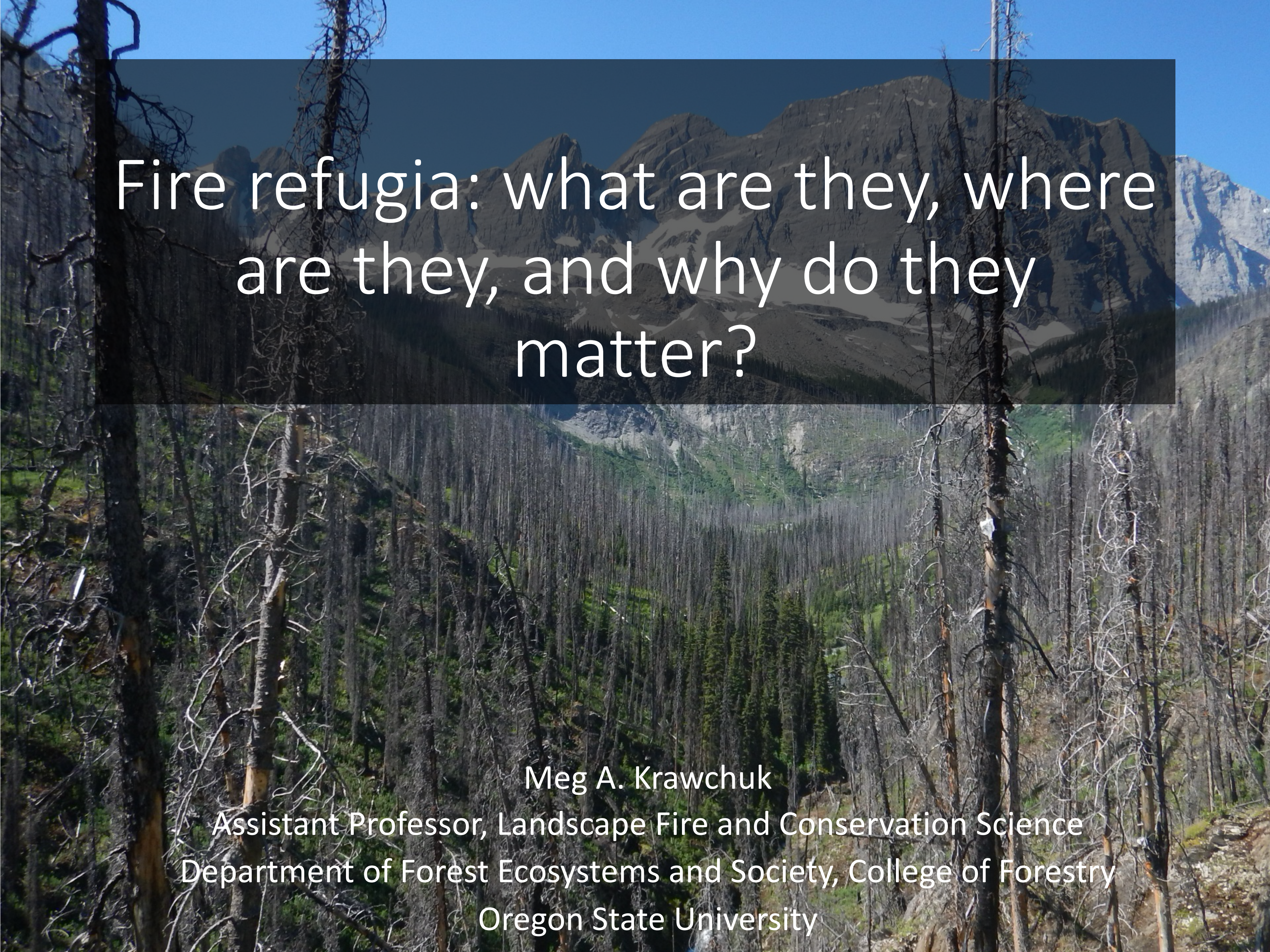
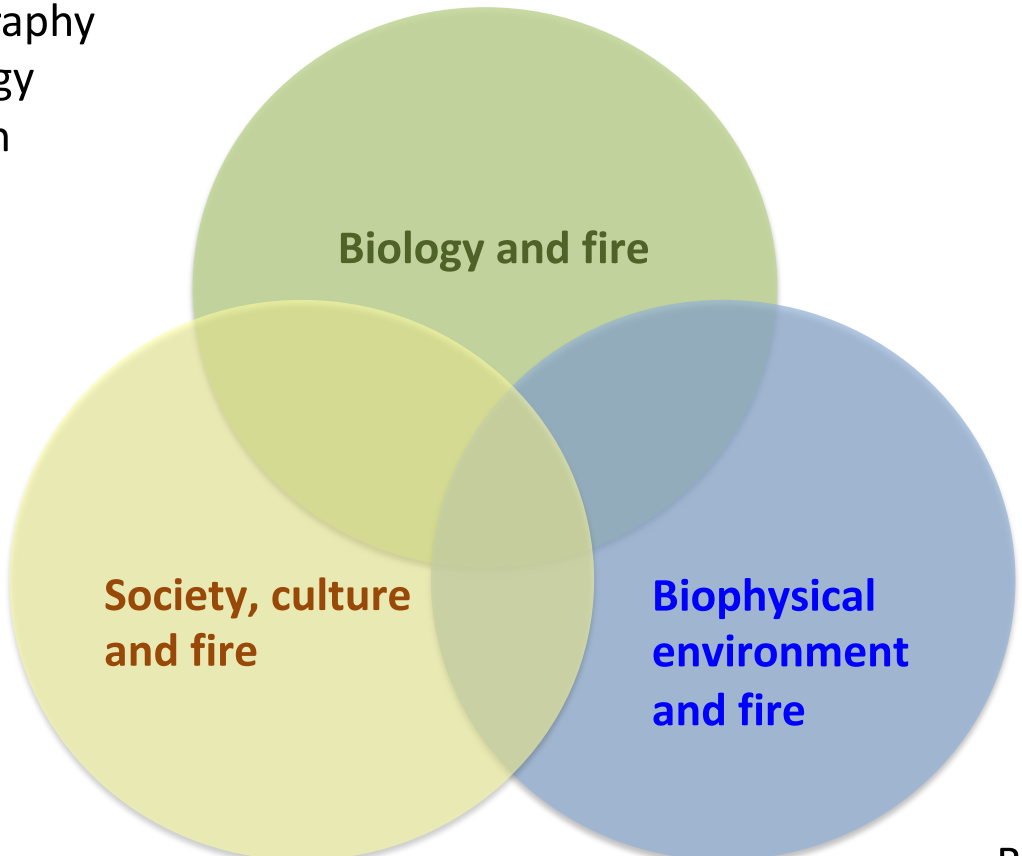


Fire refugia: what are they, where are they, and why do they matter?

Meg A. Krawchuk
Assistant Professor, Landscape Fire and Conservation Science
Department of Forest Ecosystems and Society, College of Forestry
Oregon State University

Pyrogeography

Biogeography
Physiology
Evolution
Ecology
Soils

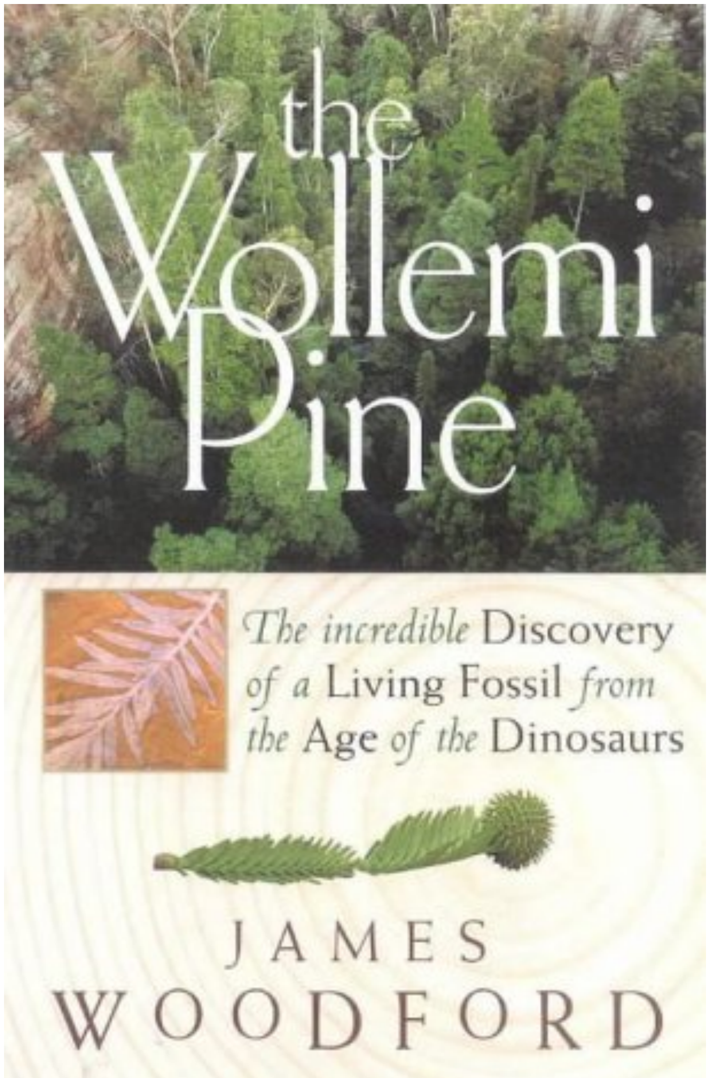


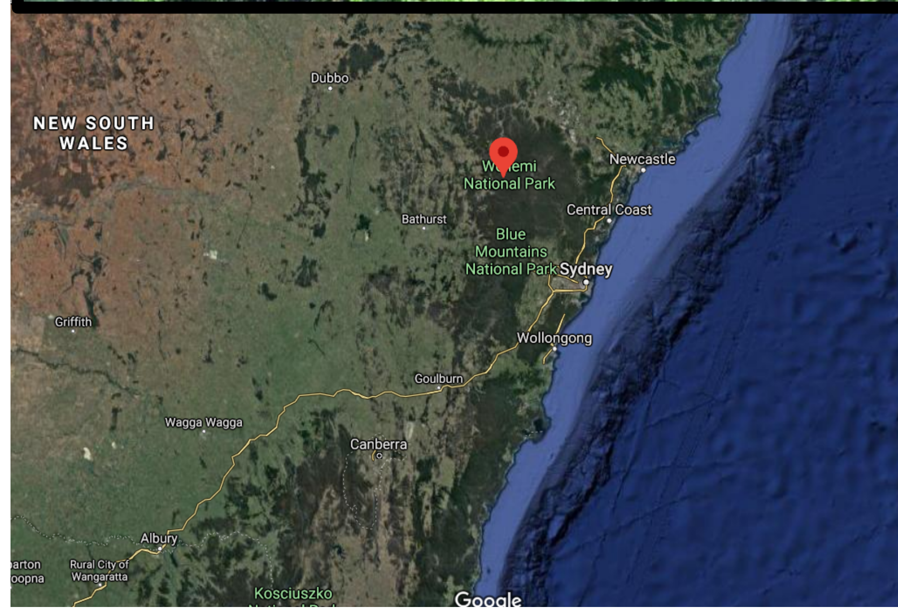
History
Politics
Sociology
Psychology
Conservation
Management

Physics
Chemistry
Hydrology
Climatology
Meteorology
Biogeochemistry

abstracted from Bowman et al (2013)

The Wollemi pine: *Wollemia nobilis*





The Wollemi pine in ancient refugium

Collaborators: cast of characters

Core refugialites
Sandra Haire, HLLE
Carol Miller, USFS-ALWRI
Jonathan Coop, WCU
Marc-André Parisien, CFS
Ellen Whitman, CFS
Geneva Chong, USGS
Ryan Walker, WCU
Garrett Meigs, OSU-WA DNR
Will Downing, OSU

