THE TEAKETTLE EXPERIMENT:

Fire and Thinning Effects on Mixed-Conifer Ecosystems

Joint Fire Science Program

Sierra Nevada Research Center

Introduction

Like much of the western United States, Sierra Nevada forests have been significantly changed by a century of logging and fire suppression.

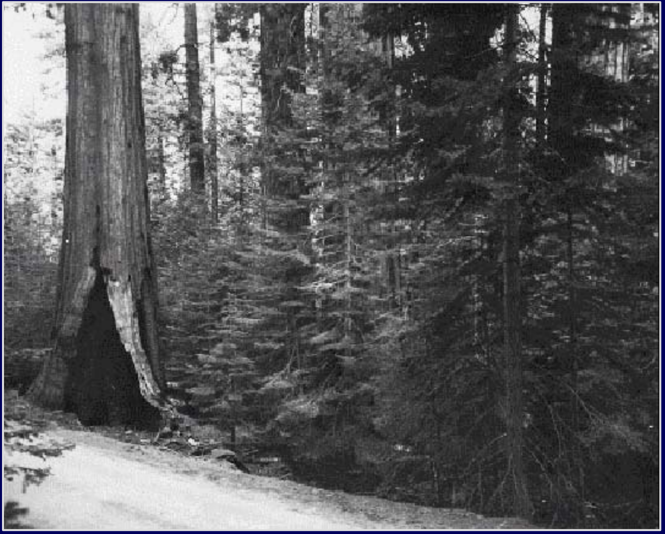
Prescribed fire and mechanical thinning are widely used for restoring forest health, but how do their ecological effects differ?

The Teakettle Experiment was initiated in response to this question. The experiment is an interdisciplinary collaboration of more than a dozen scientists, working in coordination to investigate the effects of fire and thinning treatments.

This presentation gives a brief overview of the Teakettle Experiment, presents results from the ecosystem component studies, and finishes with a summary of key ecological findings potentially useful for forest managers.

Legacy of Fire Suppression

Mariposa Grove, 1890s



Same location, 1970s

A century of fire suppression has fundamentally changed Sierra Nevada forests:

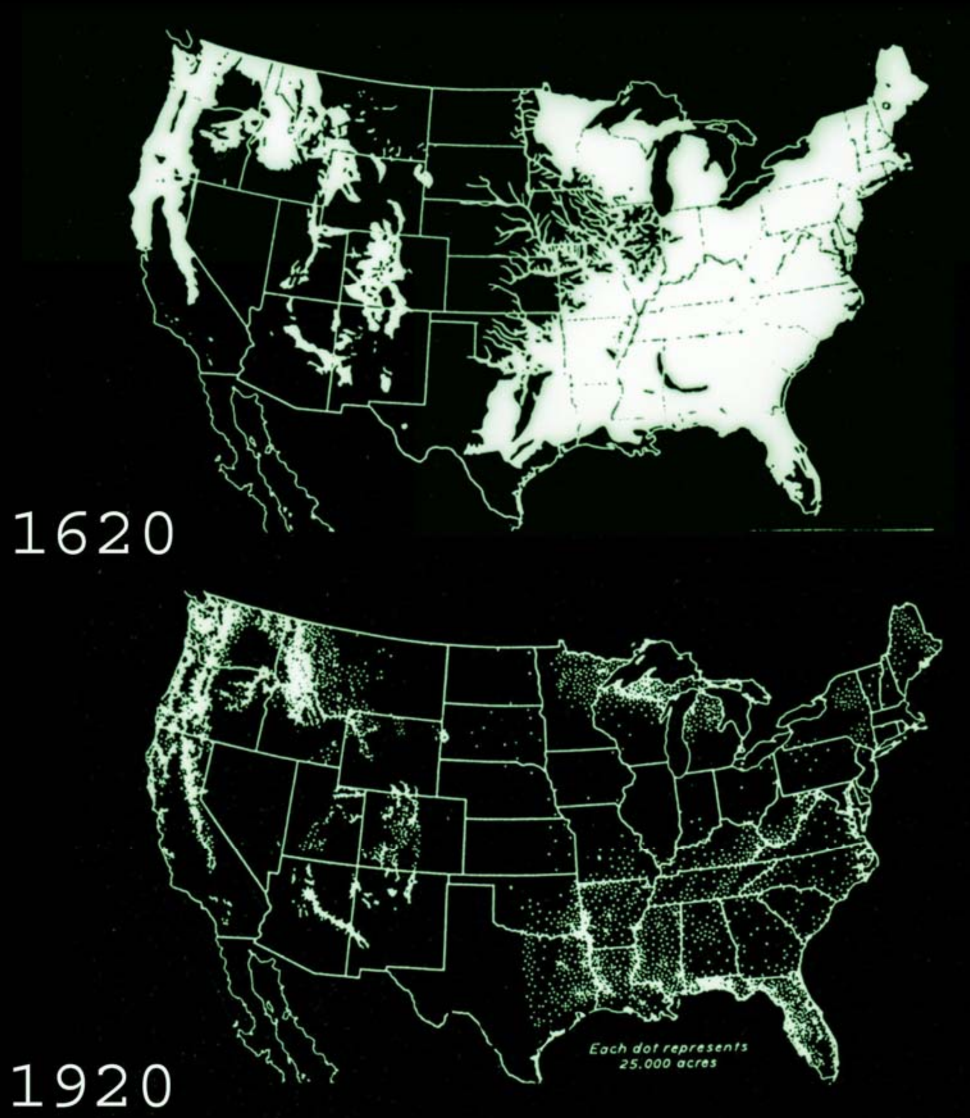
- Historically, mixed conifer's fire return interval was 12-15 years for low-intensity underburns but is now estimated to be over 600 years.
- Tree density has dramatically increased.
- Species composition is dominated by thin bark, fire-sensitive fir and incense cedar.
- Historically fire was a significant influence on plant establishment, growth, and mortality.

