What is forest resilience and how do we measure it?

North, M.P., R.E. Tompkins, A.A. Bernal, B.M. Collins, S.L. Stephens, and R.A. York. 2022. Operational resilience in western US frequent-fire forests. Forest Ecology and Management 507: 120004.

Western conifers have persisted through extreme drought and fire for centuries. Why are many of them dying now?

Extreme fire

Drought: Competition associated with stand density*

*Young, D.J., Stevens, J.T., Earles, J.M., Moore, J., Ellis, A., Jirka, A.L. and Latimer, A.M., 2017. Long-term climate and competition explain forest mortality patterns under extreme drought. *Ecology letters*, *20*(1), pp.78-86.

2020 Creek Fire*: Harbinger of future wildfire?

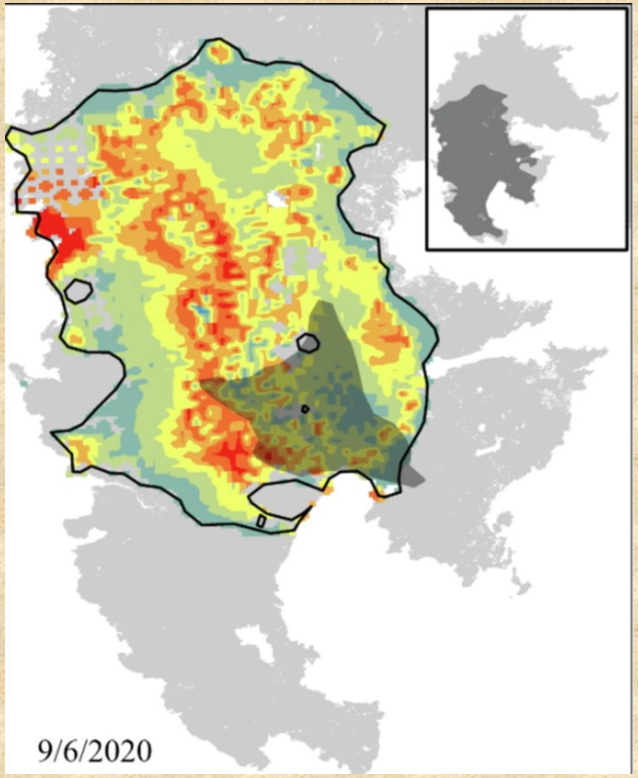
Unprecedented fuel loading

- 2012-2016 drought = 150 million dead trees
- Heavy large-size fuel loads ➔extreme fire behavior

Ignition

Sept. 6: 55,000' tall pyrocumulonimbus cloud
Atomic energy release?

Sept. 6: Thermal image
Tremendous **interior** heat

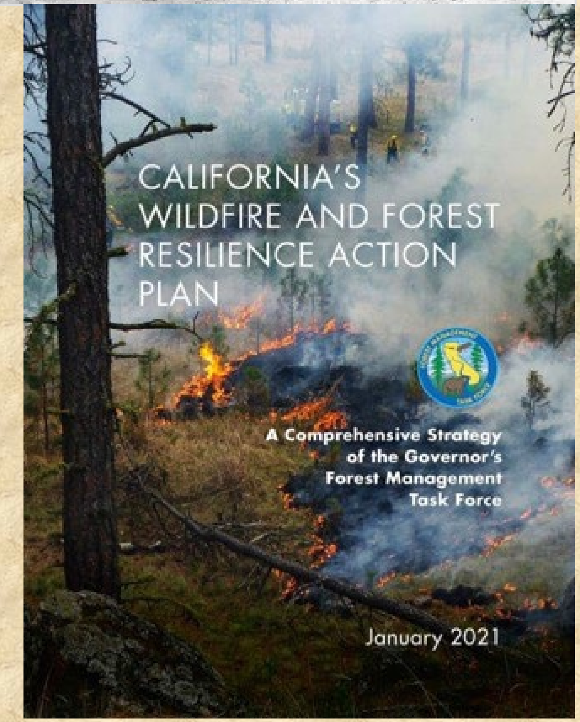


Beyond current fire models
Mark Finney: "Only analogs are mass fire events" (Tokyo, Dresden)

* Stephens, S.L., Bernal, A.A., Collins, B.M., Finney, M.A., Lautenberger, C. and Saah, D., 2022. Mass fire behavior created by extensive tree mortality and high tree density not predicted by operational fire behavior models in the southern Sierra Nevada. *Forest Ecology and Management*, *518*, p.120258.

