Can climate change increase fire severity independent of fire intensity?

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The physical context
Fire behavior and effects

Topography
Weather
Fuels
The physical context
Fire behavior and effects

Fire effects
- Fire behavior
- Fuels
- Air quality
- Soils & water
- Wildlife
- Cultural resources
- Vegetation
There is a physical AND a biological context to fire.
Can our forests take the heat? Fire, climate change and tree mortality in the western US

Predicting post-fire tree mortality
Trees vs. fire

Improving our predictions
Pre-fire conditions affect post-fire tree mortality

What does all this mean?
Impending changes?
Fire intensity
The amount of energy released by a fire.

Fire line intensity (kW m$^{-1}$):
$I = 258 \cdot \text{Flame Length}^{2.17}$
Agee (1993)

Fire severity
The amount of ecosystem change caused by a fire.

Changing climate = changing fire regime
Area burned annually is increasing

Changing climate = changing fire regime
Area burned annually is increasing
In spite of increasing suppression efforts!
Changing climate = changing fire regime
The fire season is lengthening

A. Western US Forest Wildfires and Spring–Summer Temperature

B. Timing of Spring Snowmelt

C. Fire Season Length

Westerling et al. 2006, Science

Credit: NPS
Changing climate = changing fire regime
High severity fire is increasing across the Sierra Nevada of California

Miller et al. 2009, Ecosystems
(but see Miller et al. 2012, Ecol. Appl.)
Changing climate = changing fire regime
Moderate and high severity fire is increasing across the southwestern US

FSDI = Forest Drought Stress Index = (cold season precip. – warm season VPD)

Williams et al. 2013, Nature Climate Change
Changing climate = changing forest dynamics

Tree mortality rate is increasing
Changing climate = changing forest dynamics

Tree mortality rate is increasing in western US

- 76 plots in undisturbed old forests
- observed from ~1981 to ~2004
- 87% of plots increasing mort. rate $P < 0.0001$
- mort. rate ~18 yr DOUBLING period
- temporal trend, $P < 0.0001$

Symbol size = magnitude of change
Red = increasing mortality
Blue = decreasing mortality

van Mantgem et al. 2009, Science
Changing climate = changing forest dynamics
Die-back events becoming more common?

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**Defense**
- crown height
- bark thickness

**Damage**
- percent crown scorch
- bole char height
- root damage
Predicting post-fire tree mortality
Combining observations

\[ \ln \left( \frac{Pm}{1 - Pm} \right) = \beta_0 + \beta_1 \cdot \text{Crown scorch} + \beta_2 \cdot \text{Bark thickness} \]

\( Pm = \text{probability of mortality} \)
Interactions of stressors

- - - - - - Have to sneeze

- - - - - Have to pee

Disaster

from Martin 2012, *This is a Book*
The decline spiral model of tree death

Franklin et al. 1987, BioScience
The decline spiral model of tree death

from Pederson 1998, *Ecology*

- Drought
- Acid rain
- Gypsy moth
- Armillaria
- Two-lined chestnut borer

VIGOR

TIME
The decline spiral model of tree death

from Pederson 1998, *Ecology*
Stressed trees are more sensitive to fire

Testing the decline spiral model

Fire damage

Growth  \rightarrow  \text{Death}

0  \quad 5  \quad 10

Year

\ln \left( \frac{Pm}{1 - Pm} \right) = \beta_0 + \beta_1 \cdot \text{Crown scorch} + \beta_2 \cdot \text{radial growth}

Pm = \text{probability of mortality}
Stressed trees are more susceptible to fire

- Single fire, two sites at Sequoia National Park, CA
- 668 individual white fir (*Abies concolor*)

Stressed trees are more sensitive to fire
Testing the decline spiral model

- Sugar pine (*Pinus lambertiana*), Sequoia NP
- Single (hot) Rx fire monitored at two 1-ha plots

Stressed trees are more sensitive to fire
Testing the decline spiral model

Crown health rating related to 5yr post-fire survivorship
- Five adjacent fires in Sequoia National Park, CA
- 105 individual sugar pine (*Pinus lambertiana*)
- Fisher’s exact test, *P* < 0.001
Stressed trees are more sensitive to fire