What drives these processes now?

History of Logging

Originally covering about 60% of pre-settlement America, old-growth forest has declined to less than 3% in the modern era.

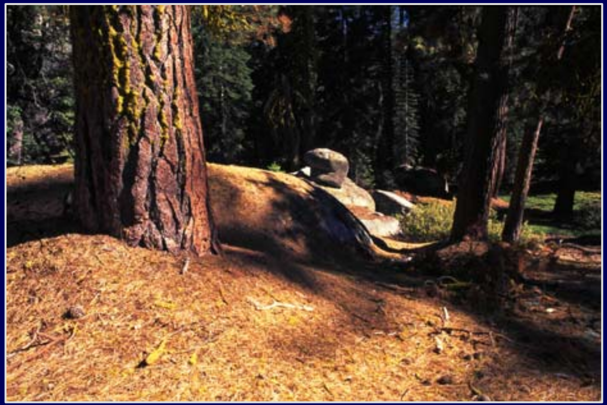
In the Sierra Nevada, historic logging varied, but in general was concentrated on accessible sites, and often harvested the largest pines. Shade, thicker litter layers and the lack of fire favored fir and cedar regeneration.



Distribution of old growth forest

Restoration Issues & Concerns

Fire suppression and logging has produced three roadblocks to forest restoration:



2) Litter accumulation can produce hot, long-duration temperatures that can kill large, old trees.

3) Much of fire-suppression regeneration is small, and of marginal economic value.

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

Mission & Goals

Because of these restoration ‘roadblocks’ some forests may require mechanical thinning before prescribed fire is applied.

The Teakettle Experiment was designed to examine how thinning and fire differ in their effects on mixed-conifer ecosystems.

Specifically, the experiment grew out of a key question raised in the *Sierra Nevada Ecosystem Project: Critical Findings Section, 1996, pp 4-5*

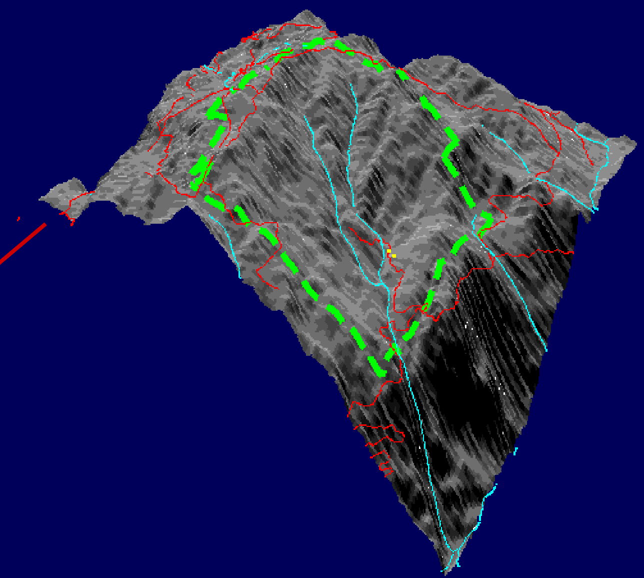
> “Although silvicultural treatments can mimic the effects of fire on structural patterns of woody vegetation, virtually no data exist on the ability to mimic ecological functions of natural fire. . .”

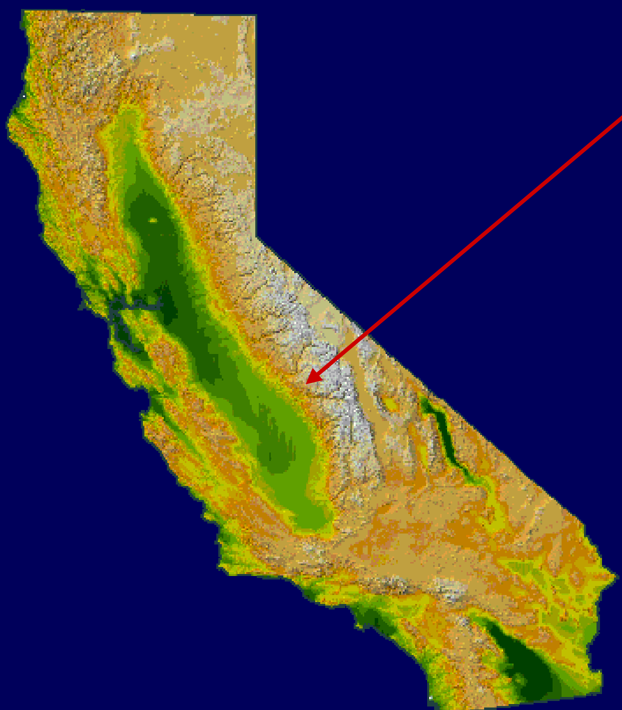
USFS crew overseeing a controlled burn

Skidder at work

Teakettle Experimental Forest:

Designated an Experiment Forest in 1938, Teakettle is a 3000 acre reserve of old-growth located 50 miles east of Fresno, California between 6200-8300 ft in elevation. The Experimental Forest is the immediate watershed surrounding Teakettle creek.