Forest resilience and its ‘baggage’

- 20th century goal: restore pre-European conditions
- 21st century: changing climate/disturbance regimes ➔ emphasize on resilience (ex., 2012 USFS Planning Rule, CA Task Force)
- Resilience difficult to define: confusion over types, scale, terms, and variability between ecosystems
- “a malleable term” (Brand and Jax 2007)
- Needs to be ecological specific



Define resilience in dry, frequent-fire forests using:
1) Ecological concepts; 2) Lit. summary; 3) Historical data & silviculture metric

In grasslands:

Fire in forests is similar to herbivory in grasslands: consumption limits the ecosystem’s biomass

When grazers (ex., zebras, bison) proliferate, they limit growth so plants rarely get big enough to compete with each other for resources

In forests:

Before suppression, low-intensity fires were frequent, limiting density so trees didn’t have to compete for resources (i.e., water, light, and nutrients)

❾Hypothesis: frequent-fire forests may have evolved with little to no competition

In 1902 timber survey in the northern Sierra Nevada, Leiberg called out how the forest was **‘understocked’** “Suppression of the young growth has always been one of the serious results of fires…the land does not carry more than 35% of the quantity of timber it is capable of supporting.

2) Literature summary*

Historically frequent-fire forests survived many fires & droughts. What's different now?

Without fire, live tree density and biomass

Competition for growth resources

Tree vigor

Drought susceptibility

Competition reduces radial growth & vigor

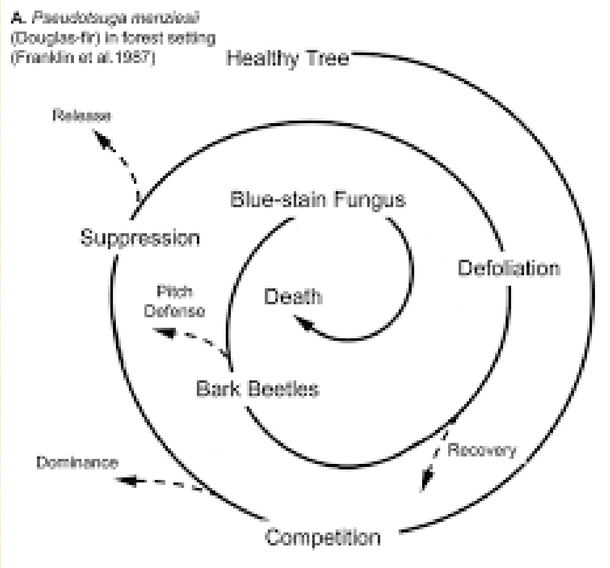
* Cailleret et al. 2017. A synthesis of radial growth patterns preceding tree mortality. Glob. Change Bio. 23:1675-90.

Hypothesis: Novel Stress

Absence of competition, trees grow rapidly and have high vigor…their best defense against stresses such as fire, drought, bark beetles and climate change

Vigorous growth supports tree defense against bark beetles: pitch blob has entombed beetle

Inter-tree competition creates chronic growth reductions➔ increased tree susceptibility to stress and mortality

