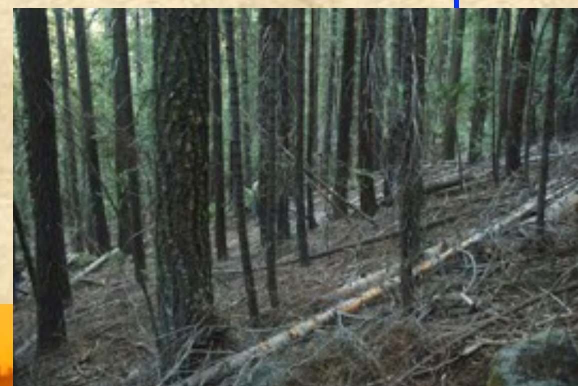
Climate Change and Implications for Forest Restoration: Creating a Resilient Landscape



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Climate Change: The Future is Here

Top 20 Largest California Wildfires

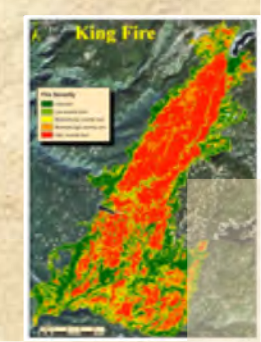
	FIRE NAME (CAUSE)	DATE	COUNTY	ACRES	STRUCTURES	DEATHS
1	**AUGUST COMPLEX** *(Under Investigation)**	August 2020	Tehama	**839,175**	26	1
2	**MENDOCINO COMPLEX** *(Under Investigation)*	July 2018	Colusa County, Lake County, Mendocino County & Glenn County	**459,123**	280	1
3	**SCU LIGHTNING COMPLEX** *(Under Investigation)**	August 2020	Stanislaus, Santa Clara, Alameda, Contra Costa, & San Joaquin	**396,624**	222	0
4	**LNU LIGHTNING COMPLEX** *(Under Investigation)**	August 2020	Sonoma, Lake, Napa, Yolo & Solano	**363,220**	1,491	5
5	**THOMAS** *(Powerlines)*	December 2017	Ventura & Santa Barbara	**281,893**	1,063	2
6	**NORTH COMPLEX** *(Under Investigation)**	August 2020	Butte, Plumas & Yuba	**280,775**	1,078	15
7	**CEDAR** *(Human Related)*	October 2003	San Diego	**273,246**	2,820	15
8	**RUSH** *(Lightning)*	August 2012	Lassen	**271,911 CA / 43,666 NV**	0	0
9	**RIM** *(Human Related)*	August 2013	Tuolumne	**257,314**	112	0
10	**CREEK FIRE** *(Under Investigation)**	September 2020	Fresno County & Madera	**244,756**	744	0
11	**ZACA** *(Human Related)*	July 2007	Santa Barbara	**240,207**	1	0
12	**CARR** *(Human Related)*	July 2018	Shasta County & Trinity	**229,651**	1,614	8
13	**MATILIJA** *(Undetermined)*	September 1932	Ventura	**220,000**	0	0
14	**WITCH** *(Powerlines)*	October 2007	San Diego	**197,990**	1,650	2
15	**KLAMATH THEATER COMPLEX** *(Lightning)*	June 2008	Siskiyou	**192,038**	0	2
16	**MARBLE CONE** *(Lightning)*	July 1977	Monterey	**177,866**	0	0
17	**LAGUNA** *(Powerlines)*	September 1970	San Diego	**175,425**	382	5
18	**BASIN COMPLEX** *(Lightning)*	June 2008	Monterey	**162,818**	58	0
19	**DAY FIRE** *(Human Related)*	September 2006	Ventura	**162,702**	11	0
20	**STATION** *(Human Related)*	August 2009	Los Angeles	**160,557**	209	2

There is no doubt that there were fires with significant acreage burned in years prior to 1932, but those records are less reliable, and this list is meant to give an overview of the large fires in more recent times.
This list does not include fire jurisdiction. These are the Top 20 regardless of whether they were state, federal, or local responsibility.
*Numbers not final.

9/17/2020

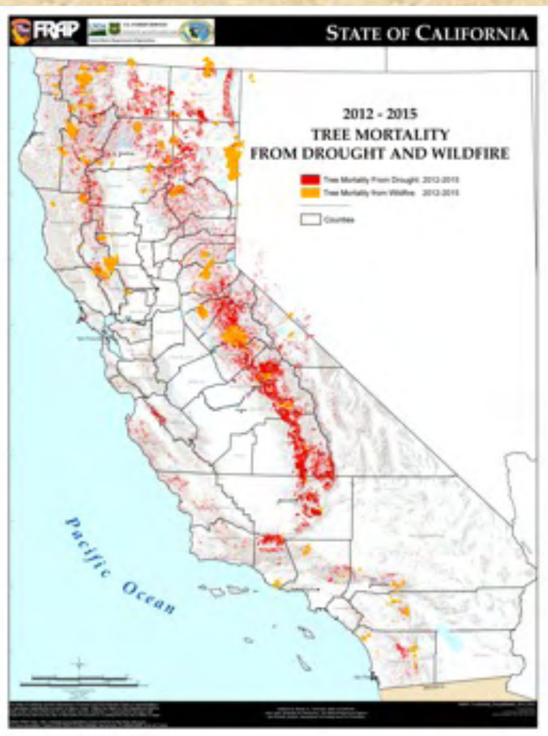
- 17 of the 20 largest CA wildfires occurred in the last 20 years
- Typically high severity is >35% of fire footprint (vs. 3-8% historically)
- Size of high-severity patches is often well beyond conifer seed dispersal
- Annual acres needing reforestation has quadrupled over last 20 years

King Fire: >55% high severity



Climate Change: The Future is Here

Overly dense forests are not only a fire problem, they also create water stress: there are too many ‘straws in the ground’



- 2012-2016: Most severe drought in last 1000 years
- In California’s Sierra Nevada >150,000,000 dead trees
- Mortality correlated with climatic water deficit and stand basal area (Young et al. 2017)
- Beetle mortality is particularly accelerating the **loss of large, old-growth (>400 yrs) trees**

Given these conditions, how do we create resilient forest landscapes in the Sierra Nevada?

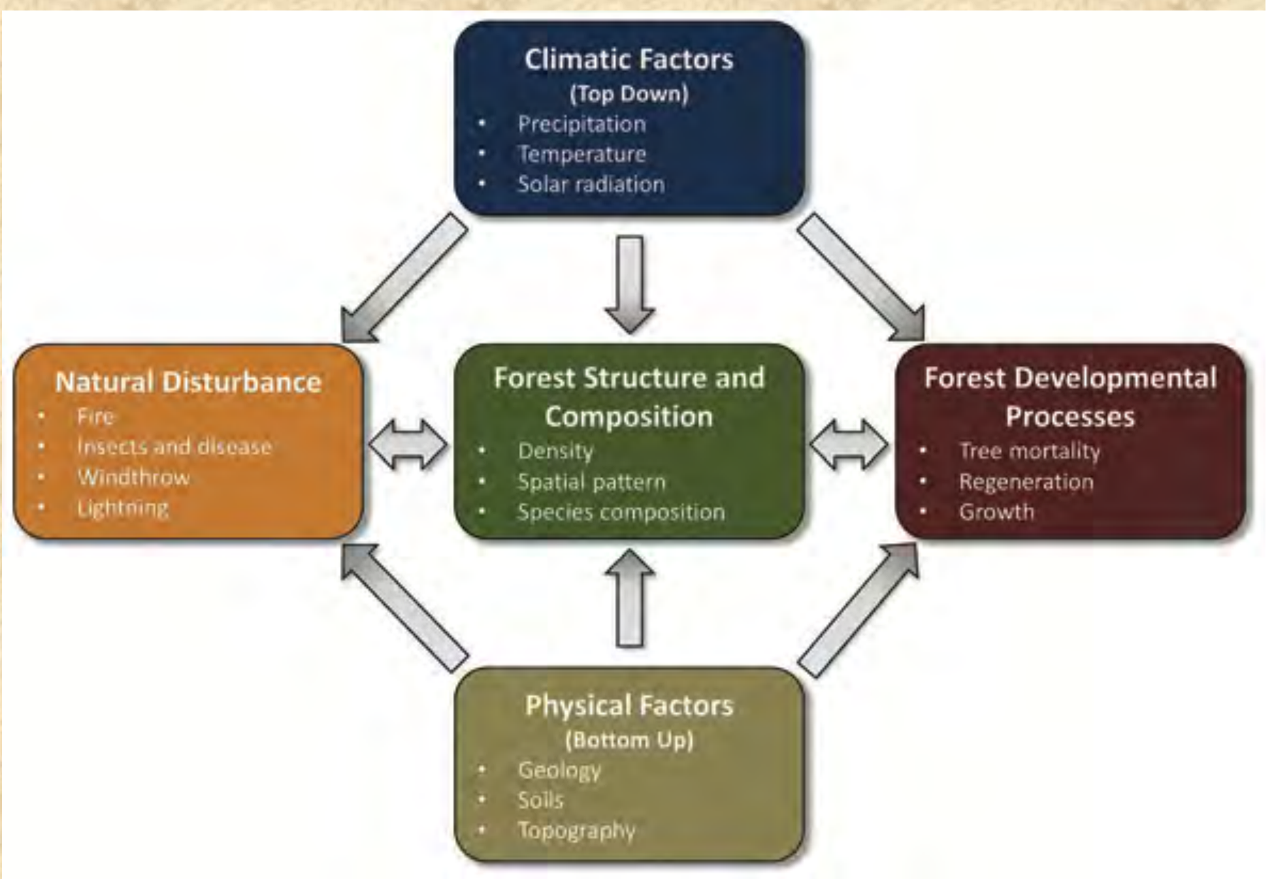
Outline:

1. What is landscape resilience and how do we create it?
2. Constraints: spotted owls, limitations on mechanical treatment and on fire use
3. Changing treatment pace and scale
4. Pyrosilviculture proposal

1. What is landscape resilience and how do we create it?

Forest structure and composition are influenced by largely immutable top down and bottom up factors, that drive disturbance and affect development processes.