Approximately two-thirds of Teakettle is mixed conifer, which contains white fir (*Abies concolor*), black oak (*Quercus kelloggii*), sugar pine (*Pinus lambertinana*), incense-cedar (*Calocedrus decurrens*), Jeffrey pine (*Pinus jeffreyi*), and red fir (*Abies magnifica*).

The last widespread fire was in 1865.

Importance of Old Growth

Why conduct a restoration experiment in old growth when most of the Sierra Nevada is younger, managed forest?

- Old growth is the baseline for historic forest conditions indicating how ecosystem processes respond to disturbance.

- Without thinning, old-growth structure is less variable, allowing plots to have similar initial conditions. This means most post-treatment differences between plots will be due to the fire and thinning treatments rather than pre-existing plot differences.

- Old-growth has fairly stable carbon and nutrient pools.

- Old forest conditions are often what restoration is striving toward.

Plot Size & Importance of Patches

1. Closed canopy

2. Shrub patches dominated by whitethorn ceanothus

3. Open gaps

4. Areas of rock and shallow soils

Mixed-conifer forest has 4 types of patches. The experimental plots needed to be large enough to have similar patch proportions in each plot. The smallest plot that contained a representative subsample of the range of mixed-conifer conditions was 4 ha (10 acres), a 200 m x 200 m square.

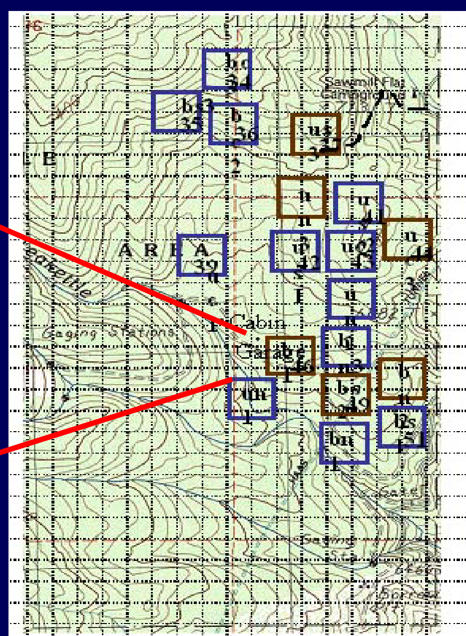
Sampling Design

There are a total of 18 plots (6 treatment types x 3 replicates of each treatment).

Each plot has a grid of sample points where all data was collected before and after the treatments. As a result, data collected by different studies can be compared to assess forest response across ecological disciplines.

Grid Point Numbering System

1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31	32	33	34	35
36	37	38	39	40	41	42
43	44	45	46	47	48	49



Study Timeline

The plots were thinned in late 2000 and early 2001. Slash was left to dry for one year. For containment and smoke regulation purposes, the plots were burned in fall (2001) rather than the historical fire season of mid-July to early September.

1998 — Pretreatment data (2-3 yrs for all studies)
1999

2000 — Treatments
2001

Post-treatment data (2-3 yrs for all studies)
2002
2003

2004 — Monitoring (5-20 yrs)
⇓

Experimental Design

The experiment uses a full-factorial design crossing 3 levels of thinning with 2 levels of prescribed burning:

	NO BURN	BURN
NO THIN	*Control*	*Burn only*
CASPO THIN * (Understory thin)	*Thin only*	*Burn & thin*
SHELTERWOOD THIN ** (Overstory thin)	*Thin only*	*Burn & thin*

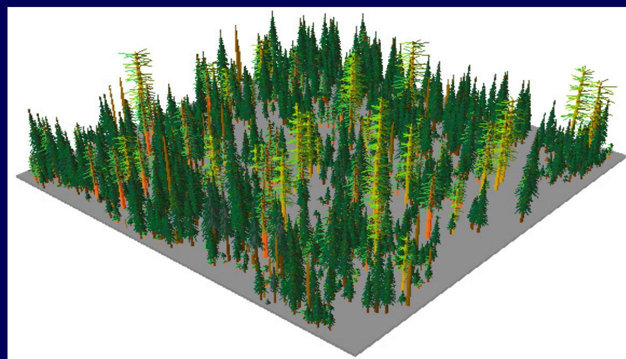
* *Based upon California Spotted Owl or CASPO guidelines (Verner et al. 1992). All trees > 10" and < 30" are removed.*

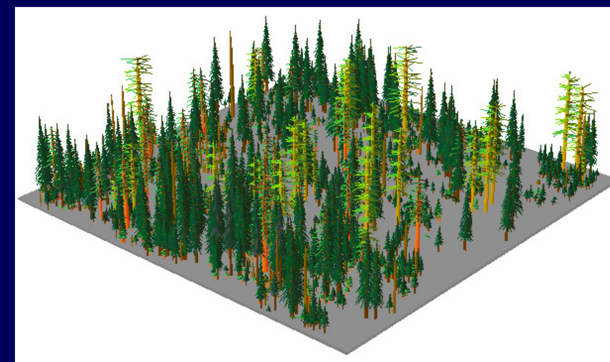
** *Based upon a common pre-CASPO thinning, leaving 8 large trees/acre approximating a 70' X 70' spacing.*

Plots were marked by the Sierra National Forest, checked for prescription compliance and tractor yarded to temporary landings.