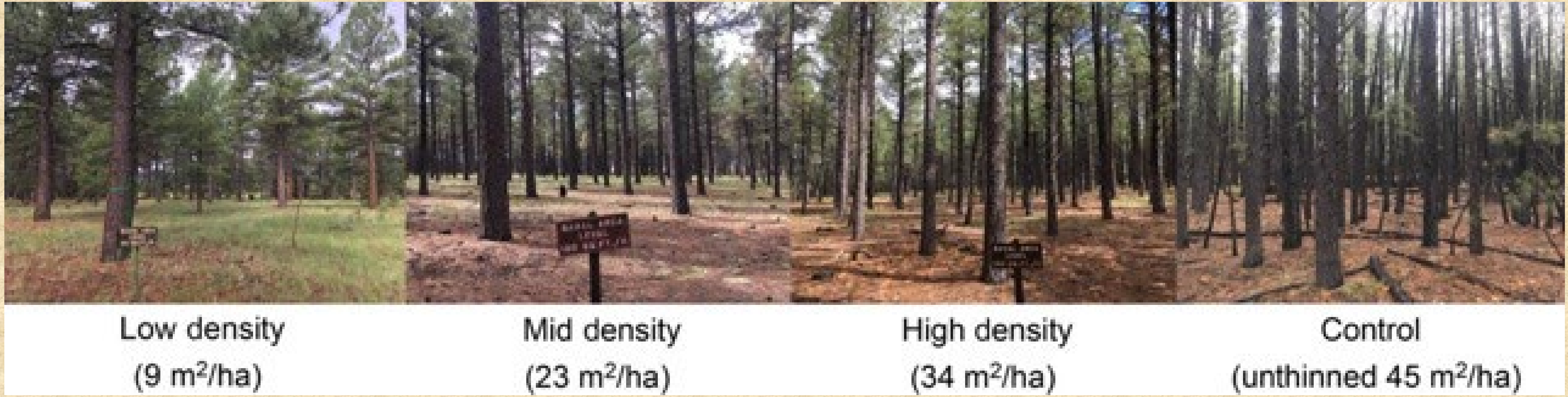


Mortality Spiral from:
Franklin, J.F., Shugart, H.H. and Harmon, M.E., 1987. Tree death as an ecological process. *BioScience*, *37*(8), pp.550-556.

In the past, frequent-fire forests were resistant to stress '**pulses**' (fire, pests), but may not be adapted to novel stress '**presses**' such as competition

If resilience is about restoring minimal competition, how do we measure it?
Stand Density Index (SDI)

SDI is a measure that combines the number of trees per acre and their size (diameter) to assess total forest biomass (or basal area)



97 ft^2/ac	248 ft^2/ac	366 ft^2/ac	484 ft^2/ac

Relative Stand Density Index (rSDI)

rSDI: how a local stand compares to a maximum amount of biomass that a particular forest type (ex. ponderosa pine) can support, expressed as a % of that maximum

Local stand rSDI = 140/400 or 35%

rSDI categories:

0-25% Free of competition
25-35% Partial competition
35-60% Full competition
$\geq$ 60% Zone of *imminent mortality*