Managing for resilience is 'reverse engineering' by accentuating differences in forest conditions with topography (bottom-up) to influence disturbance and developmental processes



So to reverse engineer forest conditions, they should be aligned with key drivers. What were they?

- The drivers of forest variability were productivity (soil moisture availability) and fire regime[2]

- **Overstory** conditions such as ***tall trees***, canopy cover, and size and number of large snags is driven by **soil moisture availability.**

- Understory conditions such as small (ladder) tree density, shrubs, and logs is determined by fire frequency and intensity.

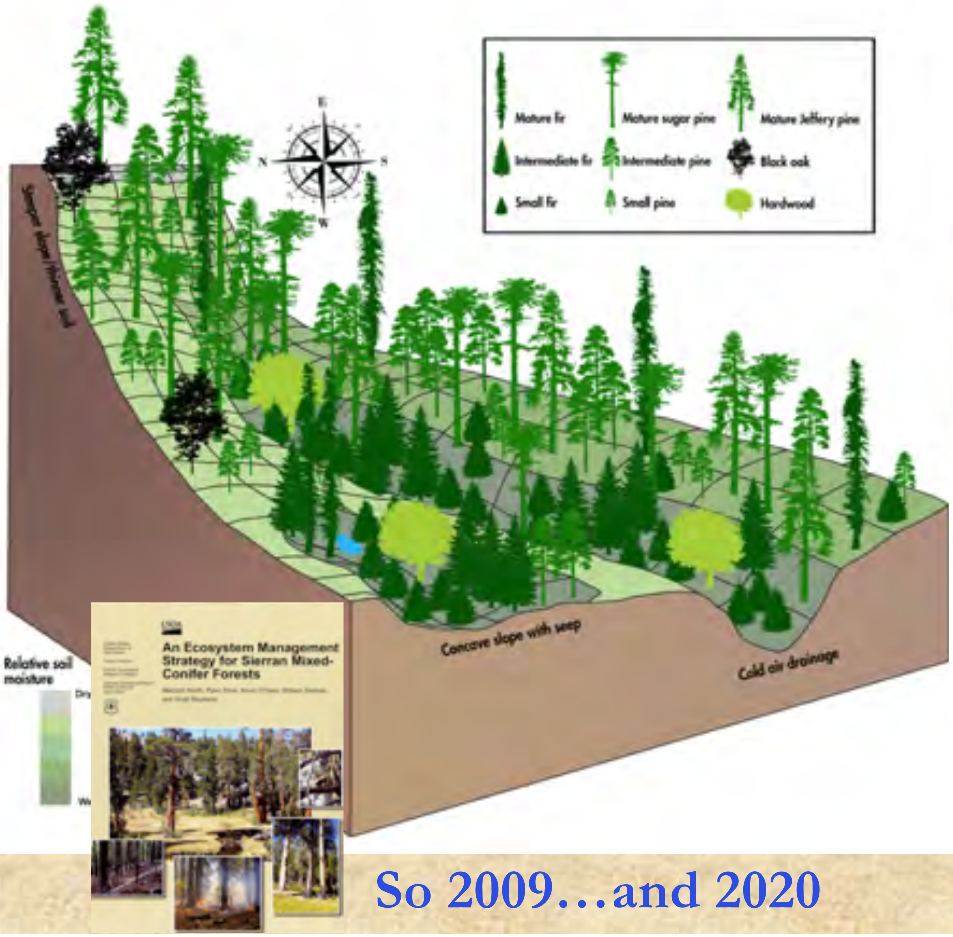
- Historically, forests were heterogenous, which is integral to their resilience[1]

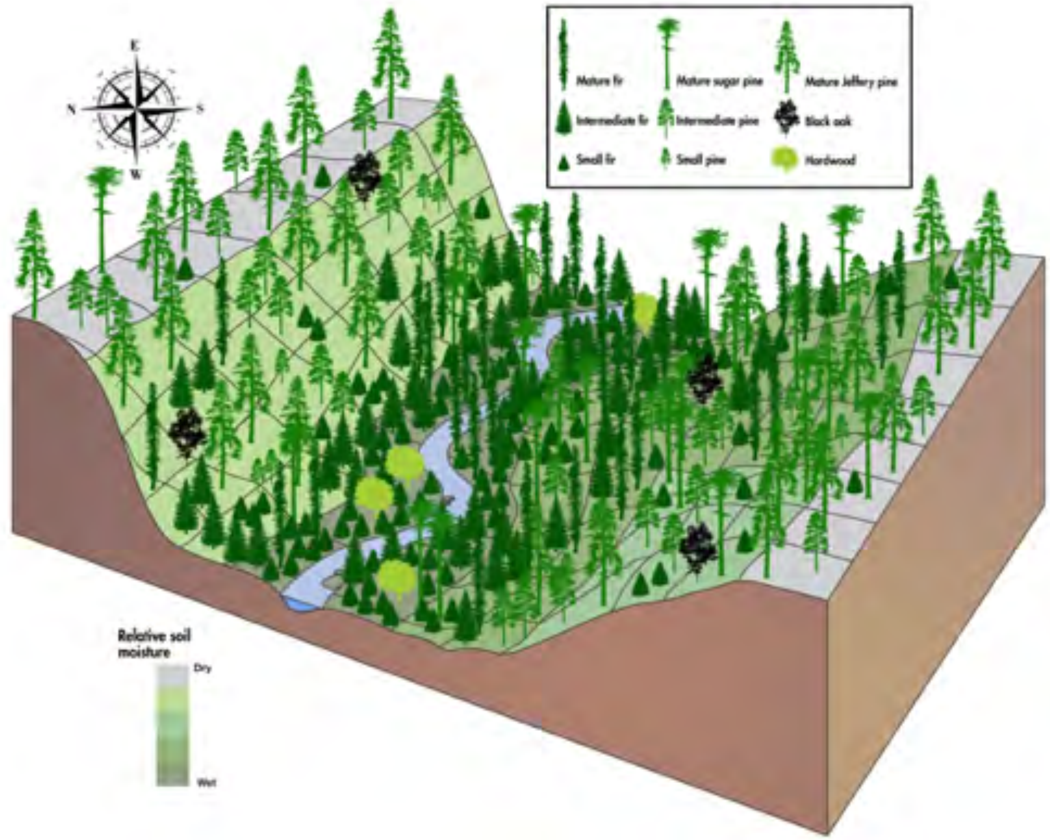
Variable forest conditions in Yosemite's Illilouette Valley

[1]Koontz, M.J., M.P. North, C.M. Werner, S.E. Rick and A.M. Latimer. 2020. Local forest structure variability increases resilience to wildfire in dry wester U.S. coniferous forests. Ecology Letters. doi: 10.1111/ele.13447.

[2]Lydersen, J. and M. North. 2012. Topographic variation in active-fire forest structure under current climate conditions. Ecosystems 15: 1134-1146.

Schematic of local density, composition, and structure in congruence with how topography influences water availability and fire intensity

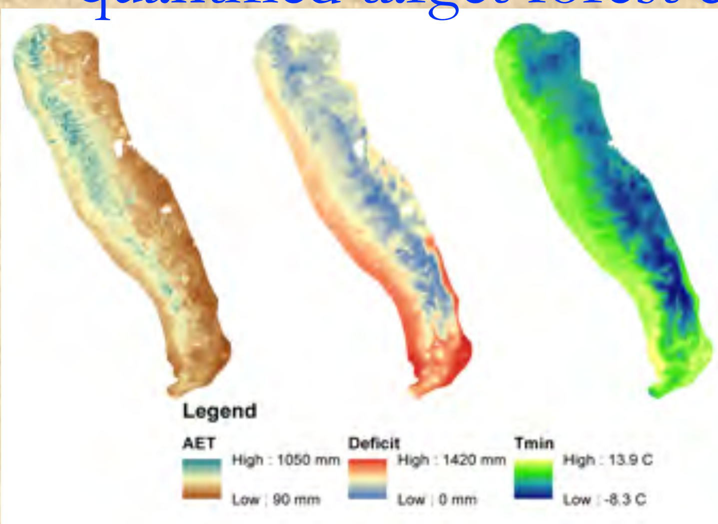




So 2009…and 2020

Is there information on how to do this?