Refugia Research Coalition
Arjan Meddens, WSU
Crystal Kolden, UIdaho/UC Merced
Aaron Ramirez, Reed College
Toni Lyn Morelli, USGS
Jen Cartwright, USGS

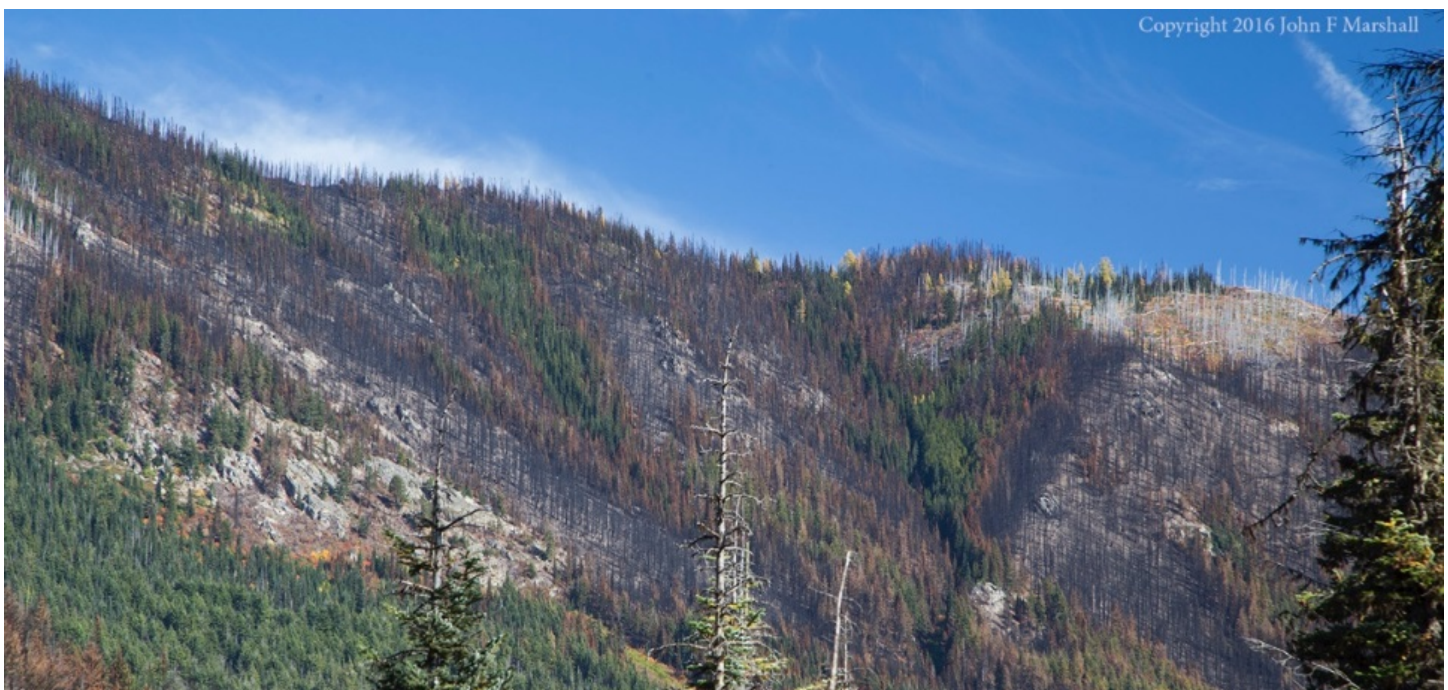
Refugia Relatives
Sean Parks, USFS-ALWRI
Chris Dunn, OSU
James Johnston, OSU
Andrew Merschel, OSU
David Moy, OSU
Joe Rausch, USFS
Claire Tortorelli, OSU
Sylvan Pritchett, OSU

CASC-Refugia
Garrett Meigs, OSU-WA DNR
Dave Bell, USFS
Matt Gregory, USFS
Ray Davis, USFS
Dave Wiens, USGS
Katie Dugger, USGS

Great Northern LANDSCAPE CONSERVATION COOPERATIVE
NSERC CRSNG
SFU SIMON FRASER UNIVERSITY ENGAGING THE WORLD
FOREST SERVICE U S DEPARTMENT OF AGRICULTURE
1868 Oregon State University
USGS science for a changing world

Menu for today

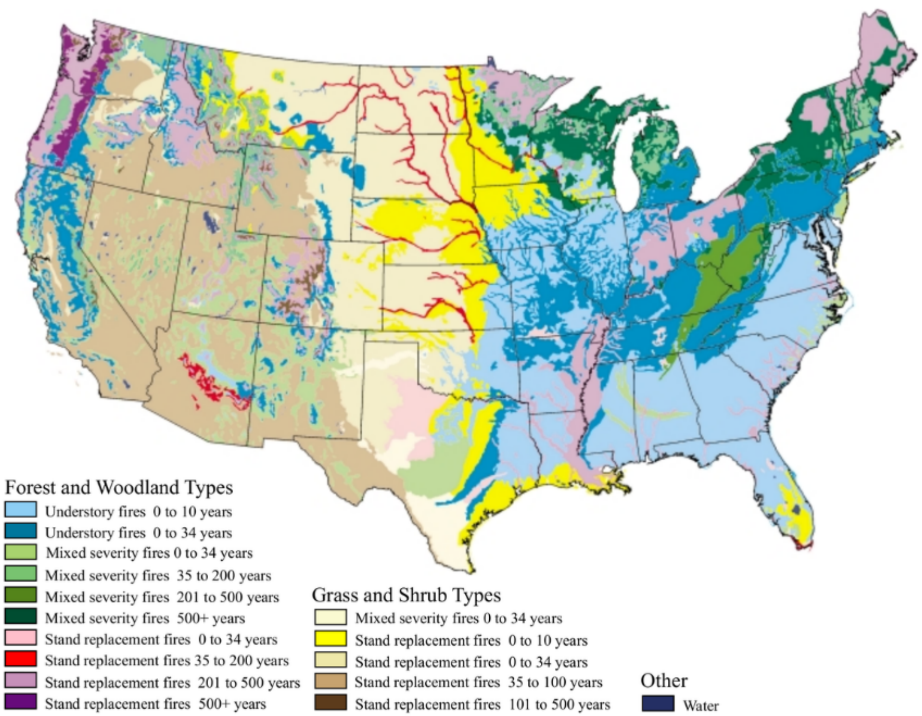
1. What are fire refugia?
2. Ongoing work and two examples
3. Why this all matters



Fire as an ecosystem process

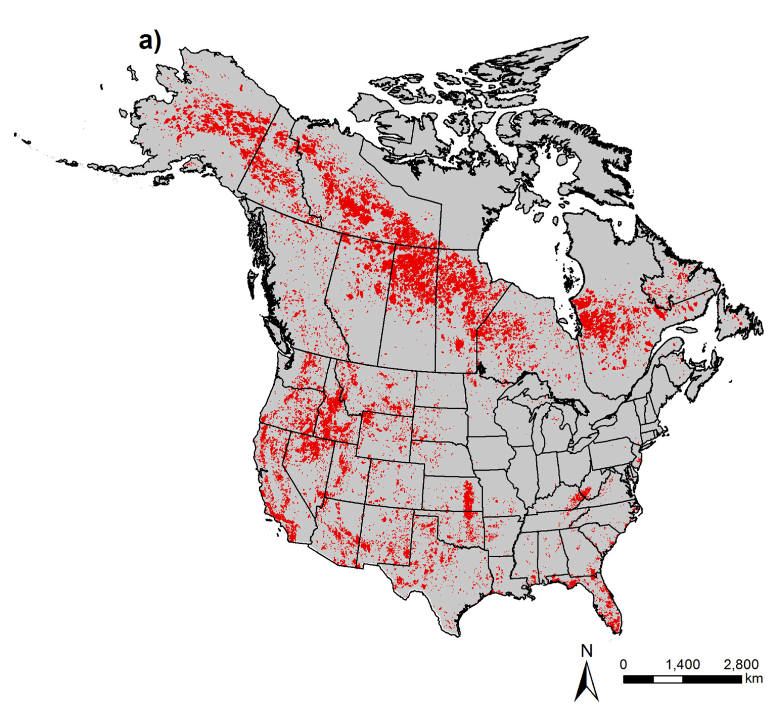
Well recognized that fire plays an integral ecological role in ecosystems, but with different tempos in different places

e.g, “historical” fire regimes



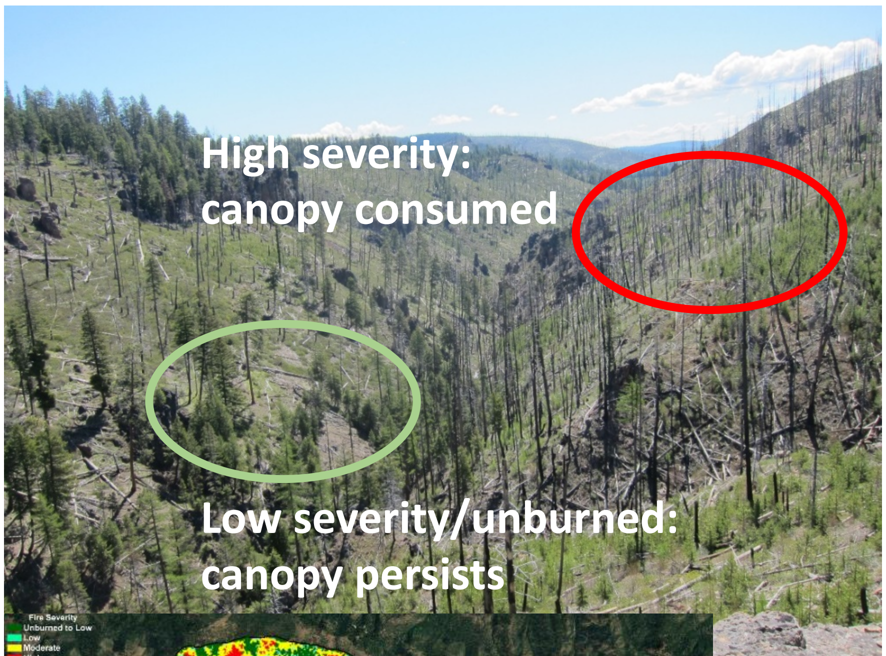
Brown and Kapler (2000)

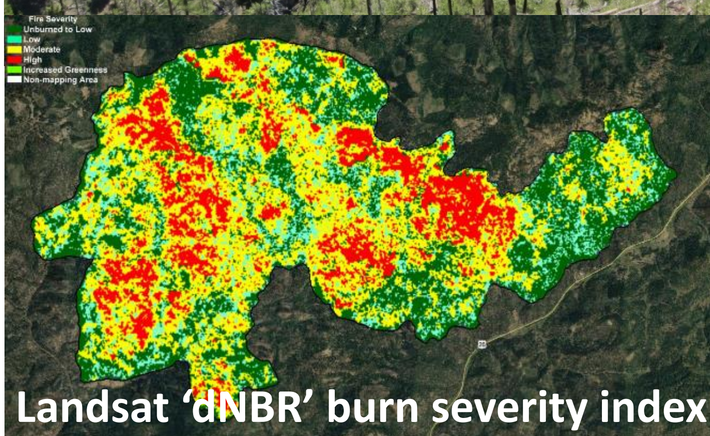
e.g., fires recorded 1984-2014



Parisien et al (2016)

Fire mosaics in forest ecosystems





Important heterogeneity, fire effects contribute to local and landscape biodiversity

Severity: amount of biomass consumed

Legacy: what persists through fire

Management need to understand fire’s patterning for goals of restoration and conservation of biodiversity

Fire refugia?