Local stand: ponderosa pine
SDI = 140

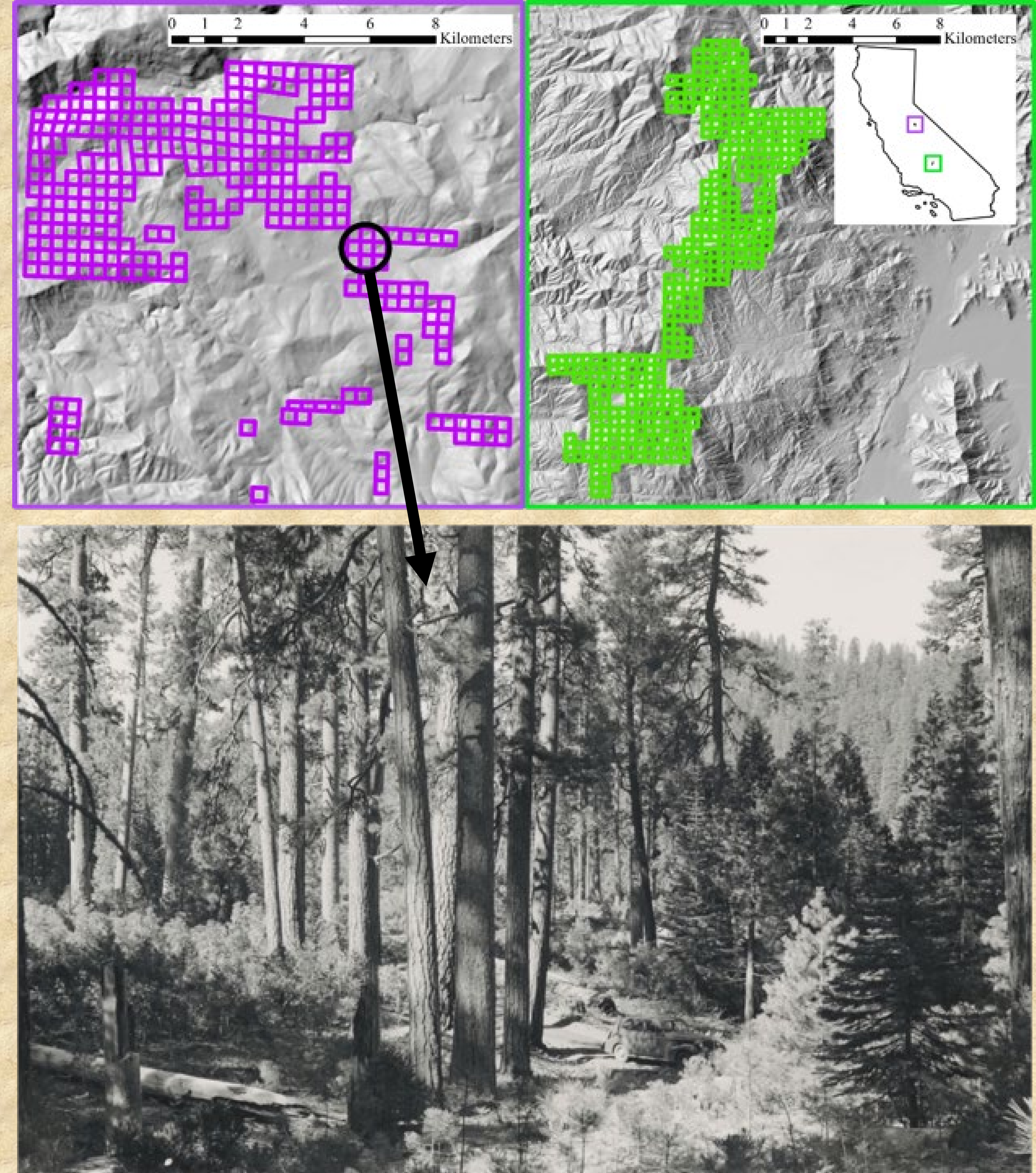
Ponderosa pine at maximum biomass
SDI = 400

Testing of this Resilience Concept with Historical Data and rSDI

Forest inventory data from Stanislaus & Sequoia National Forests used to compare forest conditions in 1911 and 2011
(Collins et al. 2015 & Stephens et al. 2015)