Yes*. Top down climate drivers and bottom up topography creates large- and local-scale variability. Using reference sites as guides, we now have quantified target forest conditions for >20 climate classes across the Sierra.



Map of layers used to classify climate – annual actual evapotranspiration (AET), climatic water deficit (Deficit), and January minimum temperature (T_{min}) – across the study area using the Flints' Basin Model.

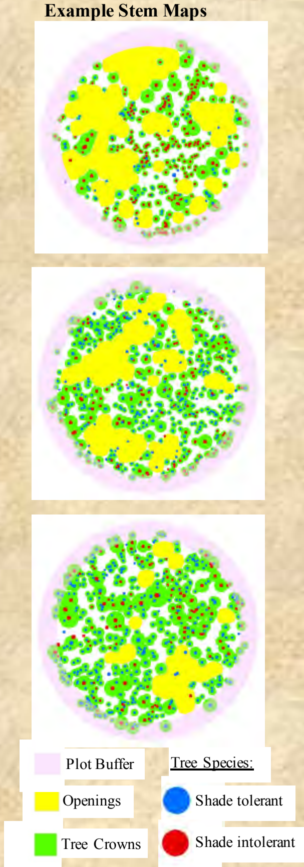
Climate conditions can be readily calculated from publicly available data such as the Flints' Basin Model

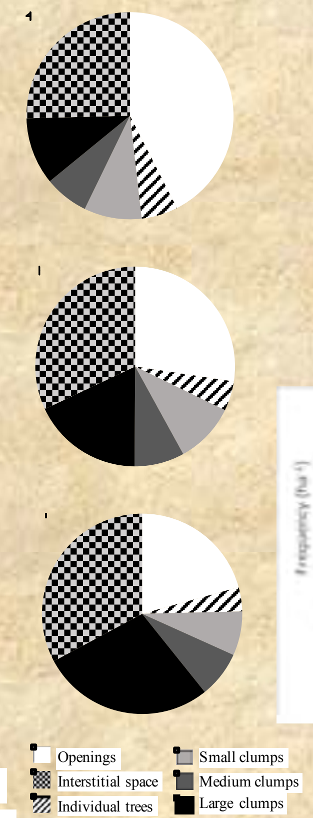
Map of climate classes with catchments containing at least one restored patch indicated.

* Jeronimo, S.M.A., V.R. Kane, D.JU. Churchill, J.A. Lutz, M.P. North, G.P. Asner, and J.F. Franklin. 2019. Forest structure and pattern vary by climate and landform across active-fire landscapes in the montane Sierra Nevada. Forest Ecology and Management 437: 70-86.

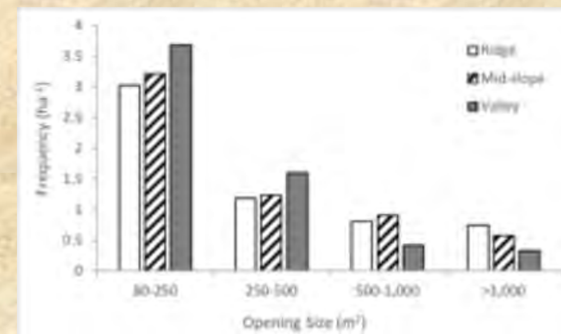
Within each climate class, how should forests conditions vary with topography? New paper* provides detailed stand structure metrics.

	Ridge		Mid-slope		Valley	
Individual Trees						
# Trees (ha^{-1})	30.2	(5.5)	31.5	(5.4)	29.7	(7.1)
% of total trees	19.1[a]	(7.3)	14.0[b]	(2.8)	11.4[c]	(3.0)
QMD	58.0	(4.1)	58.0	(5.5)	57.6	(9.4)
BA ($m^{2}\cdot ha^{-1}$)	8.0	(1.9)	8.3	(1.8)	7.7	(2.3)
% of total BA	20.9[a]	(7.9)	14.8[b]	(3.5)	10.9[c]	(3.8)
Small Clumps (2–4 trees)						
# Trees (ha^{-1})	46.0[a]	(9.2)	52.3[b]	(11.3)	39.8[c]	(14.4)
% of total trees	28.3[a]	(8.6)	23.3[b]	(5.9)	15.5[c]	(6.6)
QMD	54.1	(7.4)	55.0	(4.5)	57.1	(7.1)
BA ($m^{2}\cdot ha^{-1}$)	10.6	(3.0)	12.5	(3.1)	9.9	(3.4)
% of total BA	27.0[a]	(10.6)	22.3[b]	(6.4)	14.6[c]	(6.6)
# Clumps (ha^{-1})	18.1[a, b]	(3.6)	19.3[a]	(4.5)	15.1[b]	(5.6)
w/in-clump tree density*	679.7	(101.0)	684.6	(58.1)	774.4	(273.9)
Medium Clumps (5–9 trees)						
# Trees (ha^{-1})	36.9[a]	(21.0)	45.9[b]	(11.6)	39.8[a]	(10.1)
% of total trees	20.1[a]	(5.5)	20.1[a]	(5.0)	15.6[b]	(5.5)
QMD	57.0	(8.9)	55.4	(7.0)	60.1	(10.2)
BA ($m^{2}\cdot ha^{-1}$)	9.3	(5.0)	11.2	(4.1)	11.4	(4.3)
% of total BA	20.9	(5.9)	19.6	(6.7)	15.8	(5.9)
# Clumps (ha^{-1})	5.8	(2.9)	7.2	(1.7)	6.0	(1.7)
w/in-clump tree density*	659.8	(135.8)	686.0	(106.5)	608.1	(99.5)
Large Clumps (≥ 10 trees)						
# Trees (ha^{-1})	62.8[a]	(39.3)	101.1[b]	(39.7)	155.7[c]	(49.5)
% of total trees	32.6[a]	(13.1)	42.6[b]	(9.6)	57.6[c]	(12.8)
QMD	52.0	(10.2)	57.2	(6.5)	60.0	(8.2)
BA ($m^{2}\cdot ha^{-1}$)	14.9[a]	(10.6)	25.2[b]	(8.4)	44.6[c]	(19.8)
% of total BA	31.2[a]	(15.8)	43.4[a]	(9.3)	58.6[b]	(13.2)
# Clumps (ha^{-1})	3.8[a]	(2.0)	5.2[a, b]	(1.6)	6.4[b]	(2.0)
w/in-clump tree density*	693.7	(157.8)	624.3	(105.9)	609.7	(106)
Plot-level						
# Trees (ha^{-1})	175.9[a]	(60.2)	230.8[b]	(45.3)	264.9[c]	(41.0)
QMD	55.6	(4.9)	56.5	(3.8)	59.3	(7.7)
BA ($m^{2}\cdot ha^{-1}$)	42.9[a]	(15.9)	57.2[b]	(9.4)	73.7[b]	(19.3)
# Clumps (ha^{-1})	27.6[a]	(6.4)	31.7[b]	(5.1)	27.5[a]	(7.1)
w/in-clump tree density*	675.7	(89.7)	676.7	(54.5)	699.7	(179.6)
Mean # trees/clump	5.1[a]	(1.2)	6.3[a]	(1.2)	9.3[b]	(3.9)
Max. # trees/clump	24.1[a]	(10.6)	37.1[b]	(11.2)	73.3[c]	(41.8)





Frequency distribution of forest openings ≥ 80 m^2



*Ng, J., M.P. North, A.J. Arditti, M.R. Cooper, and J.A. Lutz. 2020. Topographic variation in tree group and gap structure in Sierra Nevada mixed-conifer forests with active fire regimes. Forest Ecology and Management 472: 118220.

How do you know when you've created a resilient forest?

Hypothesis: In forests that historically had frequent-fire regimes, after treatments ask: "Is **competition** still driving vegetation composition & structure or **disturbance**?"

Why:

Ecologists have noted that in grazed and frequent fire communities around the world, a 'healthy' system is most resilient when its well below its carrying capacity & largely lacks competition

Example:

"this region does not now carry over 35% of the timber capacity it is capable of carrying, and that deficiency is wholly due to forest fires" Leiberg (1904)

This idea of keeping frequent-fire forests well below carrying capacity has already been shown to secure stable carbon stocks[1] and recently suggested for drought resilience[2]

Note: If this lack of competition metric is valid, it has important silvicultural impacts:

We manipulate and model forests (i.e., FVS) based on density-dependent [competition] mortality

Density would be much lower & tree spatial patterns (clumpy/gappy vs. regular spacing) will differ between disturbance and competition driven ecosystems

1) Keith, H., B.G. Makcey, and D.B. Lindenmayer. 2009. Re-evaluation of forest biomass carbon stocks and lessons from the world's most carbon-dense forests. PNAS 106: 11635–11640

2) Goulden, M.L. and R.C. Bales. 2019. California forest die-off linked to multi-year deep soil drying in 2012-2015 drought. Nature Geoscience 12: 632-637.