Fire refugia: places disturbed less frequently or severely by wildfire than the surrounding landscape

(Krawchuk et al. 2016, Wood et al. 2011, Camp et al. 1997)

Low severity/unburned, sometimes referred to as fire islands, shadows, skips, residuals, refuges, or fire remnants

Related to idea of "refugia," those places where [suitable] habitats persist as surrounding landscapes change

(Keppel et al. 2012)

The ‘slow lane’ of change

Fire refugia: a conceptual model

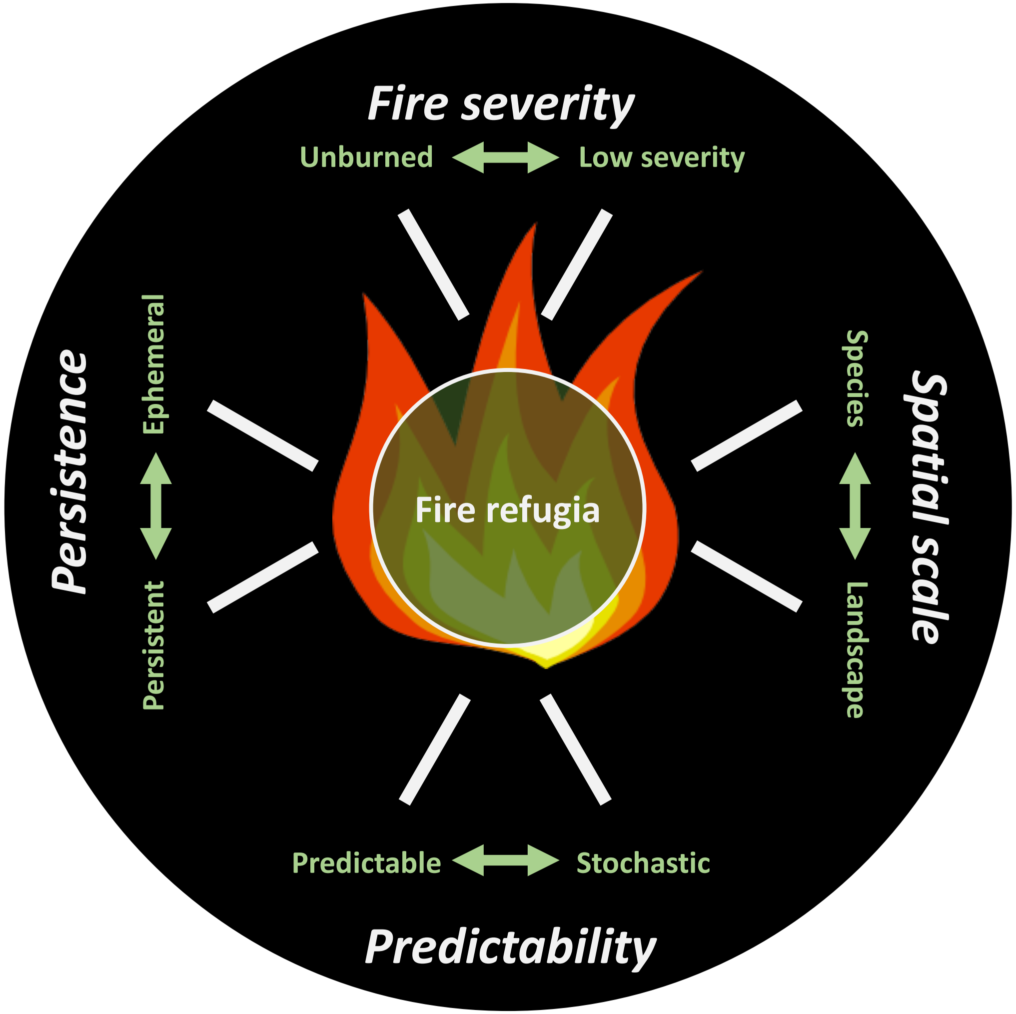
Locations that are *resistant* to disturbance from fire, that can confer *resilience* to landscapes

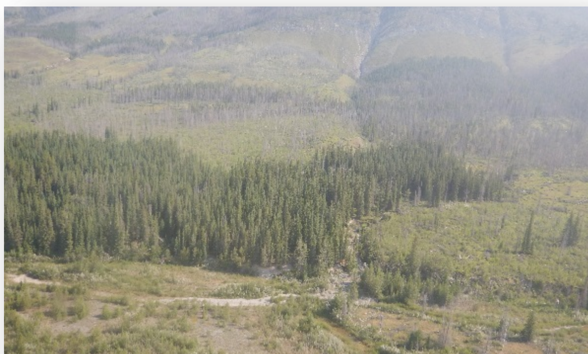
An important element of landscape heterogeneity

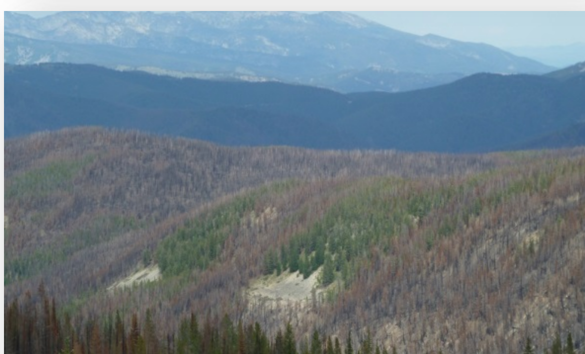
Refugium from what… for what…

Fire refugia attributes? Fire isn't binary, and neither are fire refugia

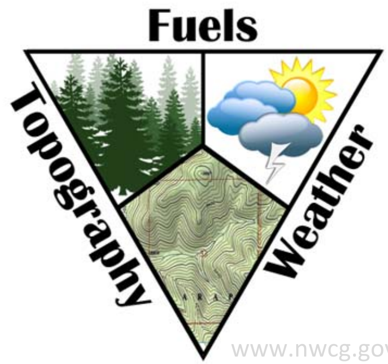
Fire refugia, the album...



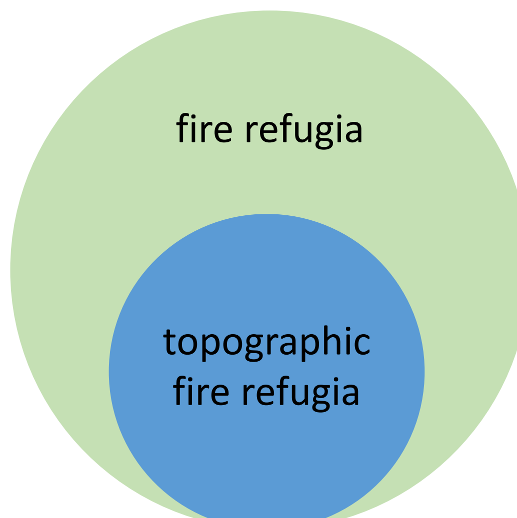




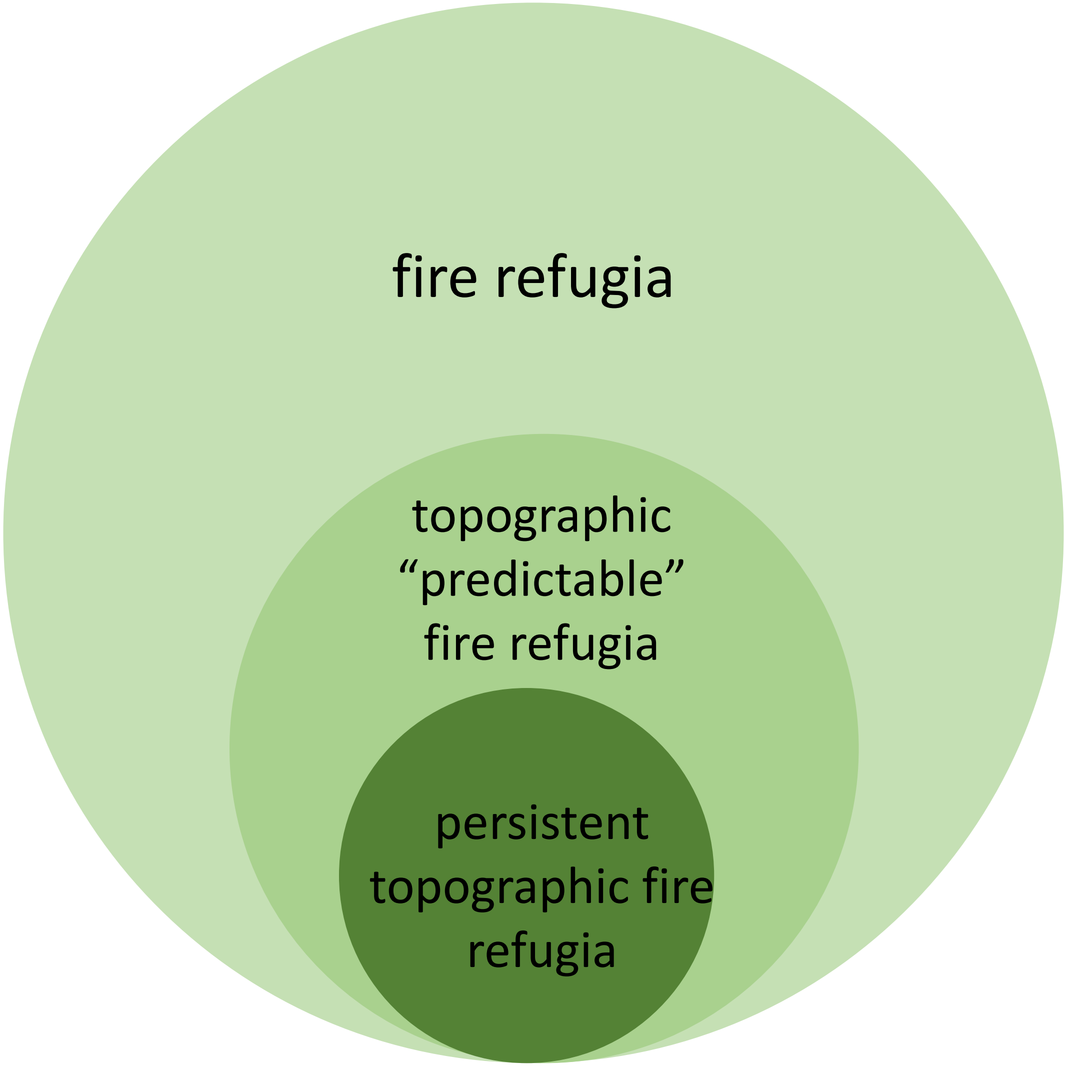
Drivers of fire refugia?



www.nwcg.gov/

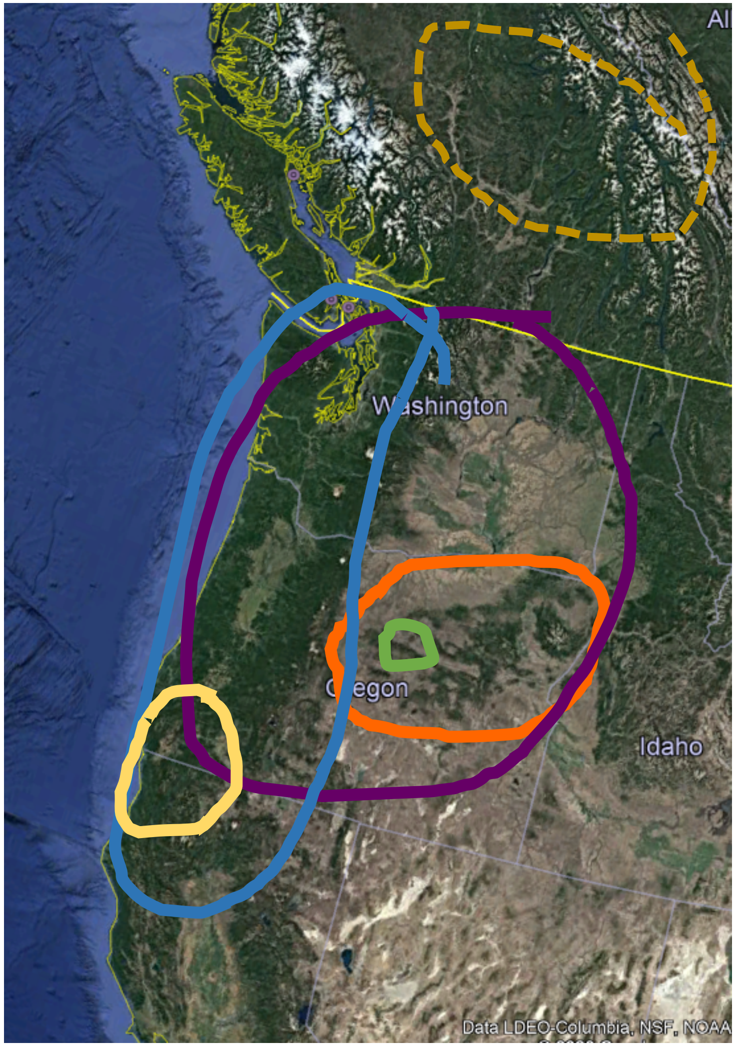


E.g., features with predictability from the topo-edaphic template?