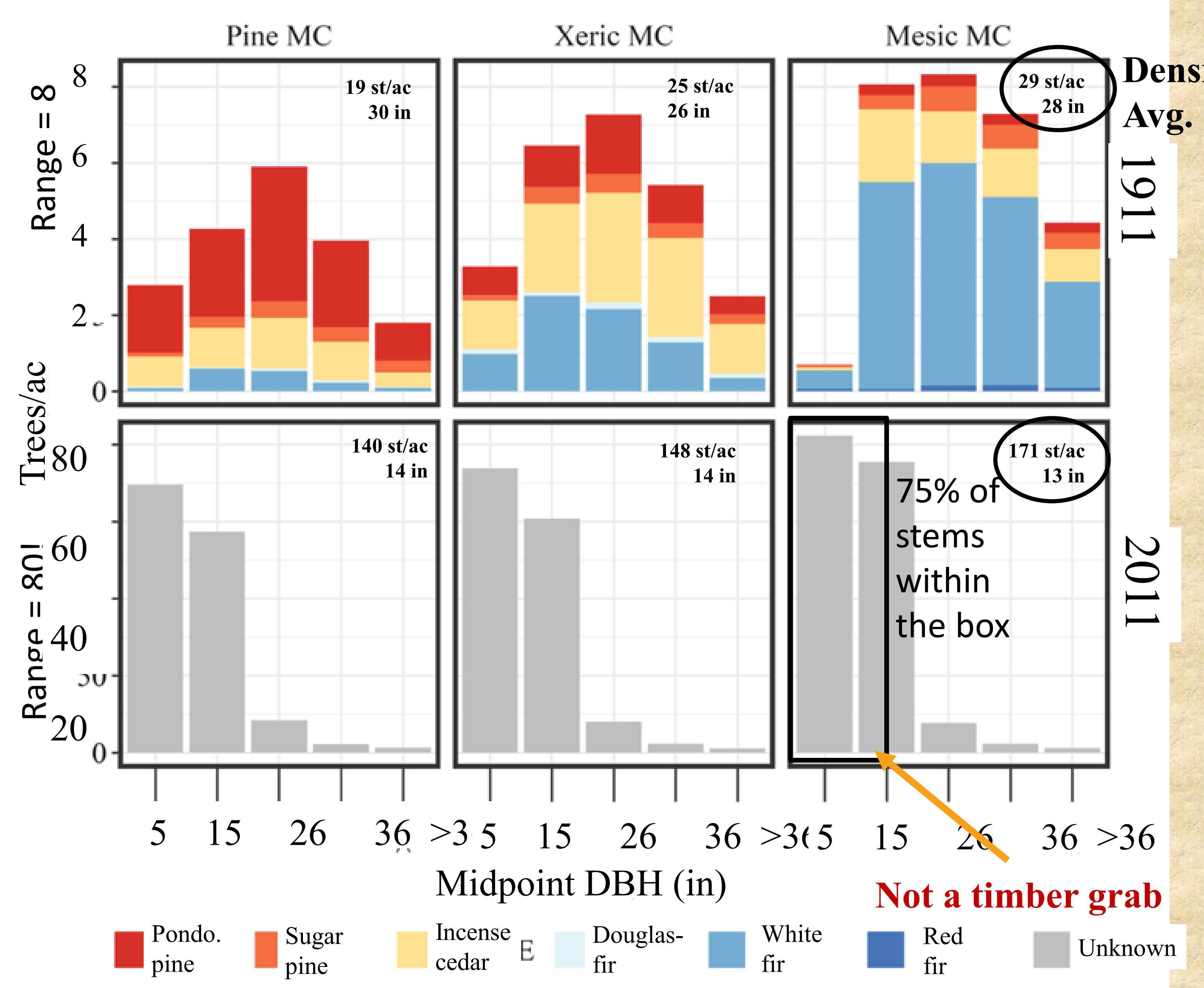
Data divided into 3 main forest types	
Pine Mixed Conifer	> 50% pine
Xeric Mixed Conifer	≤ 50% pine & ≤ 50% fir
Mesic Mixed Conifer	> 50% fir

1941 photo: Forest is starting to transition from historical (clump of large pines) to contemporary (small tree infilling) conditions.



Forest Conditions in 1911 and 2011:

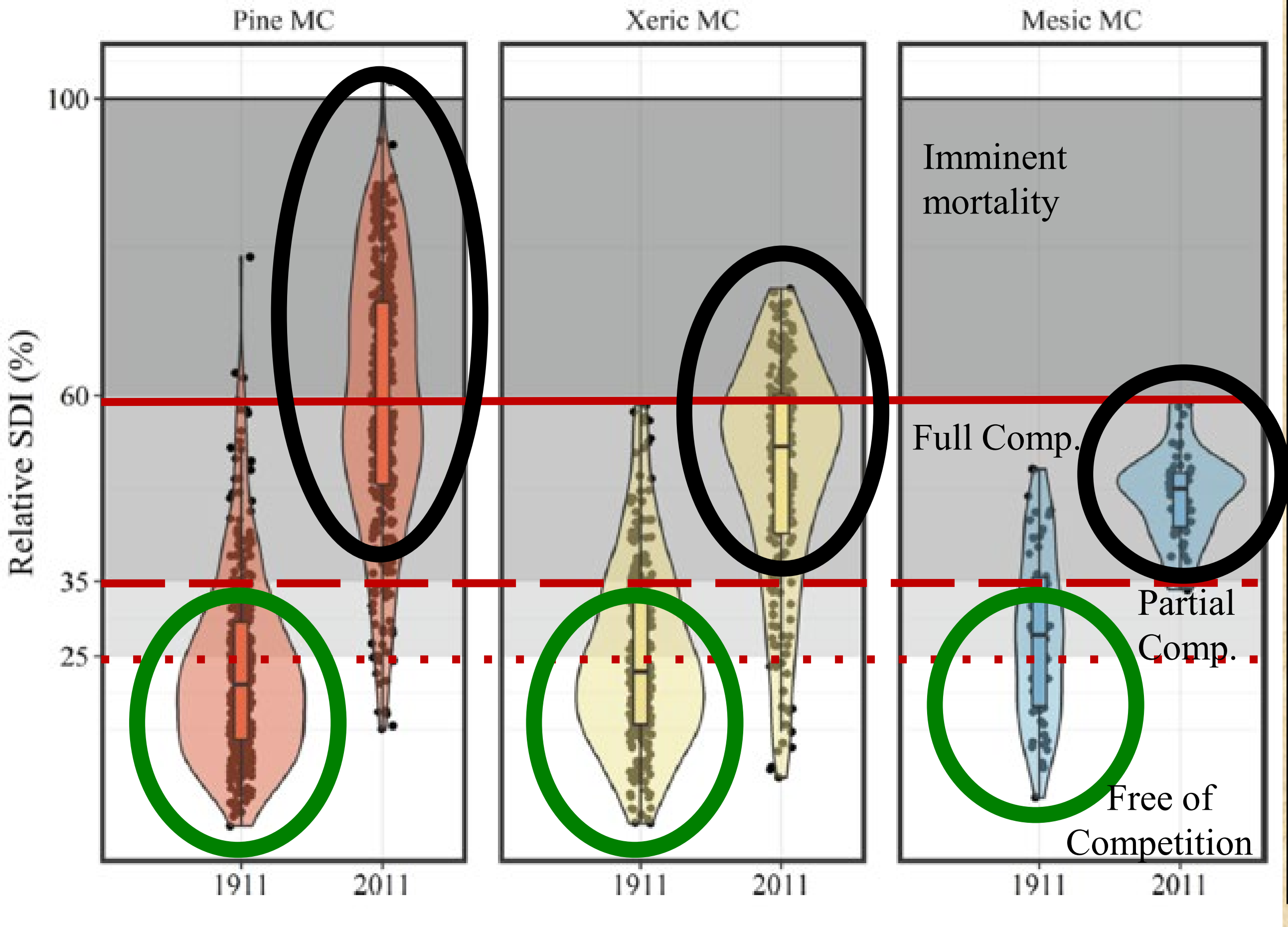
Forest density increased by 6 fold; average tree diameter dropped 50%



Bear Creek R.S., Plumas NF

SHIFTS IN THE COMPETITIVE ENVIRONMENT

RELATIVE DENSITY (%SDI_{max})



Three Forest Types

	Pine MC 1911	Pine MC 2011	Xeric MC 1911	Xeric MC 2011	Mesic MC 1911	Mesic MC 2011
A) Absolute SDI						
SDI_{metric}	206 (123-267)	535 (433-655)	275 (175-370)	551 (462-668)	378 (247-483)	632 (575-674)
$SDI_{english}$	83 (50-108)	216 (174-265)	111 (71-150)	223 (187-270)	153 (100-196)	256 (233-273)
B) Relative SDI (% of SDI_{max})						
Mean (Range)	23 (14-30)	59 (48-73)	25 (16-33)	50 (42-60)	28 (18-36)	46 (42-50)
C) % of Relative SDI Observations In Each Competitive Benchmark						
Free (<25% SDI_{max})	64	4	58	9	44	0
Partial (25-34% SDI_{max})	21	6	21	9	29	5
Full (35-59% SDI_{max})	14	42	20	57	27	95
IM (≥60% SDI_{max})	<1	48	0	25	0	0

Historic forests (1911): 73-85% of stands were free of competition or in partial competition

Contemporary forests (2011): 82-95% of stands are in full competition or the 'zone of imminent mortality'

Historically, resilient forests were low density with little competition…so what?