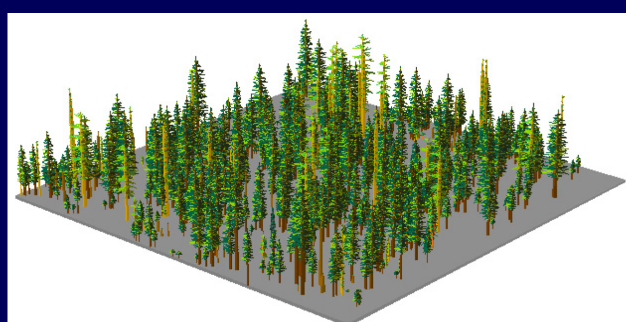
Stand Visualization of Treatments

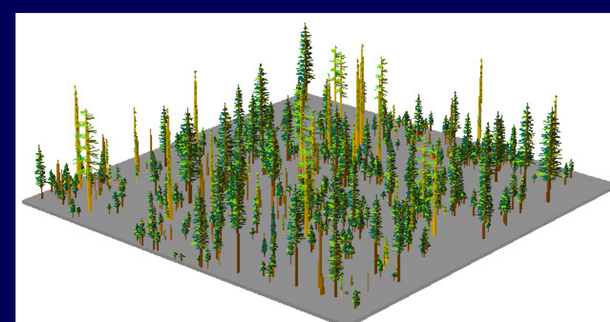
Treatments: Stand Visualization Simulations (SVS) using actual tree locations, species and diameter for all trees > 2” dbh.





10 acre plot before and after CASPO thinning (10”< remove trees < 30”). Note: clumping pattern of tree distribution.



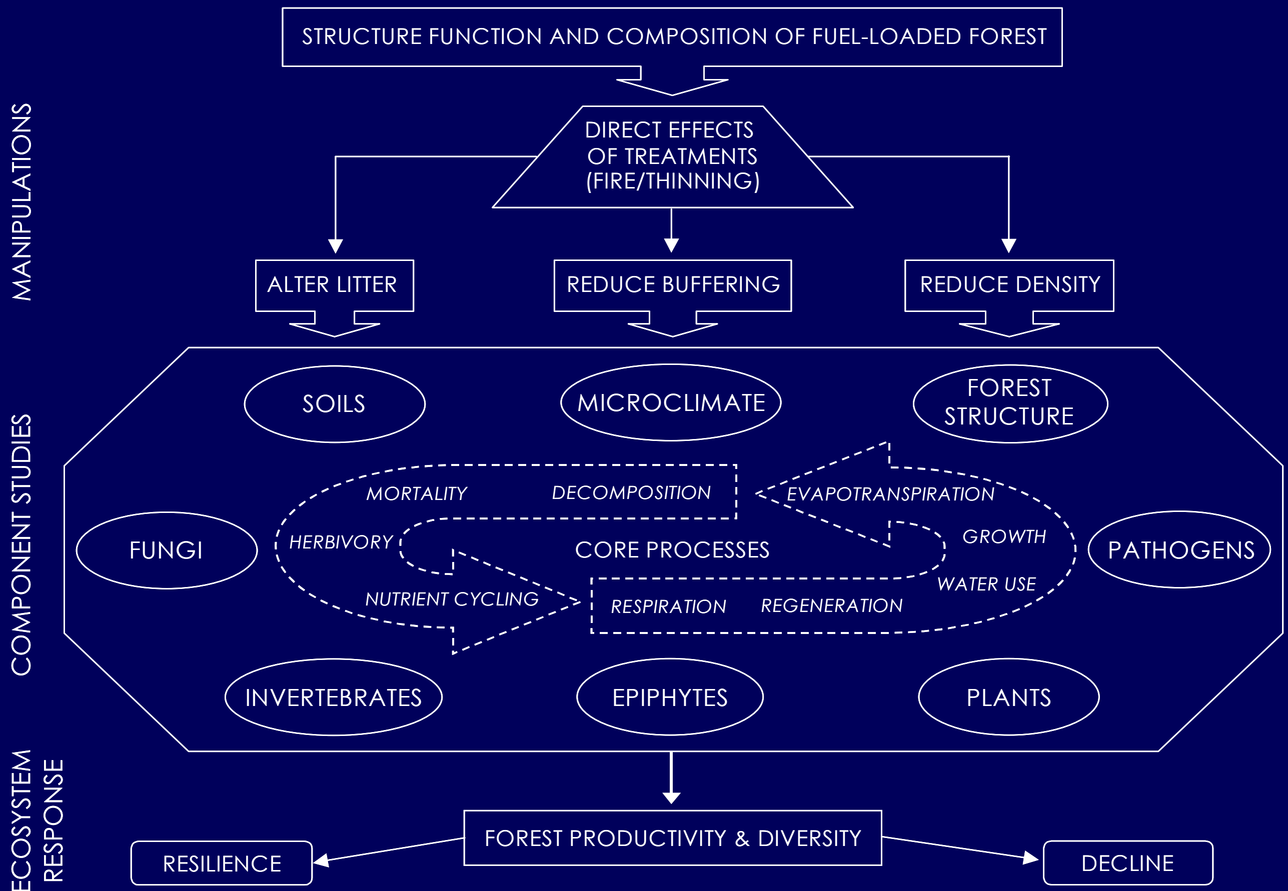


10 acre plot before and after shelterwood thinning (leave trees < 10” and 8 evenly spaced large tree/ac). Note: more regular pattern of tree distribution.

Conceptual Model

A conceptual model of forest ecosystem response to disturbance was used to guide the research project and identify which ecosystem components to study:

Fire and thinning should alter three fundamental ecosystem properties: soils, microclimate and forest structure. Changes in these properties would affect key ecosystem components, ultimately altering forest productivity and diversity.