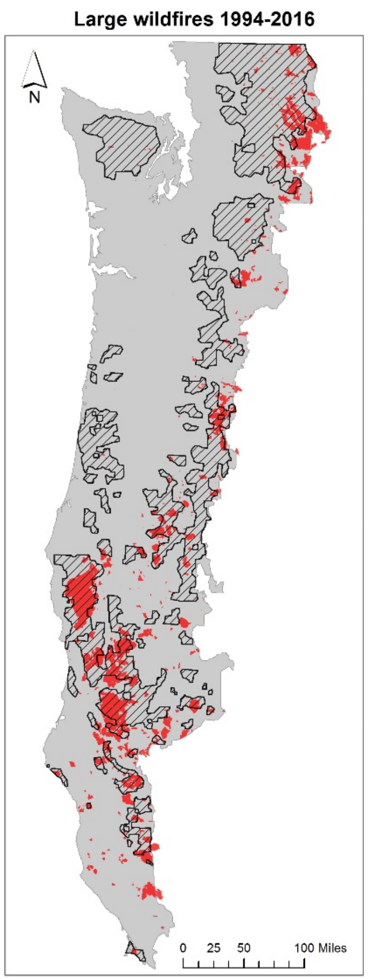

fire refugia
topographic
“predictable”
fire refugia
persistent
topographic fire
refugia

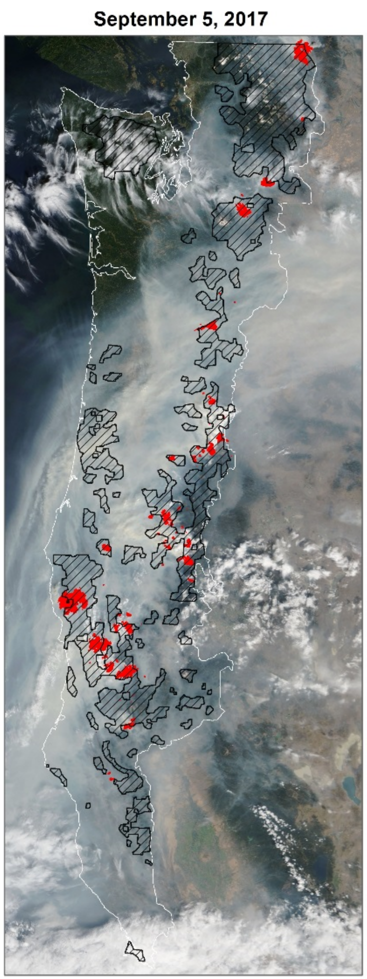
Fire refugia research projects

- Drivers of fire refugia in late-successional forests of the PNW
- Composition of contemporary forest fire refugia of Washington and Oregon
- Disjunct and decoupled, fire history of the Cedar Grove Botanical Area
- Function and form of contemporary forest fire refugia in the Blue Mountains, OR
- Persistent refugia in the Klamath-Siskiyou



Fire refugia and old-growth forests





Fire refugia in late-successional forests: Predicting habitat persistence to support land management in an era of rapid global change

<u>CASC-Refugia</u>
Garrett Meigs, OSU/WA DNR
Dave Bell, USFS
Matt Gregory, USFS
Ray Davis, USFS
Dave Wiens, USGS
Katie Dugger, USGS

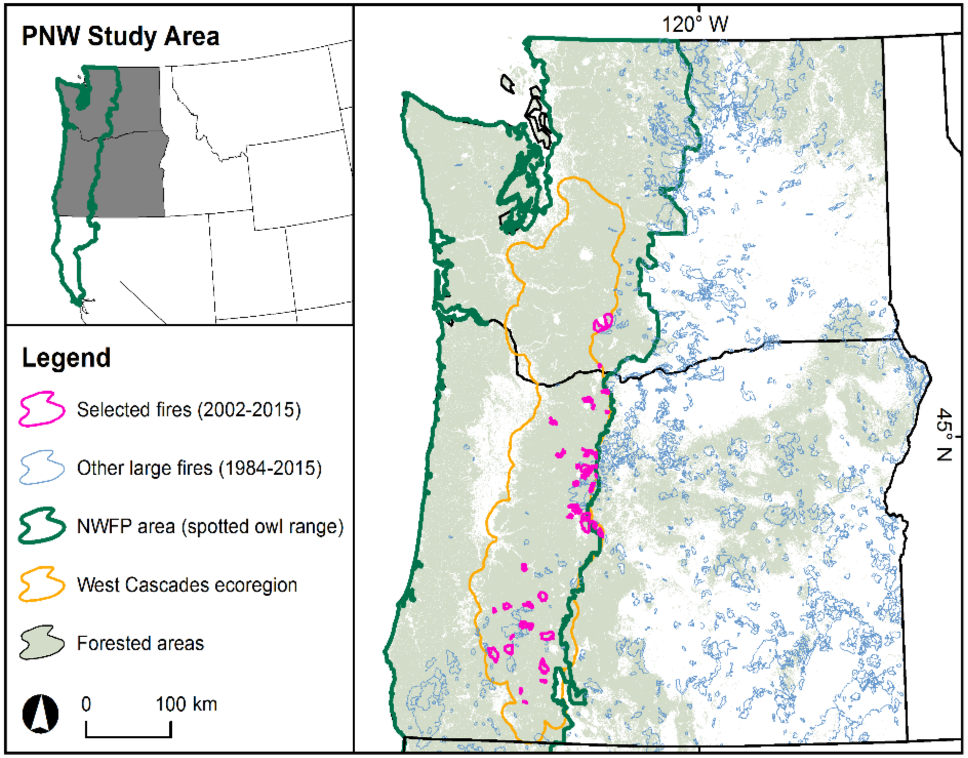
<u>Refugia Relatives</u>
Sean Parks, USFS ALWRI
Chris Dunn, OSU
David Moy, OSU
Sylvan Pritchett, OSU

Does terrain confer protection?

Is there predictability in the location of fire refugia in contemporary old-growth forests, associated with topographic features?

What is the role of forest biomass/structure?

Does this predictability vary with fire weather conditions?



n=39 fires

Meigs et al (*in review*)

Spatial hypotheses

Slope-aspect:

>cool moist north-facing slopes

Topographic convergence:

>cold air pooling, hydrologic pooling

Topographic relative position:

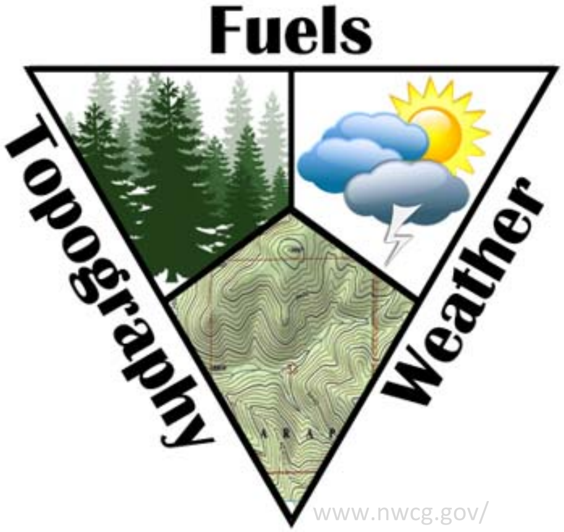
>depressions, hill-tops

Forest structure and microclimates:

>cooler/moist microclimates in older forests

Weather conditions influence fire:

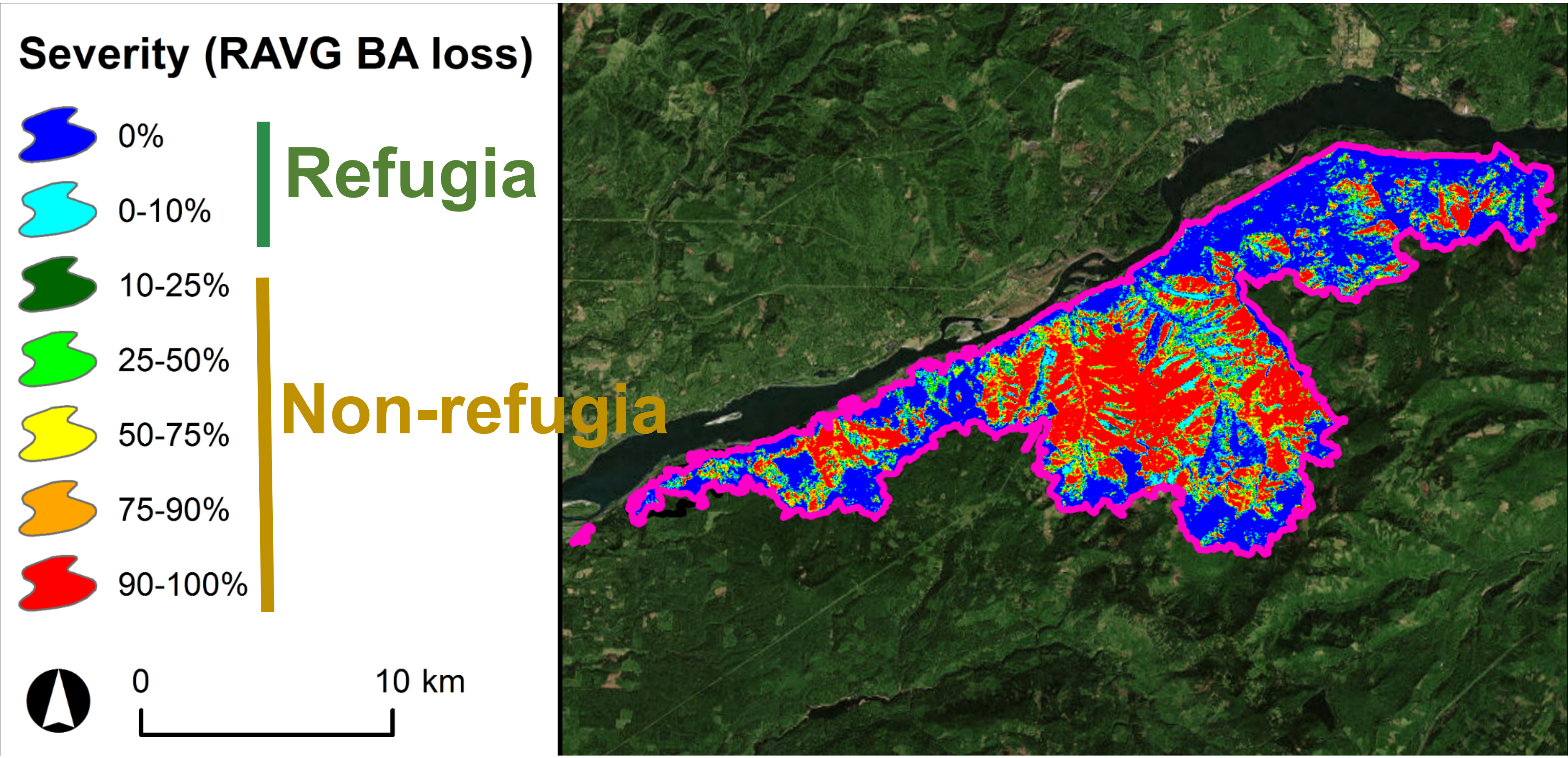
>extreme weather minimizes “bottom-up” drivers