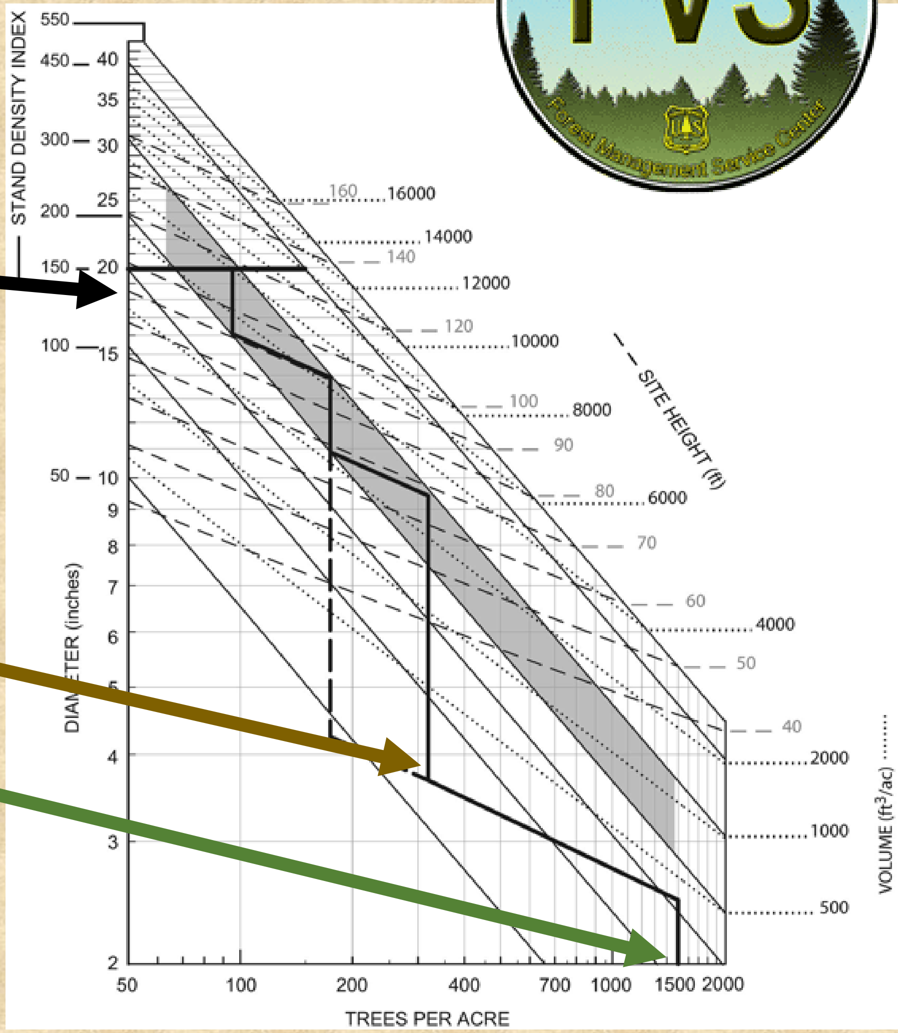
Competition is the driver of how forests are managed:

Target harvest diameter

When to thin

Initial planting density

Forestry practices often maintain stocking above 35% of SDI_{max} to sustain tree growth, and schedule thinnings as SDI approaches 60% of SDI_{max} to 'capture' density-dependent mortality



Stand density management diagram
The driver behind growth & yield models

Implications:

rSDI of 35% should be **a *maximum not a minimum***

Currently the CA Forest Service uses a $rSDI_{max} \geq 60\%$, to prioritize treatments, and would treat only 48%, 25% and 0% of our contemporary pine, xeric & mesic mixed-conifer plots.