Focus and Scale

Though there are many other large fire experiments around the nation, including several in California, the Teakettle Experiment is focused upon basic ecological processes (i.e., seral development, H_2O, temperature, light, nutrients and trophic structure), the building blocks within any ecosystem. The focus is to assess how fuel reduction affects forest succession, productivity, diversity & wildlife food webs.

STUDY SCALE

LANDSCAPE (up to 500,000 ac)	PLUMAS / LASSEN STUDY	Large-scale fire movement & behavior, spotted owls
WATERSHED (3000-5000 ac)	KINGS RIVER PROJECT	Water flow & nutrients; forest carnivores; birds; uneven-aged mgt.
STAND (100 ac)	FIRE SURROGATE STUDY	Management options; Small mammals
ECOSYSTEM (10 ac)	TEAKETTLE EXPERIMENT	Soils; microclimate; respiration; succession; food webs

FUNCTION / PROCESS

List of Studies

The following studies are the core components of the Teakettle Experiment:

STUDY	PRINCIPAL INVESTIGATOR	INSTITUTION
Microclimate, Soil Respiration	Jiquan Chen, Siyan Ma & Suong Rhu	Univ. of Toledo, OH
Soil Nutrients	Heather Erickson	Univ. Metropolitan, San Juan, PR
Decomposition	Marty Jurgenson	Michigan Technology University, Houghton, MI
Fire History	Michael Barbour, Rob Fiegener,	Univ. of California, Davis, CA
Tree Regeneration & Soil Moisture	Andrew Gray & Harold Zald	Pacific Northwest, Forest Inventory Analysis, Corvallis, OR
Canopy Invertebrates	Tim Schowalter	Louisiana State Univ, Baton Rouge, LA
Tree Pest & Pathogens	David Rizzo, Tom Smith, Tricia Maloney	Univ. of California, Davis, CA
Flying Squirrels, Chipmunks & Truffles	Marc Meyer, Doug Kelt & Malcolm North	Univ. of California, Davis, CA
Soil & CWD Invertebrates	Jim Marra & Bob Edmonds	Univ. of Washington, Seattle, WA
Lichen Growth & Dispersal	Tom Rambo	Univ. of California, Davis, CA
Nitrogen Dynamics, *Frankia* Diversity & Response to Fire	Brian Oakley, Jerry Franklin & Malcolm North	Univ. of Washington, Seattle, WA
Understory Herb & Shrub Diversity	Rebecca Wayman & Malcolm North	Univ. of California, Davis, CA
Global Climate Change & Tree Demography	Matthew Hurteau & Malcolm North	Univ. of California, Davis, CA
Mycorrhizal Diversity/Water Movement using Stable Isotopes	Tom Bruns, Antonio Izzo, Agneta Plamboeack, Todd Dawson	Univ. of California, Berkeley, CA
Seed Dispersal	Ruth Kern	Calif. State Univ. Fresno, CA
Tree/Shrub Mortality & Growth, Truffles, Cones, Coarse Woody Debris, and Diameter Growth	Malcolm North, Jim Innes	Pacific Southwest Research, Davis, CA

Focal Questions

Although Teakettle's research studies are focused on examining fire and thinning effects on each particular ecosystem component, all of the projects are directed toward providing pieces of the ecological puzzle, centered around the question: *How does thinning differ from fire in its effect on ecosystem function and succession?*

1) What are the primary influences on ecosystem function in mixed-conifer forests?

2) In the absence of fire what drives tree regeneration, growth, and mortality?

3) What are some of the key ecosystem functions of large trees and pieces of coarse woody debris?

4) How does thinning affect fire intensity and extent?

5) How does thinning differ from fire in its effect on ecosystem function and succession?

Climbing a 200 ft red fir to sample lichens

What follows is divided into 3 sections. The first section discusses ecological conditions *pre*- and *post*-treatments for the major component studies. This is followed by a section with some results that may be useful to managers. The above focal questions will be revisited in the final summary section.

Component Study: Vegetation

Pre-Treatment

- Southern Sierra mixed-conifer is highly patchy and gap edges are important for the establishment of shade-intolerant pine.
- Tree growth is significantly affected by soil depth and the bedrock water table. Once seedlings access deep, perennial water, diameter growth accelerates.
- Large logs are not moisture reservoirs or seedling nurseries, and excluding cedar, decay quickly even in the absence of fire
- Herbs have low cover (< 3%), high diversity (> 125 species), and are associated with moist, shaded conditions.
- Shrub cover (16%) is highly patchy. Manzanita is common on thin, droughty soils, and snowberry on deep, moist sites.

Component Study: Vegetation

Post-Treatment

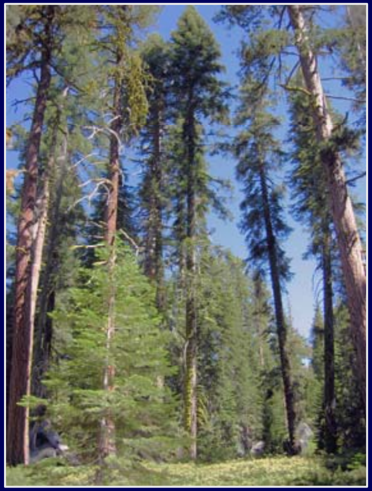
Prescribed fire had little effect on Teakettle's largest tree, a 110"dbh cedar

Large white fir killed by heat from log burning against its bole

- Thinning *without burning* significantly increases litter and slash cover, severely reducing herb diversity and cover.
- *Burning* increases herb diversity and cover, and reduces competing shrub cover.
- The fall burn had little impact on plants or litter in unthinned plots because without additional slash, fire extent and intensity was very limited.
- Fire consumed snags and logs on steeper slopes. Surviving logs and snags were highly clustered in low intensity or unburned micro-sites.
- In our cool fall fire, large tree mortality was low and usually only resulted from burning logs against the tree bole, rather than from litter mounds.