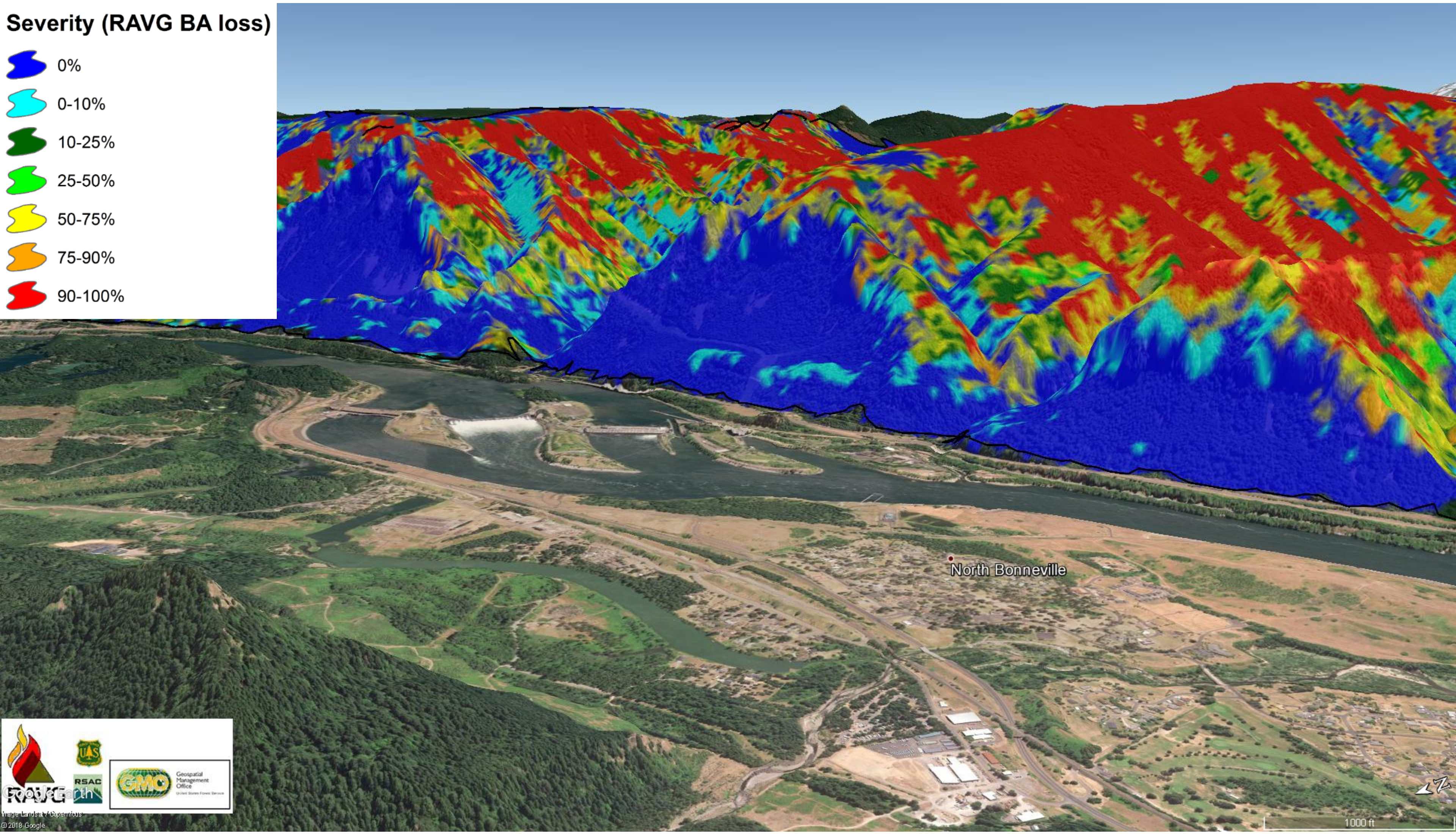
www.nwcg.gov/

Data: refugia 1/0

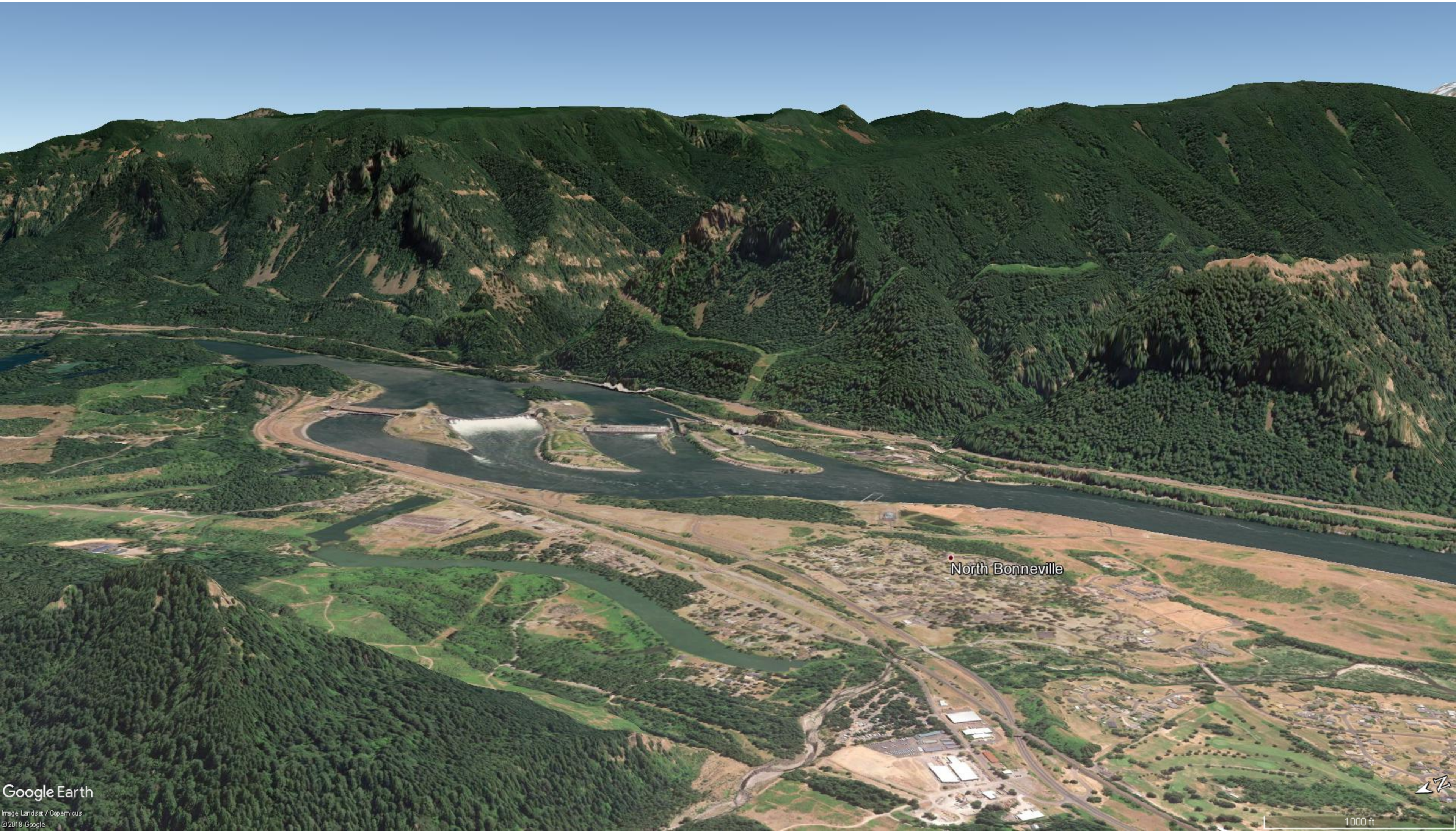
e.g., Eagle Creek Fire severity map



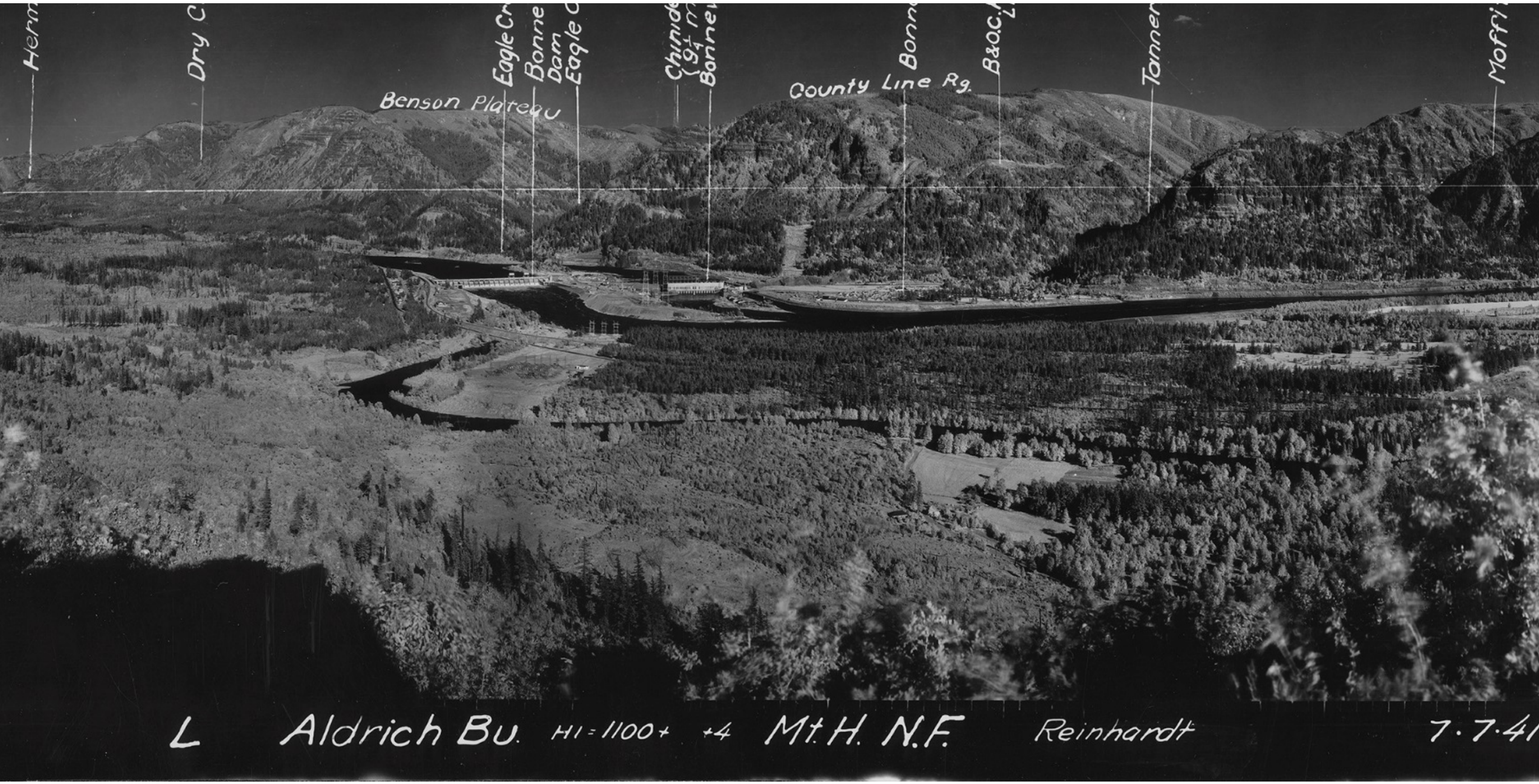
e.g., Eagle Creek landscape (Google Earth, RAVG)