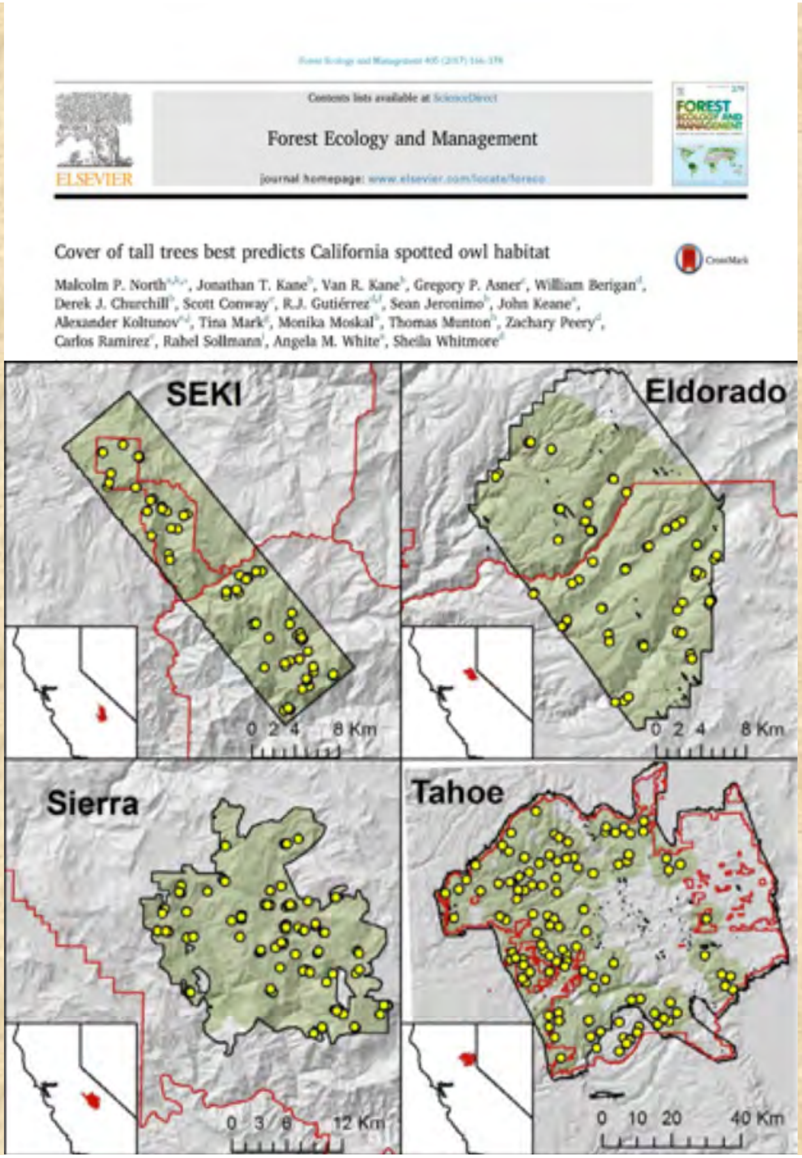
2A) Constraints: Spotted Owls

Owl's Impact on NF Land in the Sierra Nevada

Since the CASPO was published in 1992:

- ✓ Retain at least 40-50% canopy cover
- ✓ In a more recent paper, Tempel et al. (2014) "**>70% canopy cover** is associated with higher occupancy and reproduction"

How do you accommodate 70% canopy cover in fire and drought prone forests? How did the owl persist when the forest had an active fire regime and most canopy cover (before 1850) was 25-40%?



LiDAR Analysis of Spotted Owl Habitat

18 co-authors including prominent spotted owl biologists

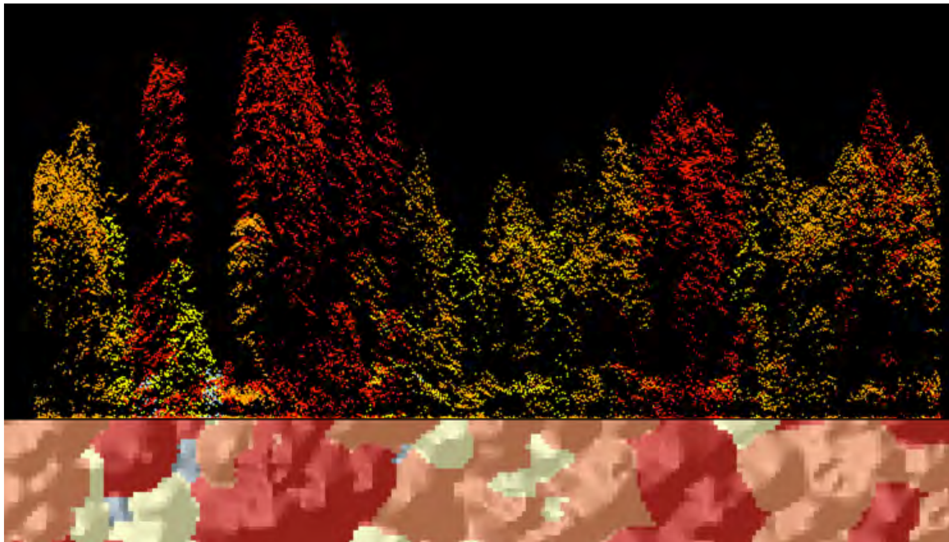
- Largest owl habitat analysis (by >10X)
- Dataset >65 Terrabytes, **100% of landscape sampled**

Study area	Nest sites	Acres
SEKI*	131	66,518
Eldorado NF	58	100,223
Sierra NF	63	101,511
Tahoe NF	64	770,795
Total	**316**	**1,039,047**

*SEKI

- Only owl demographic area with increasing population is old growth, much of it with a restored fire regime
- Used for contrast with NF conditions and as possible 'ideal' habitat

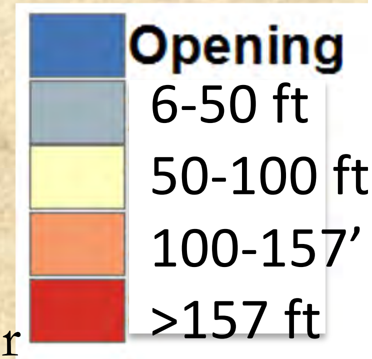
Contrasting Spotted Owl Habitat



NF: Traditional interpretation of ideal habitat:

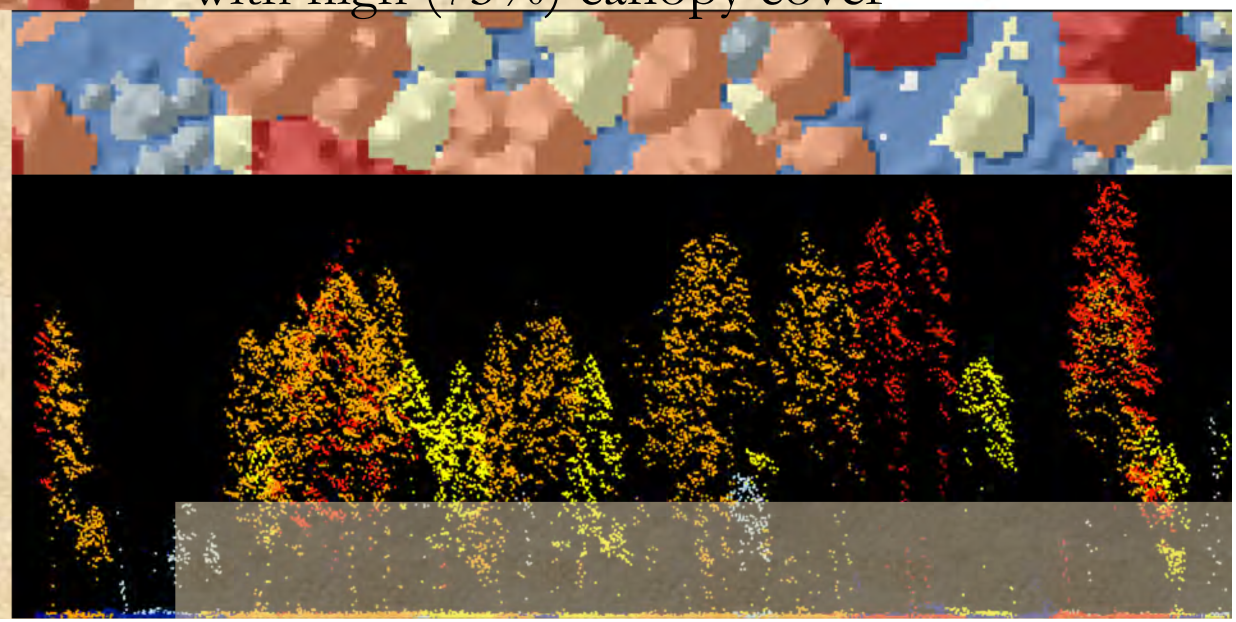
Profile showing large, tall trees

Top down canopy transect with high (75%) canopy cover



Typical SEKI Habitat

Canopy transect with 40% cover



LiDAR also found owl habitat without high cover

Profile shows tall (>157 ft) trees

Sierra Nevada forests can be managed to provide owl habitat while reducing fuels and increasing tree drought resilience

- Key habitat feature is **not total canopy cover**, but the cover in tall (>157 ft) trees.