Component Study: Tree Regeneration

Pre-Treatment



- Tree regeneration was dominated by shade-tolerant white fir and incense-cedar, although sugar pine is well-distributed in a range of sizes.
- Regeneration abundance by patch type: *closed-canopy > open gaps > shrub patches.*
- White fir, incense-cedar, and sugar pine prefer very similar light and moisture conditions.

Post-Treatment

- Pine regeneration is most abundant and has greatest growth in the burn/shelterwood.
- Higher-intensity treatments provide a greater range of microsite conditions
- Residual large overstory fir and cedar are significant sources of natural recruitment pushing stand composition back toward a fire-suppressed composition unless pine is planted or prescribed fire is re-applied

% change in seedling density (< 5” tall) after treatments

Component Study: Soil Moisture

Pre-Treatment

- Although soils are at field capacity (~25%) in mid-May after snow melt, by early July the surface layer (0-6") is at < 6%
- Isotope signatures indicate overstory trees access deep (> 3 ft) soil moisture, while shrubs and saplings compete for shallow (< 18") water.
- Higher soil moisture is associated with deep litter and high canopy cover.

Saplings & overstory trees access soil water from different depths.

Post-Treatment

Measuring soil moisture with a backpack Time Domain Reflectometer (TDR)

- Soil moisture increased in thinned plots, with the greatest increase in shelterwoods, possibly due to less tree evapotranspiration and deeper soil litter.
- With thinning, many ecosystem processes seem to be 'released' from a moisture constraint. Litter and slash than become a significant limit on some functions.

Component Study: Soil

Pre-Treatment

6′ deep soil pit

- Although there is high nitrogen in forest litter, most nitrogen is consumed by soil microbes and unavailable to trees and plants.
- In contrast, ceanothus creates hot spots of available nitrogen. These hot spots have faster decomposition rates and more soil invertebrates, but do not appear to increase tree growth.

Post-Treatment

- Blackened soils in gaps can reach temperatures lethal to plants (> 120ºF).
- Established ceanothus patches persist as hot spots of available nitrogen, even after burning.
- Yarding on dry soils caused little compaction, however after fall rains, compaction was severe.
- Skid trails substantially reduce fire extent and intensity.

Fire only burned the foreground trees due to the presence of a skid trail

Component Study: Microclimate

Pre-Treatment

- Maximum monthly mean air temperature = 61ºF (August), minimum monthly mean = 33ºF (February) and annual mean = 45ºF.
- Below-canopy solar radiation is much higher than in most forests due to hot, cloudless summers and canopy gaps common in mixed-conifer.
- Soil surface temperature can vary by more than 50º F between high canopy cover and open gaps.

Weather station; centered within each research plot

Post-Treatment

Microclimate sensor

- Microclimate variability increases in plots with moderate intensity treatments (understory thin and burn).
- In high severity treatments, microclimate becomes more spatially homogeneous but has higher diurnal fluctuations.

Component Study:
Respiration & Decomposition

Pre-Treatment

Through-fall sampler for measuring atmospheric inputs

- Decomposition rates are strongly affected by moisture.
- Litter buildup around tree boles is due to early snow melt, lower moisture and slowed decay.
- When soils are wet, soil respiration increases with temperature (*typical*). But once soils dry, respiration decreases as temperature increases.
- Soil respiration varies by patch type with the highest rates in ceanothus, possibly due to higher nitrogen availability & increased microbial activity.

Post-Treatment

- Decomposition rates increase in thinned plots, but decrease in drier, burn plots.
- Soil respiration tended to increase with thinning and decrease with burning.
- Years with deep snowpacks (El Nino) had much higher soil respiration rates.
- In the long-term, mixed-conifer sequesters carbon with understory burning, but if climate change increases winter precipitation, mixed conifer is likely to become a greater carbon source than sink.

Component Study: Pest & Pathogen

Pre-Treatment

- Bark beetle and pathogen mortality is highly localized rather than a large-scale process.
- Although mortality is concentrated on high density pockets, pests do not act as a 'correcting agent' for fire suppression. The composition of dead trees is not higher for fir and cedar and large tree mortality is significantly greater than expect. Current fire-suppressed old growth may have fewer large trees than historic conditions.
- In the last 20 years, gaps are increasing in frequency and size possibly due to pest/pathogen mortality centered on high density, drought stressed tree clumps.

High stem density increases drought stress & susceptibility to pests and pathogens

Post-Treatment

Gap created by root rot

- Initial observations suggest that plots with lower tree densities have less beetle activity and damage.
- Root diseases may be increasing in thinned plots where stumps remain. Stumps serve as entry points for wind-dispersing spores of soil-borne pathogens.

Component Study:
Small Mammals & Food Web

Pre-Treatment

Truffle found next to a squirrel dig

Squirrel in mid-flight

- Northern flying squirrels are highly associated with riparian habitat (almost always within 500 ft. of streams), where truffles are more abundant and available longer into the summer.
- Northern flying squirrels, the principal prey of the California spotted owl, have lower density compared to other western forests.
- Truffles are a key summer food source for mixed-conifer small mammals.
- Flying squirrels prefer snags over live trees and larger-diameter and taller structures for nesting.
- The lichen, *bryoria*, an important winter food source and nest material for flying squirrels, is strongly associated with red fir (also in the riparian corridor).