Testing the decline spiral model

Pre-fire growth trends predict 5yr post-fire survivorship

- Five adjacent fires in Sequoia National Park, CA
- 105 individual sugar pine

\[ P(\text{live}) = \text{DBH} + \text{Crown scorch} + \text{Bole char} + \]
\[ 30 \text{ year growth trend} + \]
\[ 30 \text{ year count of sharp growth declines} \]

\[ P(\text{live}) = \text{DBH} + \text{Crown scorch} + \text{Bole char} \]

Nesmith, *Dissertation, UC Berkeley* 2011
Stressed trees are more sensitive to fire
Prescribed fire effects across the western US

- Data from NPS and USFS
- 18 sites
- >250 plots
- >7000 trees
- Dominated by *P. ponderosa* and *A. concolor*

(Also *Pseudotsuga menziesii*, *Calocedrus decurrens* and *P. lambertiana*)
Stressed trees are more sensitive to fire
Prescribed fire effects across the western US

<table>
<thead>
<tr>
<th>Model</th>
<th>DIC</th>
<th>ΔDIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P(m) = BT + \text{Crown scorch} + \text{Bole char}$</td>
<td>4775</td>
<td>8.8</td>
</tr>
<tr>
<td>$P(m) = BT + \text{Crown scorch} + \text{Bole char} + \text{rD} + \text{Crown scorch*}\text{rD} + \text{Bole char*}\text{rD}$</td>
<td>4766</td>
<td>0</td>
</tr>
</tbody>
</table>

van Mantgem et al., 2013 *Ecol. Lett.*
Threshold responses: The physiology of aspen die-back

In aspen (*Populus tremuloides*), trees that had experienced drought in the past were more sensitive to further drought.

Evidence for “cavitation fatigue” as a cause of drought-induced tree mortality.

[Graph showing data on crown mortality and xylem tension over time, with black representing previous drought and white representing no previous drought.]
Stressed trees are more sensitive to fire
Parallels in tree physiology

Heating from fires can cause:
1) Cavitation (bubble in xylem water column)
   a) sap heating (reducing surface tension, Michaletz et al. 2012, *New Phytol.*)
   b) from higher vapor pressure deficit (Kavanagh et al. 2010, *Fire Ecology*)

2) Xylem element deformation (Michaletz et al. 2012, *New Phytol.*)
Stressed trees are more sensitive to fire
Prescribed fire effects across the western US

van Mantgem et al., 2013 Ecol. Lett.
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Agee (1993)

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**Fire severity**
The amount of ecosystem change caused by a fire.

Tree mortality, crown scorch, bark char height, and depth of burn. Organic matter consumption (Keeley 2009, *Int. J. Wild. Fire*).
There are known knowns; there are things we know that we know.

There are known unknowns; that is to say there are things that, we now know we don't know.

But there are also unknown unknowns – there are things we do not know, we don't know.

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The decline spiral model of tree death

Franklin et al. 1987
The decline spiral model of tree death

1. A conceptual model for fire-caused tree mortality

Franklin et al. 1987
dNBR, differenced normalized burn ratio

Problems with remote sensing of fire severity if comparison interval is short?

\[
dNBR = NBR_{\text{prefire}} - NBR_{\text{postfire}}
\]
dNBR, differenced normalized burn ratio

Problems with remote sensing of fire severity if comparison interval is short?

van Mantgem et al., 2011 For. Eco. & Manage.

Black Hills, South Dakota
Forest fires and CO$_2$ emissions

* C transfer due to tree mortality was about fourfold higher than pyrogenic C emission.

* High-severity (and moderate-severity) fire exerted disproportionate C impacts across the study landscape.

Meigs et al. 2011 Ecosystems
I'M CHANGING THE CLIMATE!
ASK ME HOW!
Current NPS natural resources policy:
-- When possible, restore and maintain naturally-functioning ecosystems.
-- When this is not possible, “maintain the closest approximation of the natural condition.”