Eagle Creek landscape (Google Earth, pre-fire)

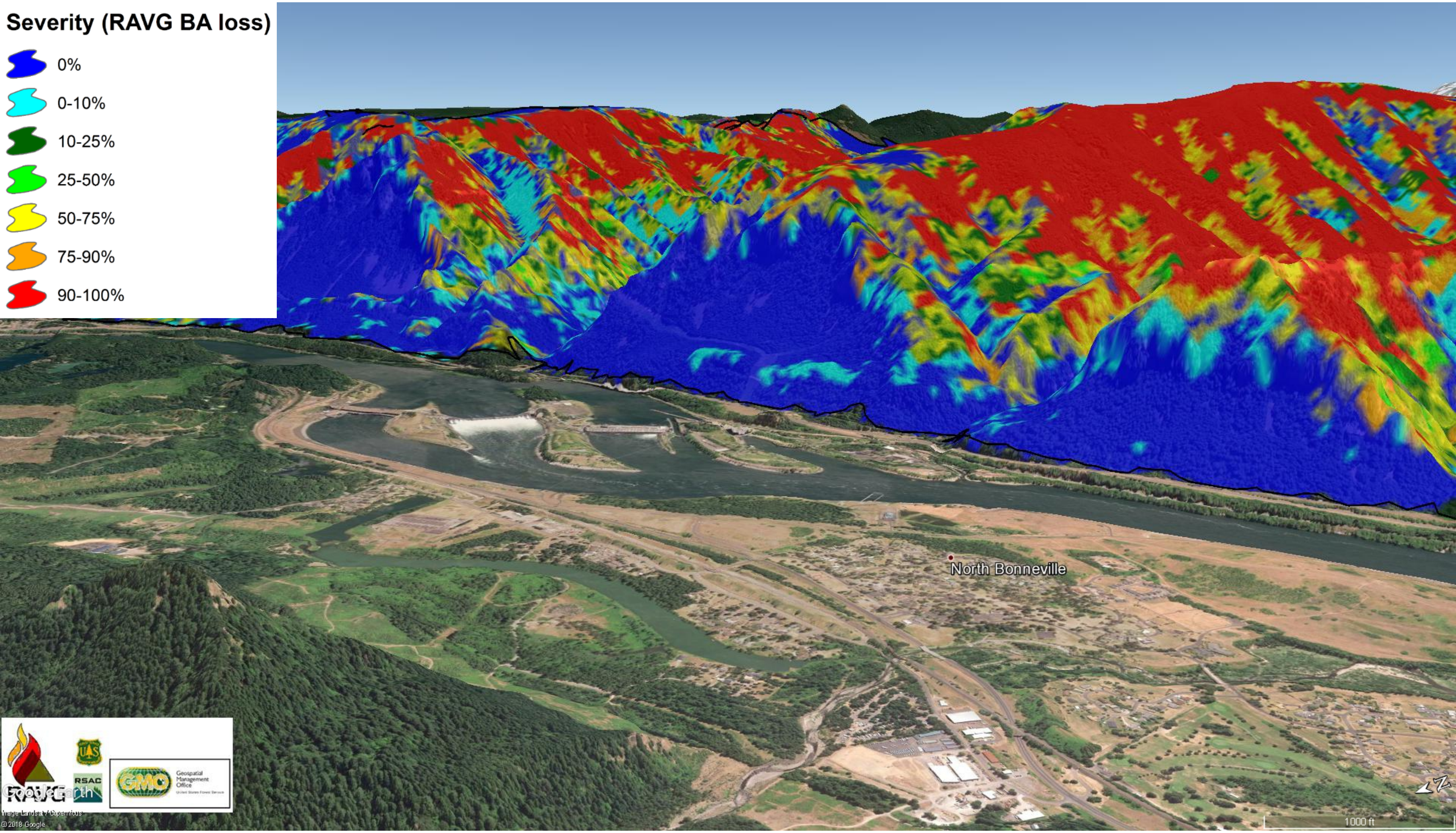


Eagle Creek landscape (1941)



http://maps.tnc.org/osbornephotos/index.html

Eagle Creek landscape (Google Earth, RAVG)



Data: fire weather

Key datasets: stratification and predictor variables

Fire weather: **Energy Release Component (ERC)**; fuel moisture and potential energy release from a fire.

- Based on MODIS day of burn and interpolated weather station data.
- 2 bins based on percentiles: **low/moderate** (<90th percentile); **high** (>=90thpercentile) conditions.

Data: topography

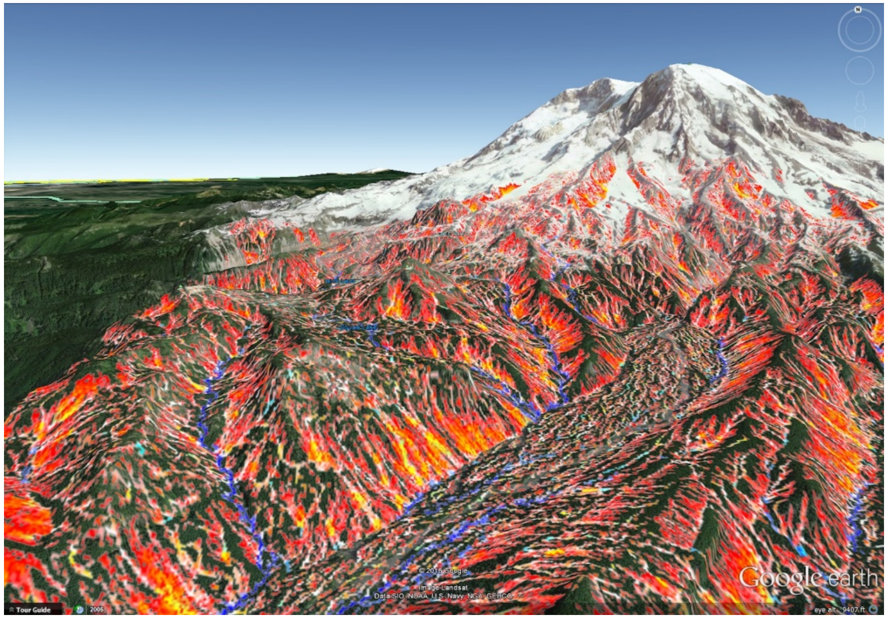
Key datasets: stratification and predictor variables

Fire weather: **Energy Release Component (ERC)**; fuel moisture and potential energy release from a fire.

- Based on MODIS day of burn and interpolated weather station data.
- 2 bins based on percentiles: **low/moderate** (<90^{th} percentile); **high** (>=90^{th}percentile) conditions.

Topography from digital elevation models.

- Predictor variables:
  - local aspect
  - local slope
  - catchment area
  - catchment slope
  - flow path
  - relative position
  - topographic convergence
  - topographic wetness



Mt. Rainier: opentopography.org

Data: forest biomass/structure

Key datasets: stratification and predictor variables

Fire weather: **Energy Release Component (ERC)**; fuel moisture and potential energy release from a fire.

- Based on MODIS day of burn and interpolated weather station data.
- 2 bins based on percentiles: **low/moderate** (<90th percentile); **high** (>=90th percentile) conditions.

Topography from digital elevation models.

- Predictor variables:
  - local aspect
  - local slope
  - catchment area
  - catchment slope
  - flow path
  - relative position
  - topographic convergence
  - topographic wetness

Forest biomass/structure

GNN biomass

Landsat enhanced vegetation index (EVI)

Analysis

Data analysis: boosted regression trees (BRTs)

BRTs handle different types of predictors, interactions, missing data, nonlinear data (Elith et al. 2008).

Random points representing 5% of the fires of interest, 100 m buffer from perimeter (Parks et al. 2018).

All points pooled for ecoregion-scale inference *(n* = 13,267)*.*

Parameterizing the machine: ≥1000 trees, learning rate = 0.001, tree complexity = 5, bag fraction = 0.5.

Evaluate refugia predictability among strata with ROC-AUC

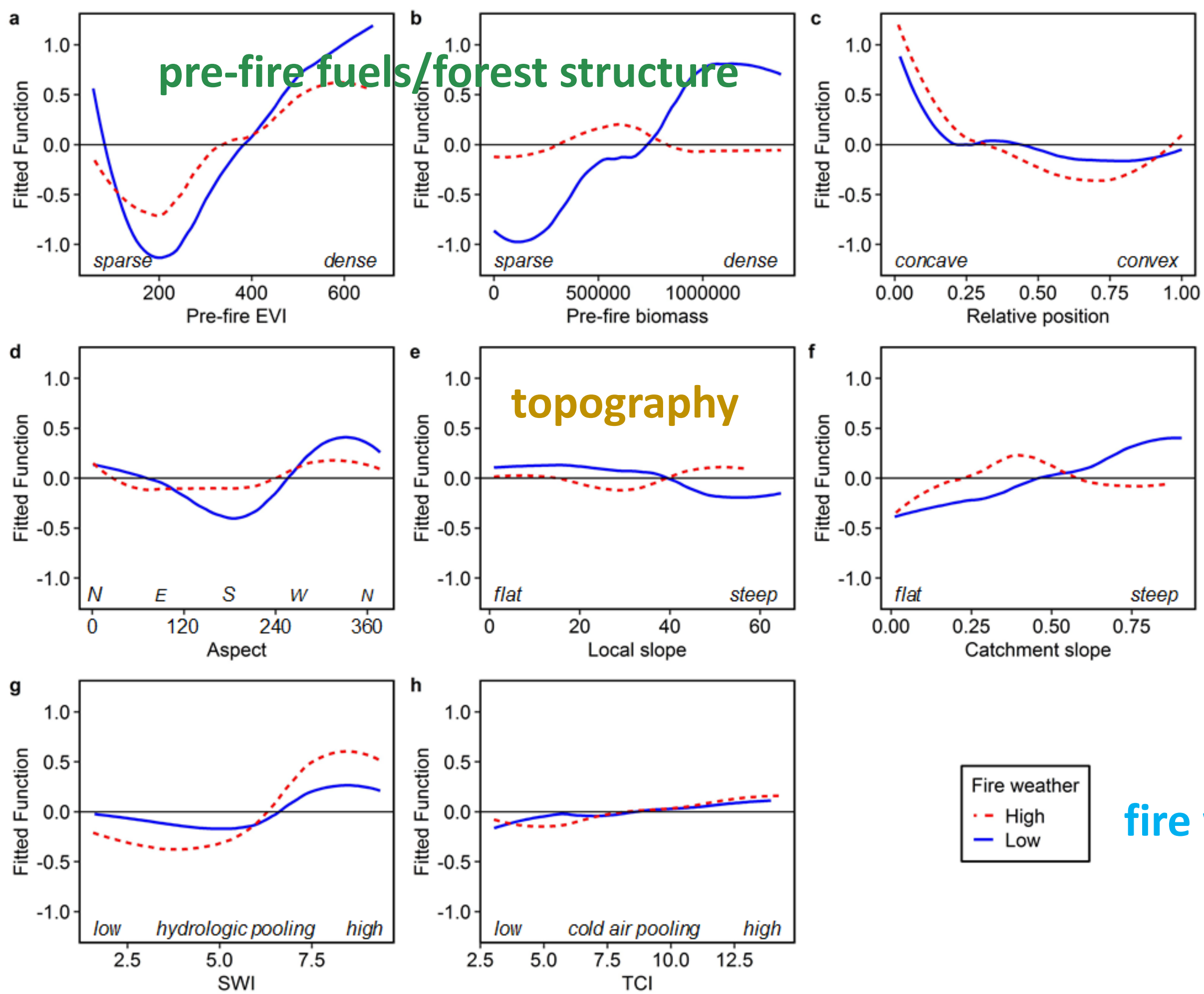
- 0.5: random
- >0.6 to ≤0.7: fair
- >0.7 to ≤0.8: good
- 1.0: perfect

BRTs also enable predictive maps!

techemergence.com

Drivers of fire refugia

Probability of refugia



fire weather

Summary of results

Higher *probability and predictability* of fire refugia under more moderate fire weather conditions

Pre-fire live fuels strong predictors of fire refugia, with higher refugia probability in forests with higher pre-fire biomass

Probability of fire refugia higher in topographic settings with:

- concave topographic position
- relatively northern aspects
- steep catchment slope
- hydrologic pooling
- cold air pooling

Does terrain confer protection?