- Owls actually avoid areas with understory (6-50' strata) cover suggesting that **reducing ladder fuels and stem density should not adversely impact owls.**

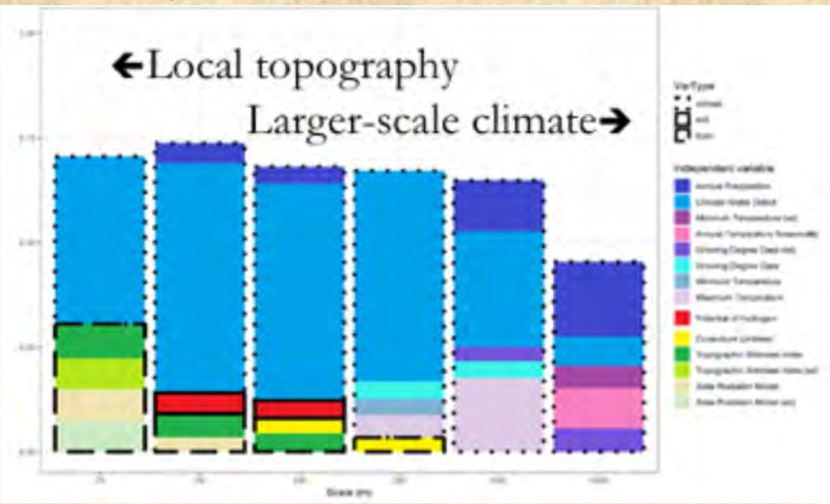
Kramer, A, G.M. Jones, S.A. Whitmore, J.J. Keane, F.A. Atuo, B.P. Dotters, S.C. Sawyer, S.L. Stock, R.J. Gutiérrez, and M.Z. Peery. 2021. California spotted owl habitat selection in a fire-managed landscape suggests conservation benefit of restoring historical fire regimes. Forest Ecology and Management 479: 118576 (released 2 days ago)

"Consistent with other studies of this species, owls selected forests dominated by medium and large trees and avoided areas with smaller trees within their home ranges…[owls] avoided larger patches of severely -burned forest (odds of selection decreased by 20% for every 10 ha increase in severely-burned patch area)."

"Owl Strategy: Work with the hand you're dealt, but plan for the future"

- Many current owl PACs are not in sustainable locations (i.e., often using steep, remote slopes that were inaccessible to logging where there are remnant older forests) prone to fire and drought.
- Building landscape resilience should consider planning to transition owl habitat **to landscape locations best able to support tall trees.**
- This means identifying optimal locations and fostering large tree development in wet, fire refugia areas.

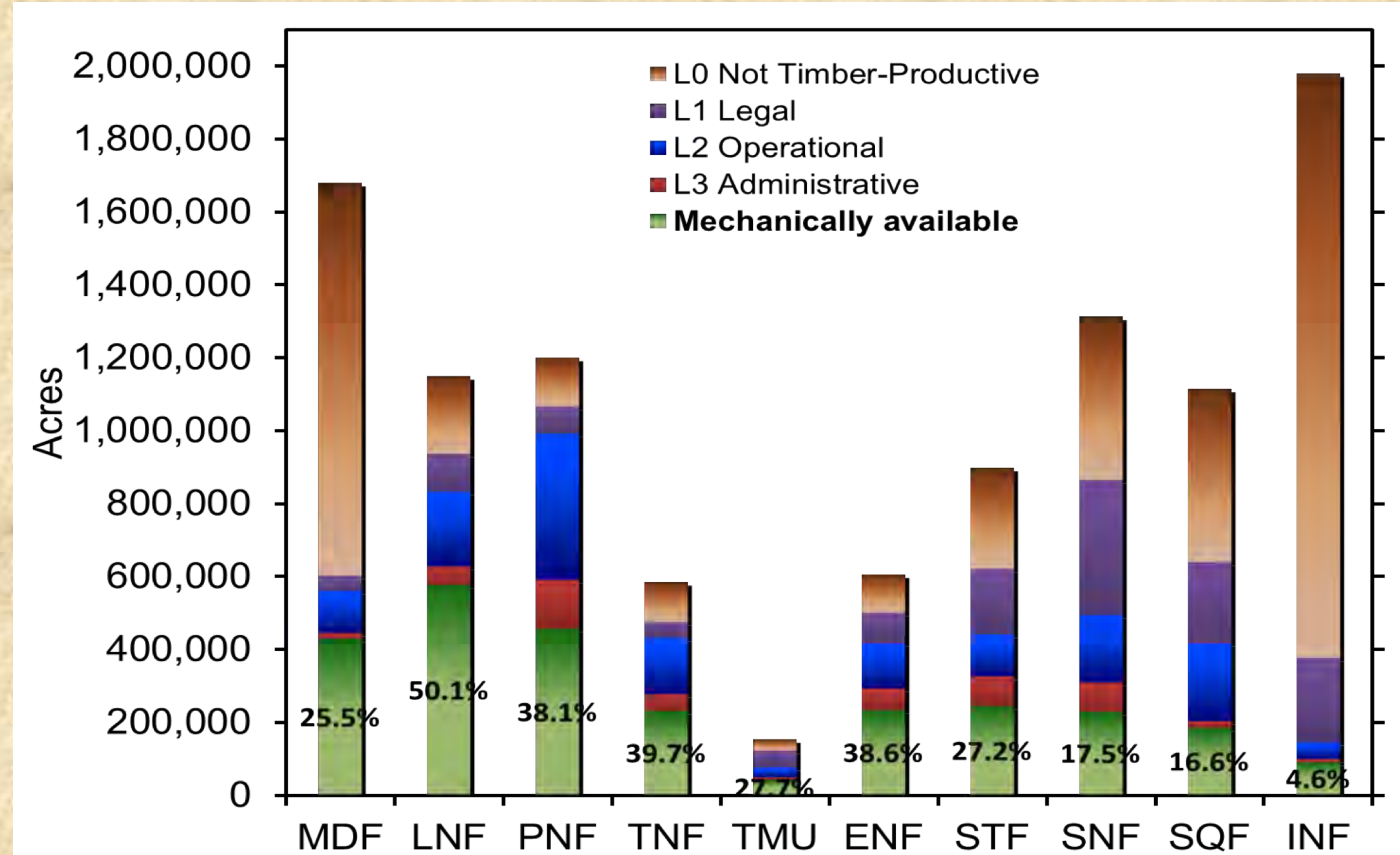
Location and height of tall trees is driven by scale-nested factors that drive water availability*…easy to identify in GIS



*Fricker, G.A., N.W. Synes, J.M. Serra-Diaz, M.P. North, F.W. Davis, and J. Franklin. 2019. More than climate? Predictors of tree canopy height vary with scale in complex terrain, Sierra Nevada, CA (USA). Forest Ecology and Management 434: 142-153.