However, treatments to minimize competition would be much higher: 96%, 91% and 100% of the 3 forest types.

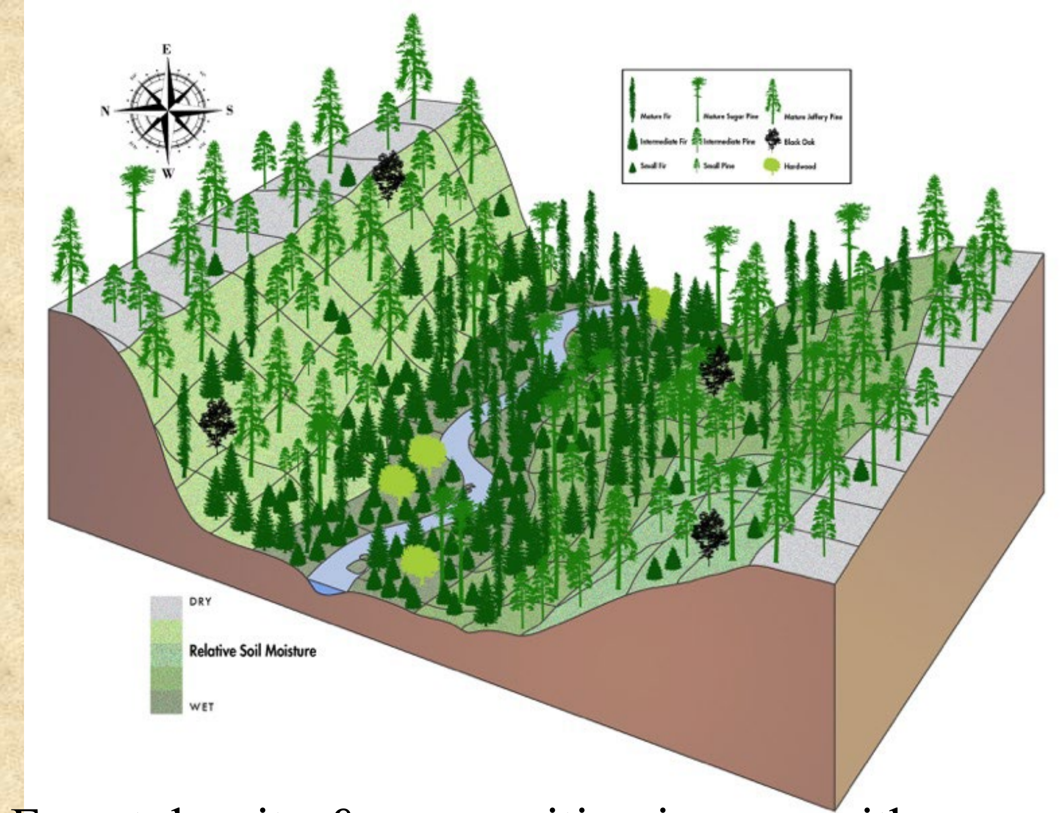
rSDI: Flexibility but not a license for even spacing

Historical range of rSDI values was 14-39%

Provides flexibility to manage for denser forests (i.e., spotted owl habitat) on sites with greater soil moisture (often the limiting growth resource) and more open forest on drier sites (i.e., steep slopes, thin-soil ridge tops).

Reducing competition does not equate to planting and thinning treatments that maximize regular tree spacing.

Creating a more complex spatial pattern combining individual trees, clumps of trees and openings (i.e., ICO), makes forests more resilient to high-severity fire & drought



Forest density & composition in sync with topographic moisture availability

ICO pattern in active-fire forest (Yosemite)

In Sum:

- Fuels reduction is much needed, but it’s triage
- With changing climate and disturbance regimes, forests need to be resilient to a variety of stresses
- That resilience requires very low tree densities that significantly reduce competition
- Ecosystem services such as carbon storage, wildlife habitat associated with large trees, pest/pathogen resistance depend on vigorous tree growth

Questions?

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