Is there predictability in the location of fire refugia in old-growth forests associated with topographic features?

Yes, and…

Does this predictability vary with fire weather conditions?

And this matters for understanding where we are least likely to lose old-growth forests to higher severity fire in the future

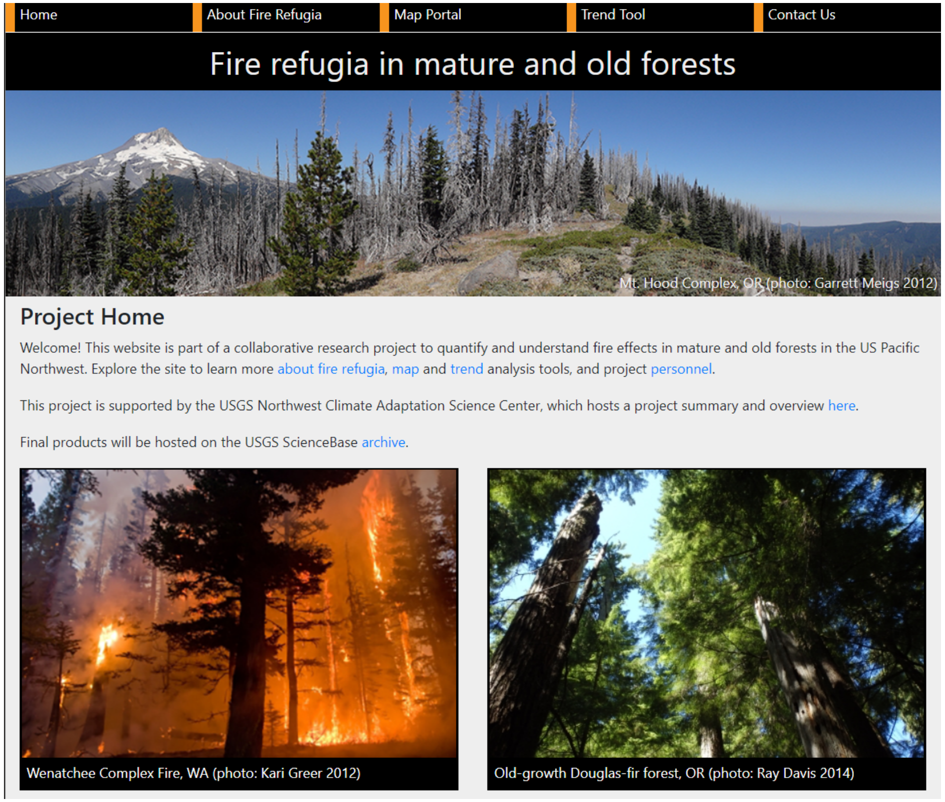
And where we might best invest in conservation and restoration measures

Meigs et al (*in review*)

Next steps…

Refined analyses for entire study region, added explanatories

Feeding to our collaborative project with aim of integrating outcomes into land management and policy decisions



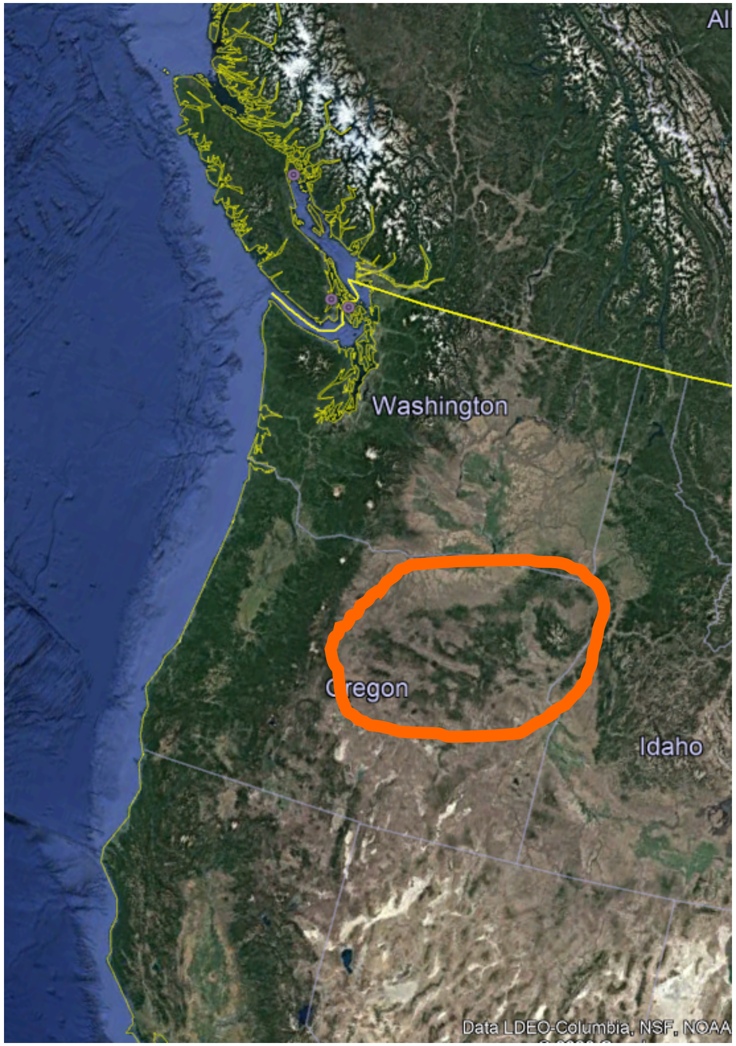
Function and form of fire refugia

Influence of fire refugia spatial pattern on post-fire forest recovery in Oregon's Blue Mountains

Historically frequent, low severity fire

Experiencing contemporary fire as infrequent, high severity events

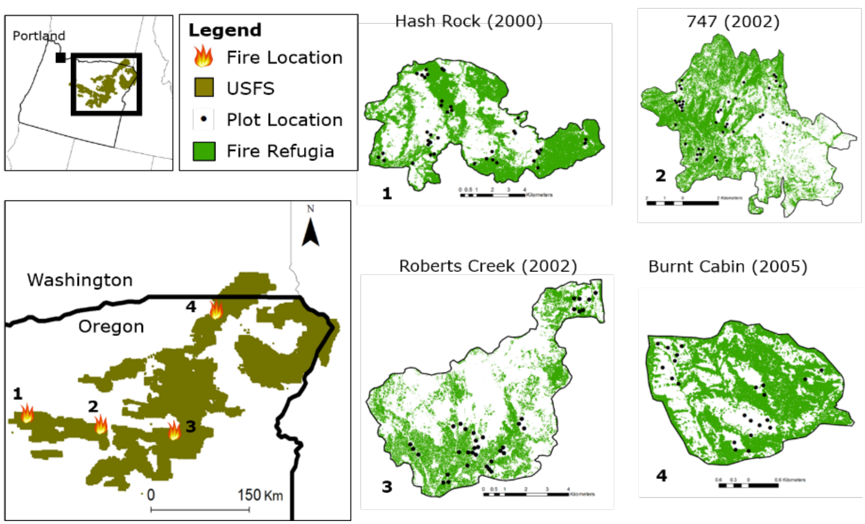
Concern about forest recovery – what is the post-fire future of these forests?



Downing, Krawchuk et al (2019) Landscape Ecology

Function and form of fire refugia

Fire refugia function as seed sources: for tree re-establishment in adjacent patches of high severity fire