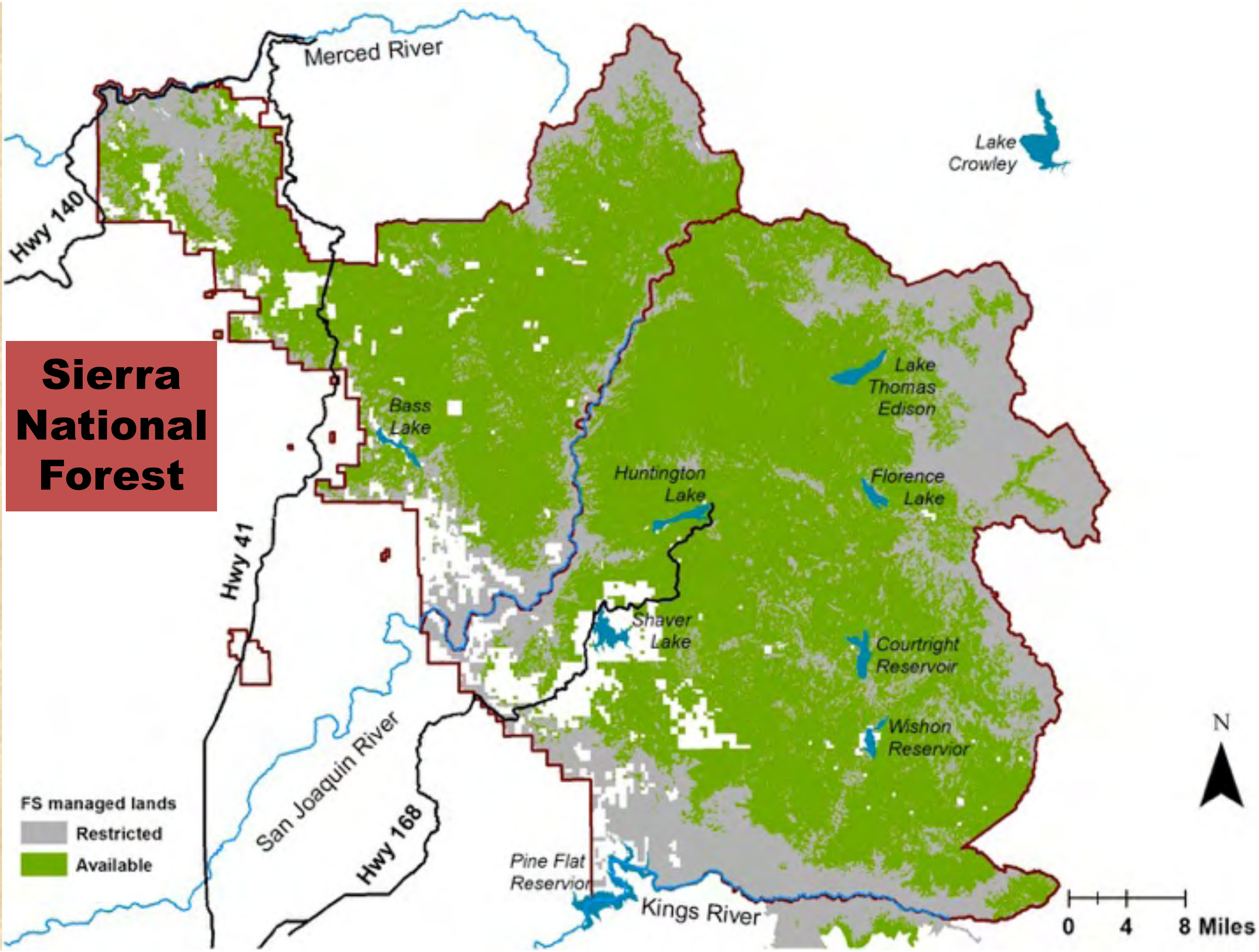
2B) Mechanical Constraints: If We Got 'Serious', Could We Thin Our Way To Resilience?

Reduction in FS acres Available for Mechanical Treatment

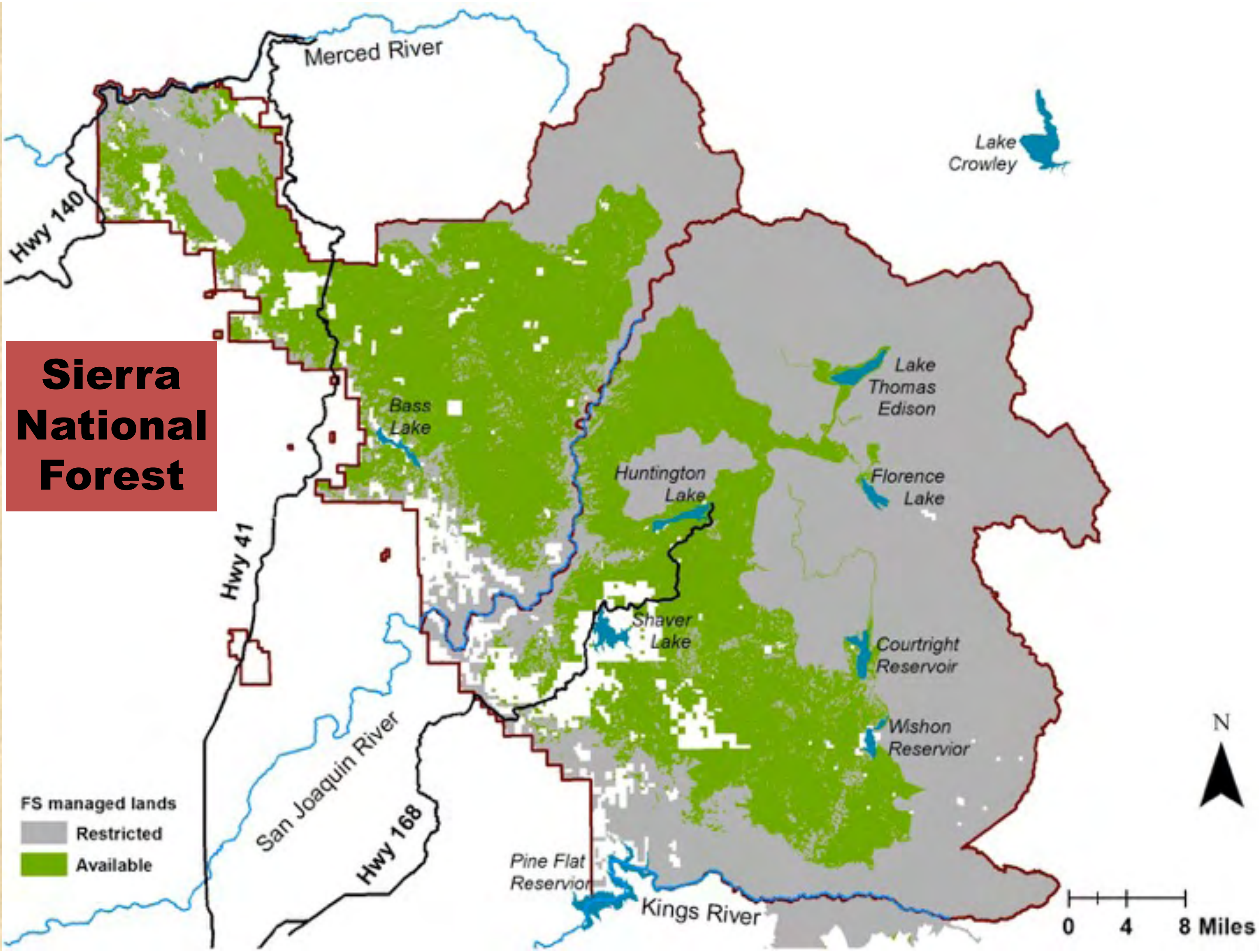


North, M., A. Brough, J. Long, B. Collins, P. Bowden, D. Yasuda, J. Miller and N. Suighara. 2015. Constraints on mechanized treatment significantly limit mechanical fuels reduction extent in the Sierra Nevada. Journal of Forestry 113: 40-48.