Component Study:
Small Mammals & Food Web

Post-Treatment

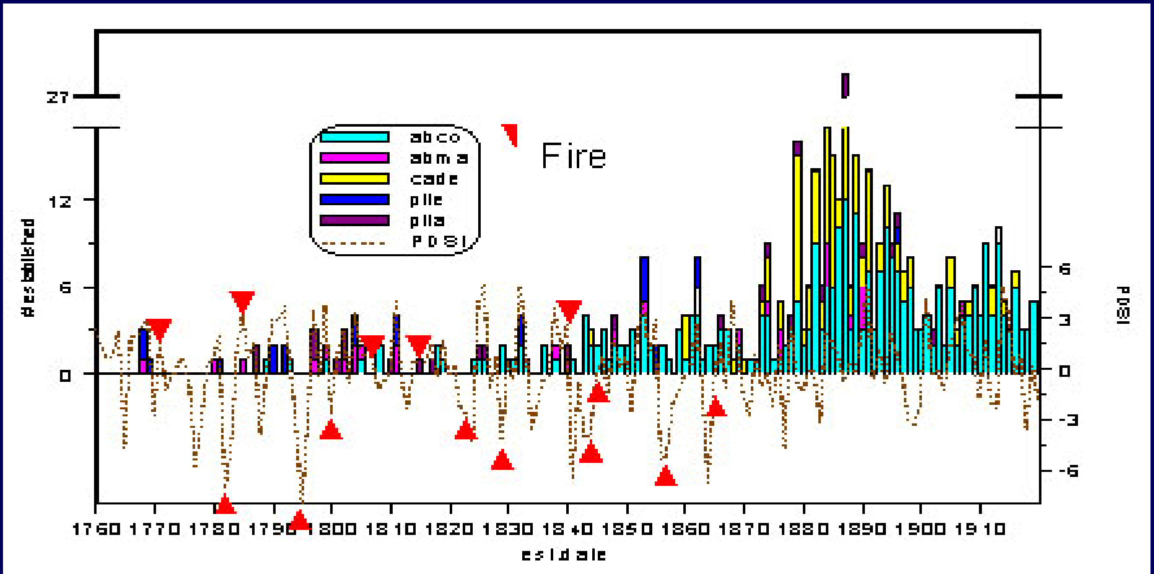
- Treatment type (fire vs. thinning) does not affect truffle abundance.
- However, treatment severity does, with high intensity (shelterwood and burn) significantly reducing short-term truffle abundance.
- In shelterwoods, lichen growth and dispersal (to colonized new trees) is reduced.
- Fire and thinning treatments do not change chipmunk abundance or distribution.
- Fire and thinning treatments seem to have no effect on flying squirrel abundance or home range size, possibly because few riparian trees were thinned or burned.

Riparian areas serve several important functions for flying squirrels

Component Study: Fire & El Niño Effects

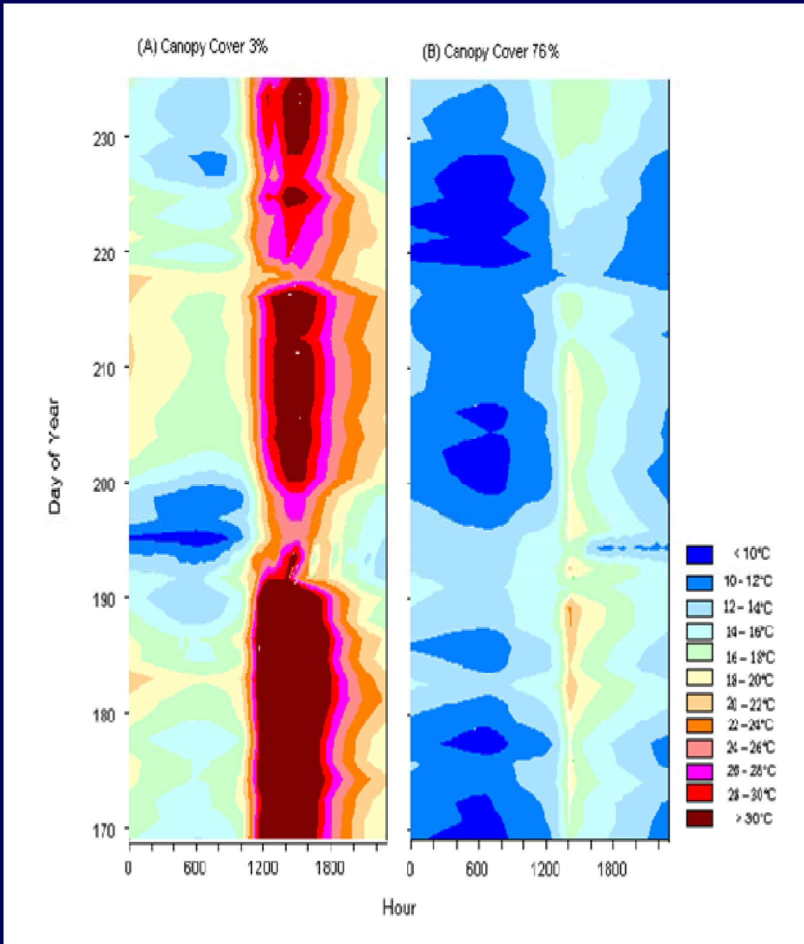
- Some trees are > 400 years old, but most (>70%) originated after 1870.
- Historic fire events are associated with dry La Niña years, though those fires were not significantly larger in extent.
- Tree response to fire and wet El Niño years varies by species:
  - a) *Jeffrey pine, sugar pine and red fir establish in wet El Niño years.*
  - b) *Sugar pine establishes after fire.*
  - c) *Most white fir and incense cedar established a decade after fire stopped*

# of trees by species established between 1760-1920. Dashed line is the Palmer Drought Severity Index, (plotted on 2nd Y axis) with + and - values correlated with wet and dry years, respectively. Red arrows are fire events.