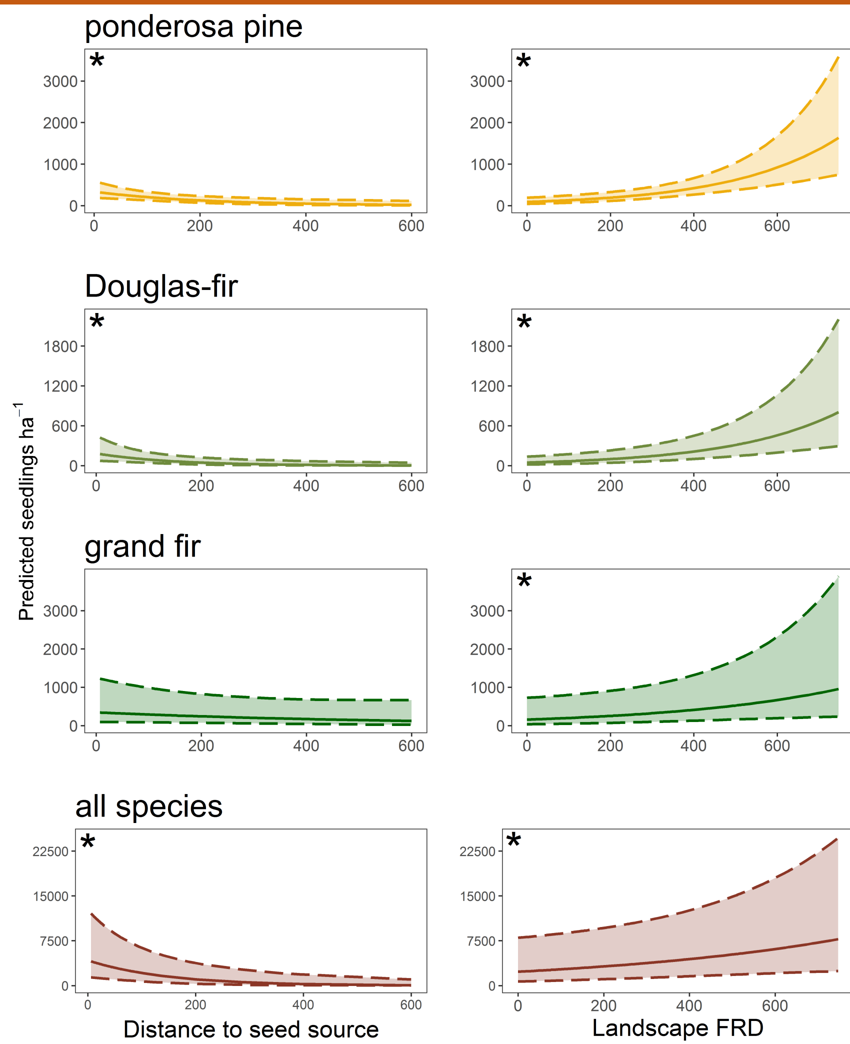
Elevations: 900m to 2140m

Downing, Krawchuk et al (2019) Landscape Ecology

Local and landscape seed sources

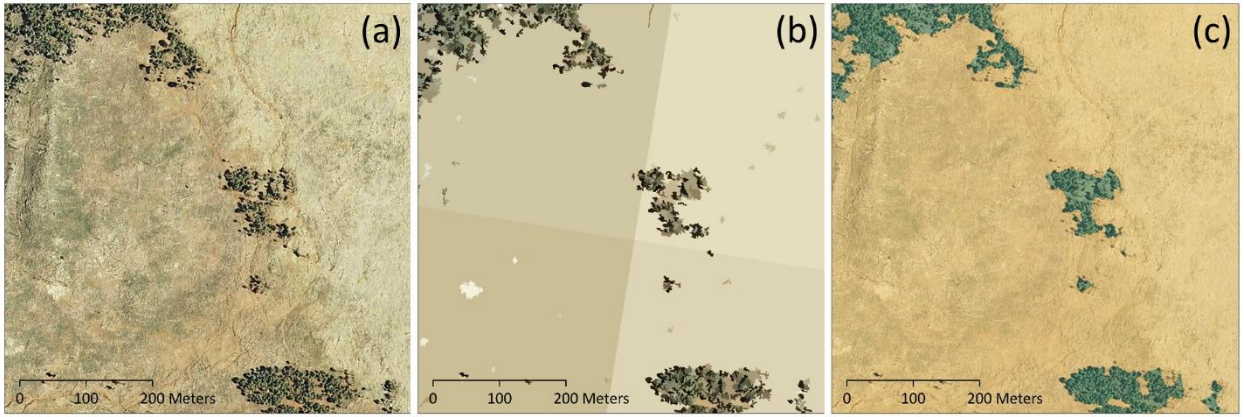
Both **local and landscape** metrics of fire refugia, as indicators of tree seed source, are important for forest re-establishment in fire mosaics

Ecological patience



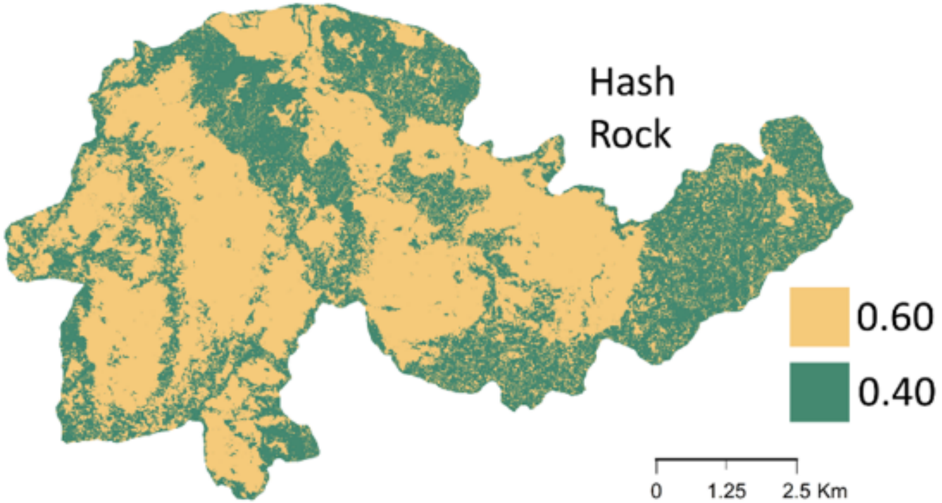
Downing, Krawchuk et al (2019) Landscape Ecology

Landscape metrics of seed source?



1-m NAIP imagery

classified fire refugia map



Walker et al (2018)

Environments supporting seedlings

Parameter	Ponderosa pine			Douglas-fir			Grand fir			All species		
	Coef.	ΔAIC	*P*-value	Coef.	ΔAIC	*P*-value	Coef.	ΔAIC	*P*-value	Coef.	ΔAIC	*P*-value
Dist. to seed source	**– 0.004**	**6**	**0.009**	**– 0.007**	**6**	**0.012**	– 0.002	1	0.199	**– 0.007**	**5**	**0.004**
Refugia density	**0.003**	**14**	**< 0.001**	**0.004**	**10**	**< 0.001**	**0.002**	**3**	**0.044**	**0.002**	**2**	**0.048**
Burn severity	0.002	1	0.089	**0.003**	**4**	**0.019**	– 0.0004	– 2	0.80	– 0.001	– 1	0.380
elevation	3.77	–	0.324	0.36	–	0.935	**25.30**	–	**0.013**	**10.06**	–	**0.039**
Elevation^2	**– 9.68**	**10**	**< 0.001**	**– 8.37**	**5**	**0.002**	**– 17.42**	**13**	**0.015**	**– 12.15**	**19**	**< 0.001**
Moisture deficit	**10.34**	–	**< 0.001**	0.84	–	0.79	1.71	–	0.75	5.87	–	0.21
Moisture deficit^2	**7.58**	**21**	**0.004**	**8.47**	**8**	**< 0.001**	**23.54**	**23**	**< 0.001**	**10.52**	**20**	**< 0.001**
Heat load	0.59	– 2	0.62	**– 3.69**	**5**	**0.009**	– 2.64	0	0.18	0.75	– 1	0.51
Basal area	0.003	– 5	0.72	**0.032**	**5**	**0.002**	0.002	– 2	0.90	– 0.001	– 2	0.89
Shrub cover	**0.013**	**3**	**0.006**	0.007	– 1	0.24	– 0.005	– 1	0.45	– 0.005	– 1	0.30

facilitation by shrub community?

Downing, Krawchuk et al (2019) Landscape Ecology

Why does it matter?

These dry mixed conifer forests do seem to be resilient to stand replacing fire,… ecological patience

However, grand fir much more common in establishment than expected historically

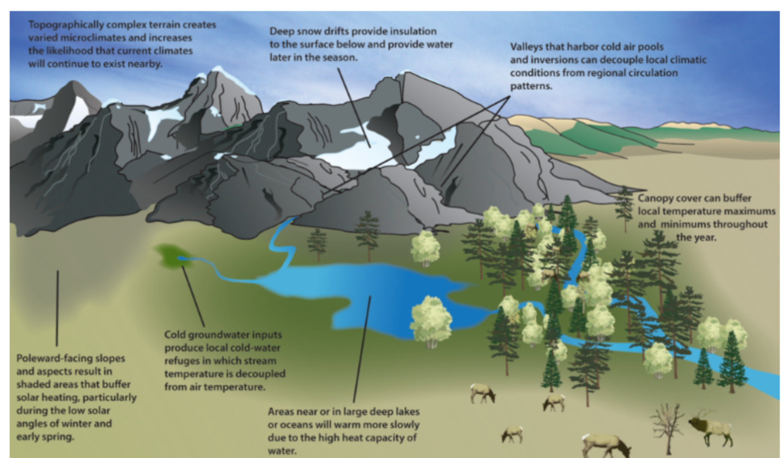
Contributing to understanding resilience and restoration of dry mixed conifer forests of the Inland West (fills a gap that existed in the Blues)

Landscape NAIP maps being used as estimates of seed source for landscapes in the SW, prioritize planting and restoration

CLIMATE CHANGE REFUGIA

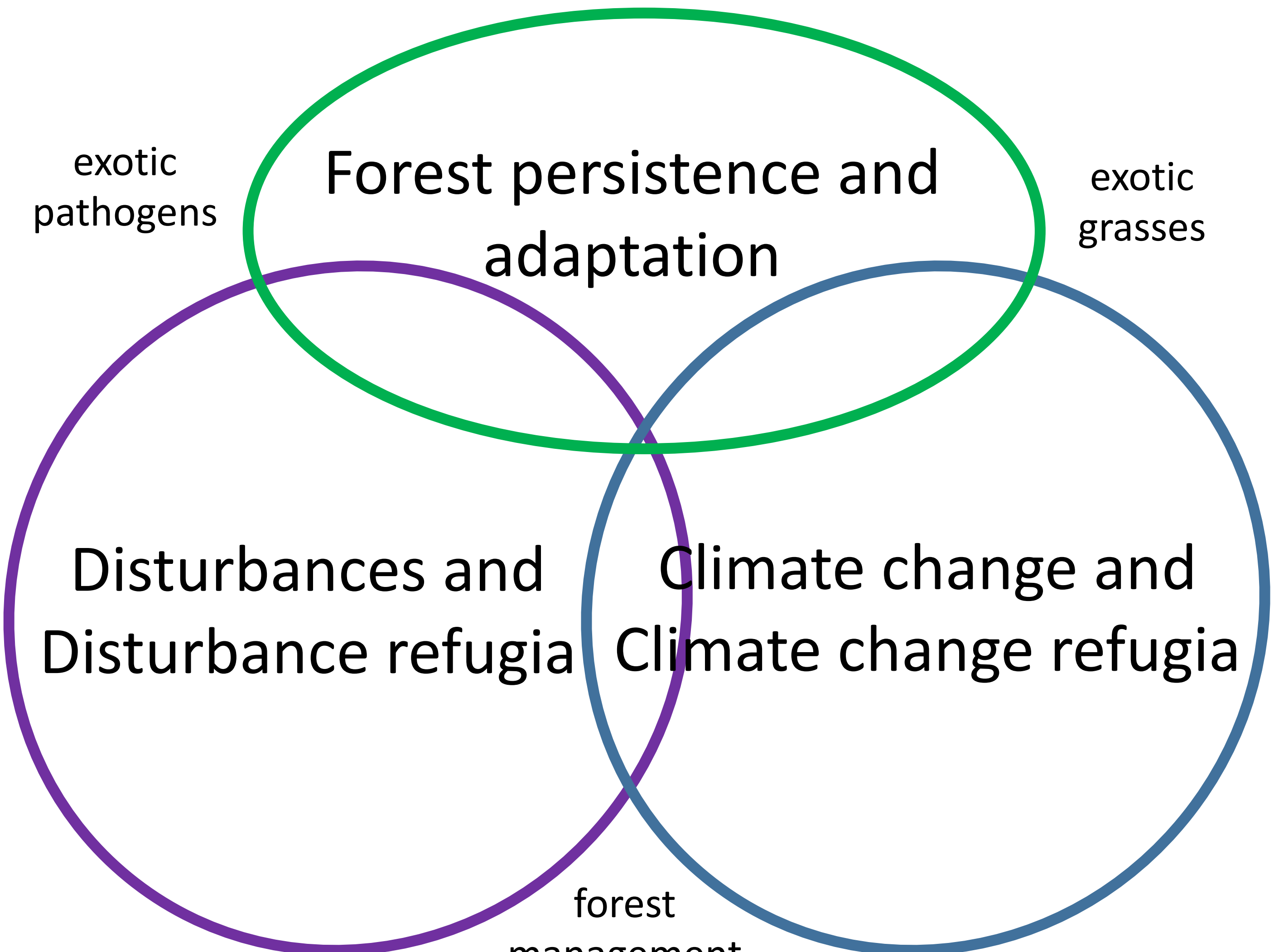
Warmer air and water temperatures, changing precipitation patterns, and altered fire regimes associated with climate change threaten many important natural and cultural resources in the northwestern and northeastern U.S. However, not all places on the landscape are changing in the same way. Refugia are locations that will likely experience less change or exhibit increased resilience compared to the surrounding landscape. This can occur from independent or interacting processes that dampen local climatic variability through time or amplify spatial heterogeneity within a region. In Figure 1 (to the left) we review representative examples of these processes. How and whether these processes will be maintained as climate changes in the future remain important research questions. These refugia may provide an opportunity for protecting important natural and cultural resources in the face of climate change.

As identification is key to conserving climate change refugia, we begin with a discussion of the processes that create them. Climate change refugia are characterized by the occurrence of relatively stable local climatic conditions that



https://www.climaterefugia.org/

Disturbance refugia in the context of climate change



Thank you