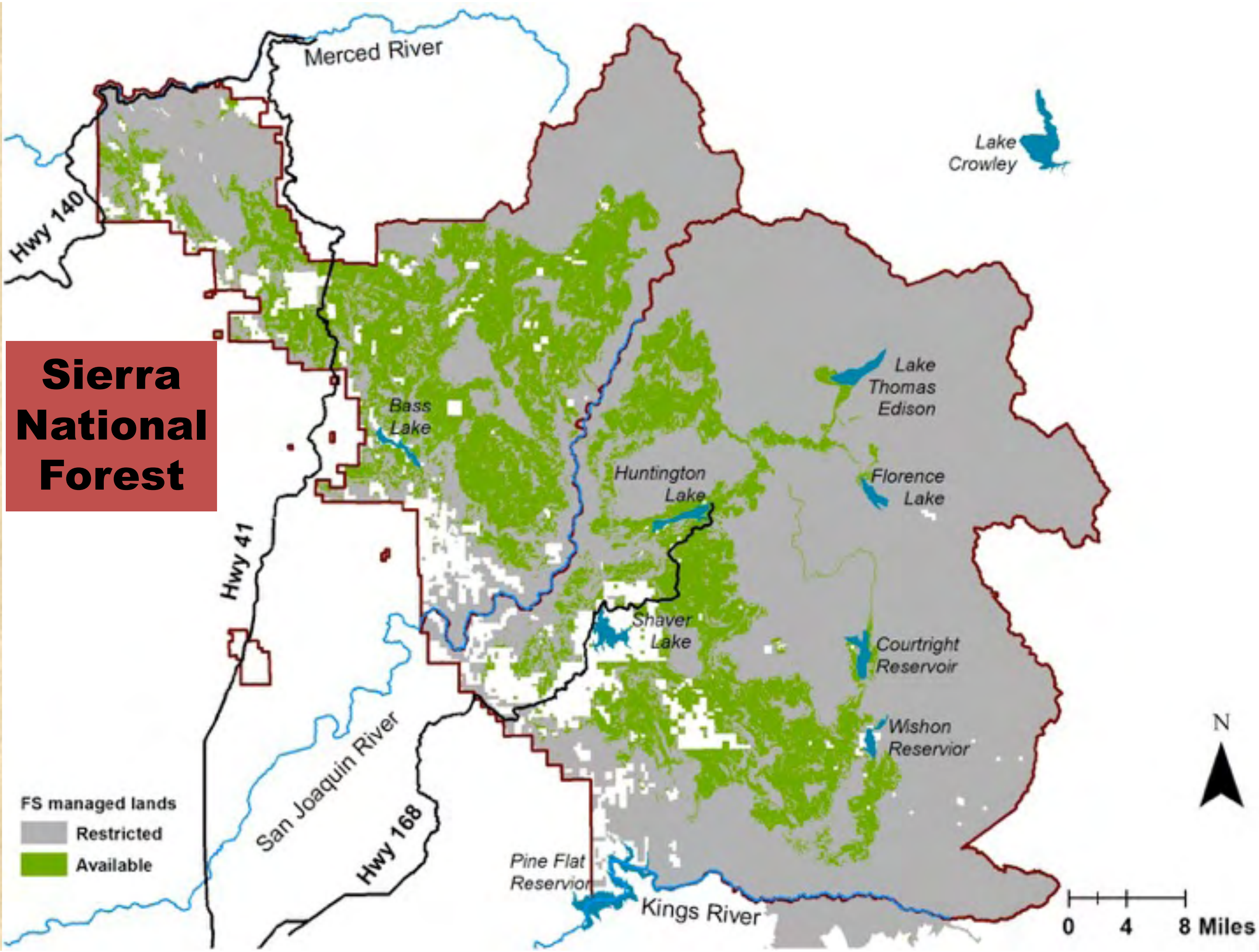
Sierra National Forest



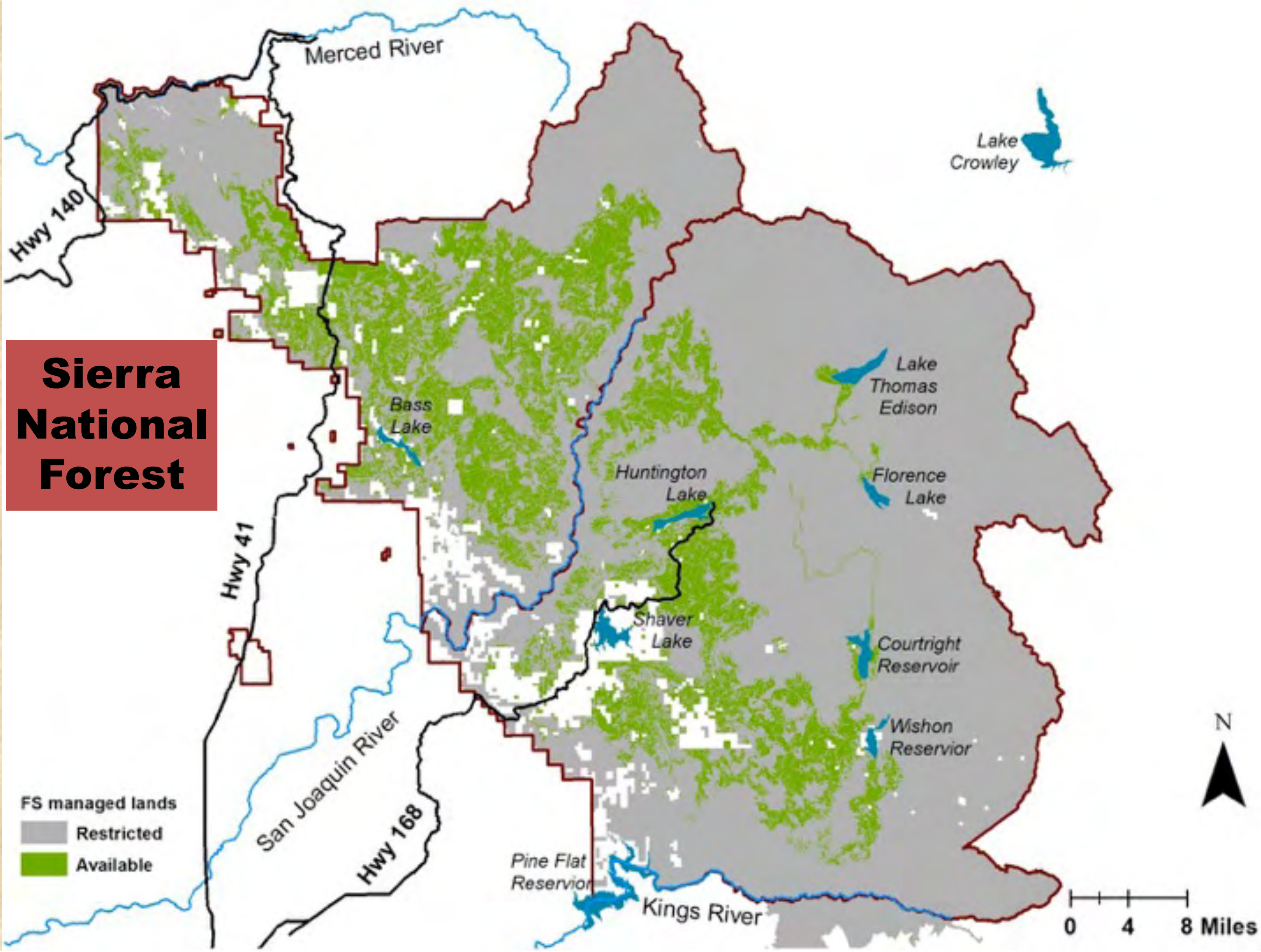
Sierra National Forest

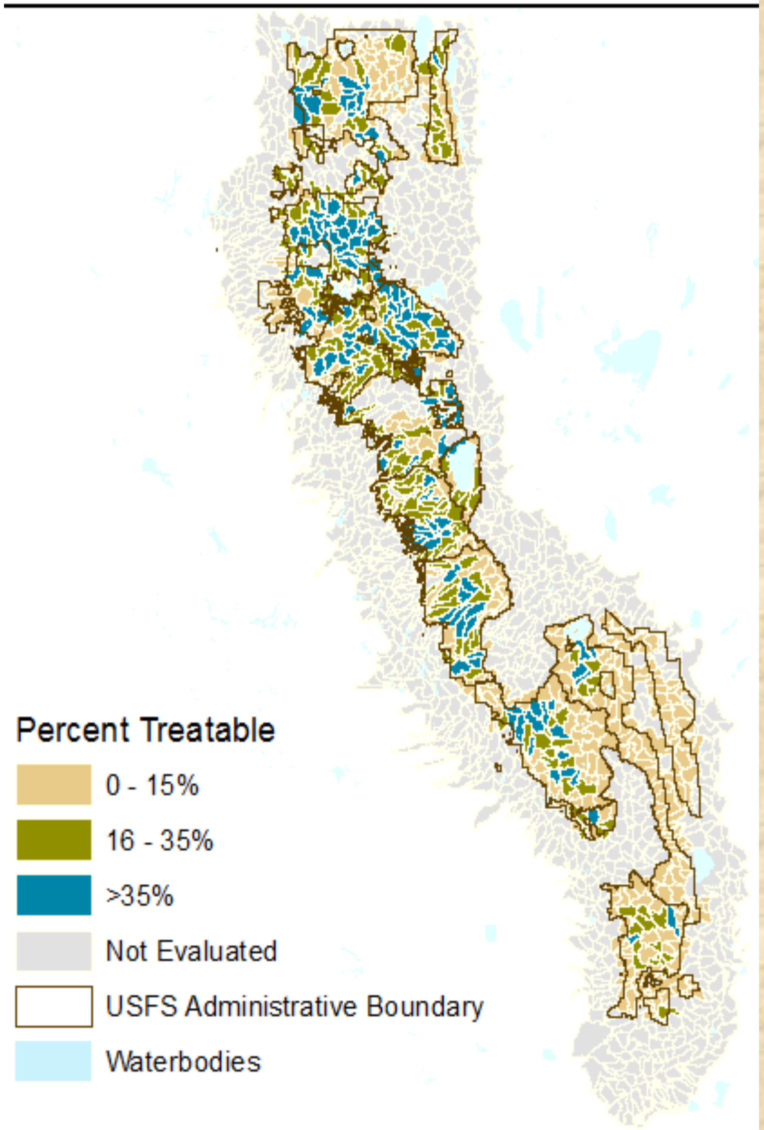


Sierra National Forest



Sierra National Forest





Analysis by Subwatersheds (HUC12) ≈ Firesheds

National Forest:		Level of Constraint		
	HUs with >25% FS ownership	High (85-100%)	Moderate (65-84%)	Light (<65%)
Modoc	96	51.0%	32.3%	16.7%
Lassen	98	22.4%	39.8%	37.8%
Plumas	87	20.7%	44.8%	34.5%
Tahoe	54	24.1%	48.1%	27.8%
LTBMU	16	37.5%	50.0%	12.5%
Eldorado	50	26.0%	50.0%	24.0%
Stanislaus	53	49.7%	30.2%	20.1%
Sierra	77	66.2%	15.6%	18.2%
Sequoia	70	72.9%	22.8%	4.3%
Inyo	109	91.7%	3.7%	4.6%
	710	**46.2%**	33.7%	**20.1**%
	Total		Average	

- **20%** of subwatersheds you could thin your way to resilience
- **46%** of subwatersheds need prescribed fire or managed wildfire for effective landscape treatment

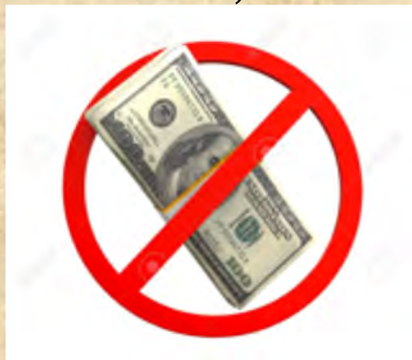
2C: Fire Use Constraints

Fire suppression and human settlement have produced roadblocks

2) Surface fuel accumulations produce hot, long-duration temperatures that can kill large, old trees.

