at site x

Excess zeros?

Zero-inflated negative binomial model
Do different processes matter for different species?

Fire occurs at site x

Seedlings Present or Absent?

1. Logistic Regression (binomial distribution)
   - All Species
   - Douglas-fir
   - Ponderosa pine
   - Lodgepole pine
   - Grand fir

2. Count model (negative binomial distribution)
   - Excess zeros?
   - Zero-inflated negative binomial

If seedlings are present, how many?
Results

Seedling presence/absence – all spp.

Threshold probability of 0.87 predicts seedling presence < 95 m from a live seed source.

All sites with basal area > 5 m² ha⁻¹ had a high probability (> 85%) of seedling re-establishment.
Results

Seedling presence/absence by spp.

Distance to seed source is important for seedling re-establishment for all species except lodgepole pine.
Statistical Analysis

Logistic Regression & Count Models

1. Logistic Regression
   (binomial distribution)
   - All Species
     - Douglas-fir
     - Ponderosa pine
     - Lodgepole pine
     - Grand fir

   Do different processes operate for different species?

2. Count model
   (negative binomial distribution)
   - Excess zeros?
   - Zero-inflated negative binomial

Fire occurs at site x

Seedlings Present or Absent?
## Results

### Seedling abundance - all spp.

<table>
<thead>
<tr>
<th></th>
<th>All Species</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Presence/</td>
<td>Count</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Absence</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Distance to Seed Source</strong></td>
<td>-0.014</td>
<td>-0.007</td>
<td></td>
</tr>
<tr>
<td><strong>Low Burn Severity</strong></td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td><strong>Moderate Burn Severity</strong></td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td><strong>High Burn Severity</strong></td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td><strong>Time Since Fire</strong></td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td><strong>Elevation</strong></td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td><strong>Heat Load Index</strong></td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td><strong>Stand Basal Area</strong></td>
<td>0.072</td>
<td>0.032</td>
<td></td>
</tr>
<tr>
<td><strong>Vegetation Cover</strong></td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
</tbody>
</table>

*Distance to seed source is the overriding variable determining seedling presence and abundance post-fire.*
## Results

### Seedling abundance - All spp.

<table>
<thead>
<tr>
<th>Source</th>
<th>Douglas-fir</th>
<th>Ponderosa pine</th>
<th>Lodgepole pine</th>
<th>Grand fir</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Presence/Absence</strong></td>
<td><strong>Count</strong></td>
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<td><strong>Count</strong></td>
<td><strong>Presence/Absence</strong></td>
</tr>
<tr>
<td><strong>Distance to Seed Source</strong></td>
<td>-0.011</td>
<td>-0.006</td>
<td>-0.011</td>
<td>-0.009</td>
</tr>
<tr>
<td><strong>Low Burn Severity</strong></td>
<td>--</td>
<td>2.051</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>Moderate Burn Severity</strong></td>
<td>--</td>
<td>2.578</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>High Burn Severity</strong></td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>Time Since Fire</strong></td>
<td>--</td>
<td>0.146</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>Elevation</strong></td>
<td>0.001</td>
<td>0.001</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>Heat Load Index</strong></td>
<td>-2.452</td>
<td>-2.997</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>Stand Basal Area</strong></td>
<td>0.072</td>
<td>0.042</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td><strong>Vegetation Cover</strong></td>
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</table>
## Hypotheses

<table>
<thead>
<tr>
<th><strong>Burn severity:</strong></th>
<th><strong>Patch size:</strong></th>
<th><strong>Topography &amp; Microhabitat:</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Higher burn severity may alter post-fire microenvironment and eliminate seed sources (e.g., Savage &amp; Mast 2005)</td>
<td>Isolation of live seed sources can limit seed dispersal into burned areas (e.g., Donato et al. 2009, Haire &amp; McGarigal 2010)</td>
<td>Regeneration will be limited on warmer, drier south facing slopes and at low elevations (Dodson &amp; Root 2013)</td>
</tr>
</tbody>
</table>
Distance to seed source is the **mechanism** by which burn severity influences seedling re-establishment.
Hypotheses

**Patch size:**
Isolation of live seed sources can limit seed dispersal into burned areas (e.g., Donato et al. 2009, Haire & McGarigal 2010)
• **Size** and **spatial configuration** of stand-replacing patches are key drivers of post-wildfire recovery.

• **Over 75%** of area burned in stand-replacing patches is **within 95 m** of a lower severity edge.
Measures of forest resilience:
Are trees regenerating where they existed prior to the fire?
Does the species composition remain the same?
Are trees regenerating where they were prior to the fire?

Disturbance (Fire)

Dispersal

Germination

Survival

Growth

Distance to Seed Source < 95 m

Heat Load Elevation Stand Basal Area

Present

Abundant

Abundant

Abundant
Measures of forest resilience:
Are trees regenerating where they existed prior to the fire?
Does the species composition remain the same?
More abundant in stand-replacing patches depending on pre-fire levels of serotiny

More prolific due to its potential to disperse 2 – 3x further than other species

Does the species composition remain the same?

Discussion

- Douglas-fir (*Pseudotsuga menziesii*)
- ponderosa pine (*Pinus ponderosa*)
- lodgepole pine (*Pinus contorta*)
- grand fir (*Abies grandis*)

Does the species composition remain the same?
Summary & Implications

1. The combination of different species and patch heterogeneity created a landscape that is **highly resilient** to large wildfires.

2. This holds so long as:
   1. No repeat fires before trees reach reproductive maturity.
   2. The proportion of stand-replacing patches does not increase.
   3. The suitable niche for seedlings does not disappear.

3. Given the potential for more area burned in the future, more area will likely burn severely, thus the **size** of high severity patches may influence post-fire recovery.
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