3) Smoke production

5) Revenue (or lack thereof)

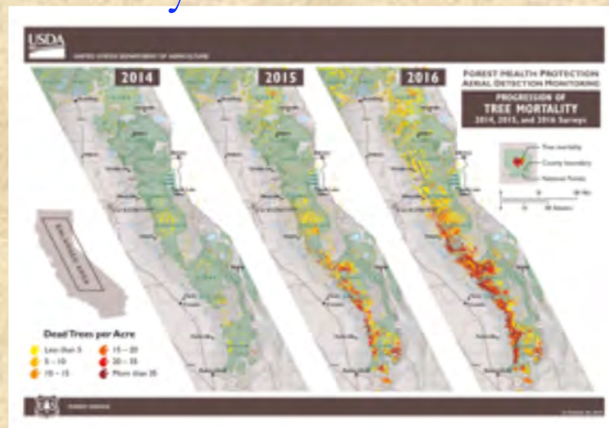


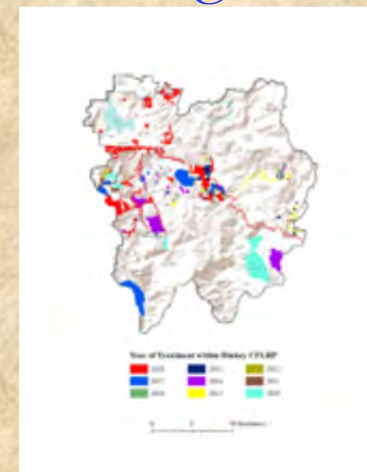
1) Small and intermediate size trees can 'ladder' surface or ground burns into catastrophic crown fires.

4) Liability

Whatever type of fire is restored, it will not replicate the historical fire regime

3) Changing treatment pace and scale: Need to increase pace and scale, otherwise treatments are blown out by severe wildfire and drought





Example: Dinkey CFLRP treated 9310 ha over 9 years

Over that same period, drought killed roughly 400,000 ha of trees and wildfire burned about 10,000,000 ac

How do we change current pace and scale on National Forests?

Historical Rate of Fire	487,486 acres/year
Rates of Treatment* (1998-2008)	36,854
• Mechanical treatment	28,598
• Prescribed fire	8,256

* North, M.P., B.M. Collins, and S.L. Stephens. 2012. Using fire to increase the scale, benefits and future maintenance of fuels treatments. Journal of Forestry 110: 392-401.

→ **Current treatment is 7.6% of historical rate**

→ **Annual Deficit = 450,000 acres/year (NF lands in Sierra Nevada)**

→ **At current pace, due to maintenance, 2/3's of the forest will never be treated**

→ **Sierra Nevada forests are very productive…maintenance takes over all your effort unless you can find an economic, scalable means of making treatments extensive and economical.**

Where does the logic of this lead?

Some Deductions:

Deficit is so large, there's no point in arguing over thinning vs. burning: silviculture and fire need to come out of their silos and explicitly work together to increase pace and scale: Pyrosilviculture

Scale up and concentrate efforts: Firesheds (≈30-60,000 ac or HUC 12s) need to be >35-50% fuels reduced to moderate fire intensity and probably drought/beetle resistant.

Use the extensive but blunt effects of fire to link treatments, thin stand density, and for phenotypic selection (i.e., individuals with thicker bark and earlier branch abscission).

Use precision but limited scale of thinning to affect fuel abundance and continuity, generate revenue to support fire, and facilitate widespread fire use.

Increase thinning by using it to not only aid suppression, but strategically for 1) anchors, 2) ecosystem assets, and 3) revenue

1) anchors used to facilitate fire expansion
A network of anchors across a landscape would act as control points for connecting and moderating managed fire treatments

- Reason: There are many Sierra Nevada fire/water sheds untreated because mechanically available acreage is too small to effect fire with thinning alone
- In eastern Australia, with about 20% of landscape in strategic 'anchors', they reached a tipping point for widespread fire use

Green is areas available for mechanical thinning

Central subwatershed above is left untreated because only 10% of area is available to mechanical treatment

Additional Uses for Thinning:

2) Ecosystem assets:

Areas where fuel and density reduction are needed but important ecosystem services (i.e., spotted owl nests, large carbon stores, riparian corridors) mean more precise control over fire severity is needed.

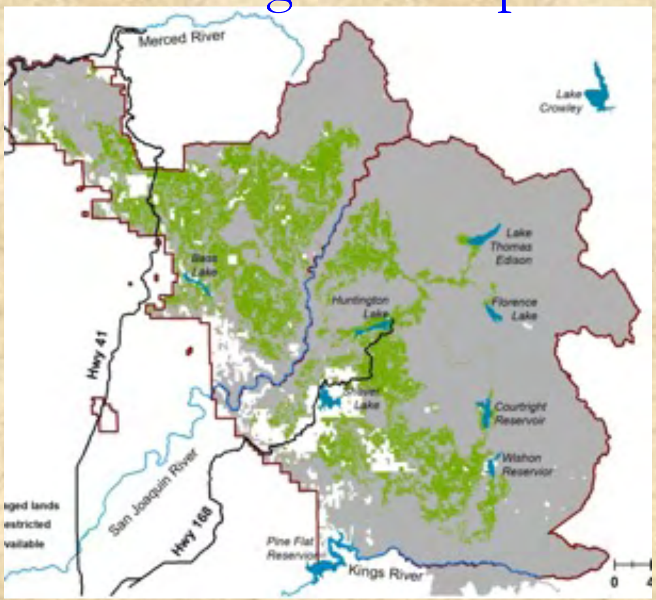
Spotted owl nest in fuel loaded stand

3) Revenue:

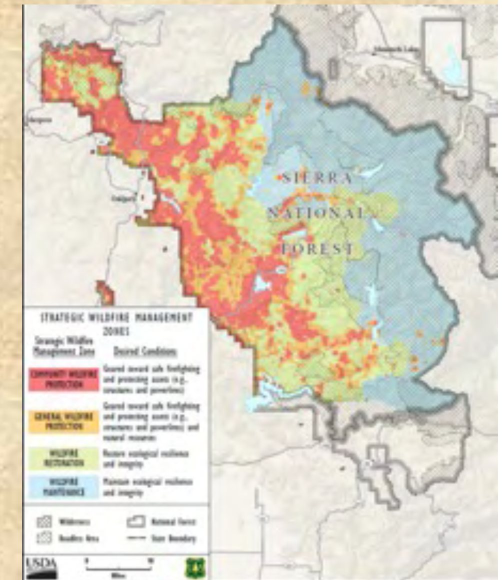
Forest treatments need a supporting revenue stream. In wet, productive locations infilling has produced large fire-intolerant trees whose removal can help restore stand density, increase water availability, and their revenue can support local fire restoration.

Large white fir on a wet site

Zoning Landscapes for Different Fire Objectives: Forest Plan Revision



3 Early Adopter NFs in southern Sierra used the mechanical constraints and other analyses to delineate 4 zones in the NF with different levels of fire use. The wildfire 'Restoration' and 'Maintenance' now require justification for putting out a fire in those zones.



- To scale up Rx/managed fire, will need to **keep it burning** using Yosemite's push/pull approach: 'Push' fire into low fuel areas (ex. granite outcrops) during bad weather/dispersion and 'pull' it across landscape during good conditions (Air Resources Board will need to allow much longer burn windows).
- Wildfire is by far the largest forest 'treatment' (100-500,000 ac/yr). Post-fire move focus beyond just salvaging & planting high severity➔ leverage 'restoration work' of low/moderate severity areas, with thinning (to 'harden' fire resilience) and Rx burning.


Questions?
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