Some Key Results for Management: Canopy Cover, Temperature & Soil Moisture

- Tree canopy cover is vital for moderating the extreme surface temperatures that occur on dry, cloudless summer days.
- Gaps have greater soil moisture than shaded tree clusters, possibly because of deeper winter snow pack and less root mining of soil water.
- Surface temperatures were not significantly increased by understory CASPO thinning and soil moisture increased.
- Overstory shelterwood thinning dramatically increased temperatures but soil moisture also increased possibly reducing stress on understory herbs and seedling regeneration.

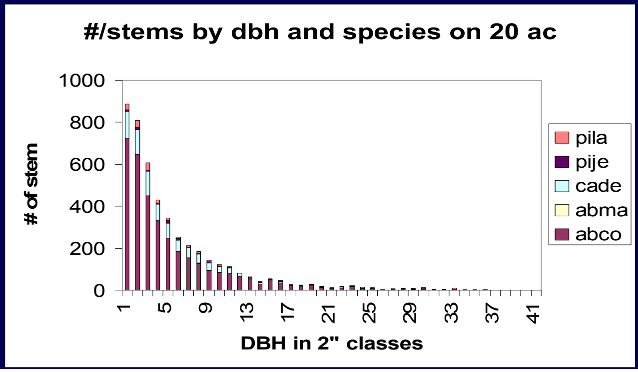


Surface temp. differences between open (3%) & high (76%) canopy cover: X axis is hour of day and Y axis is Julian day of the year (6/10 – 8/20)

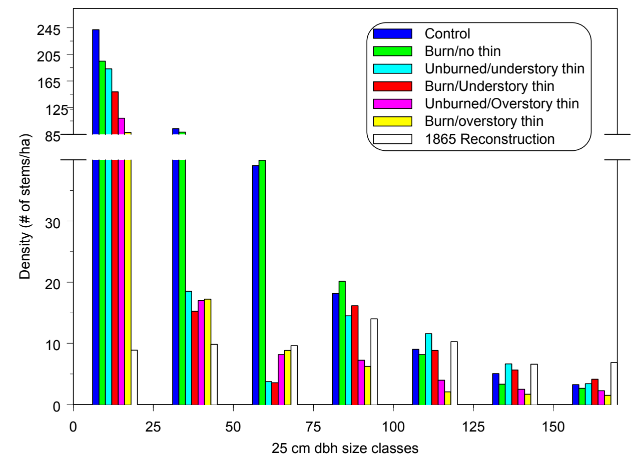
Some Key Results for Management: Diameter Distribution

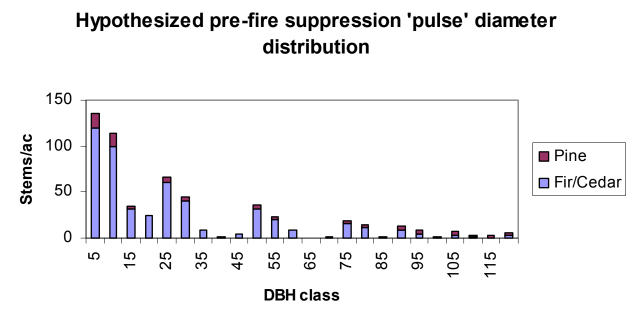
- Some thinning prescriptions determine the numbers of desired trees in each diameter class from the reverse J shaped curved (middle graph).
- This distribution, however, is more typical of forests where density-dependent competition for light drives stand mortality.
- If episodic fire and El Niño events are strong influences on mortality and recruitment, a desired diameter distribution might be a diminishing 'sine' curve shape (top graph).
- Reconstruction of 1865 stand conditions suggests that with an active fire regime mixed conifer is almost 50% shade-intolerant pine with as few as 30 trees per acre. Diameter distribution follows a diminishing sine curve with few small trees and more large trees than under modern conditions.

Current dbh distribution

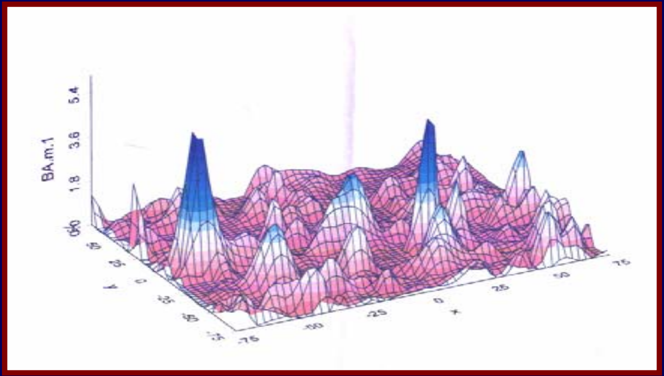


Treatments and 1865 dbh dist.

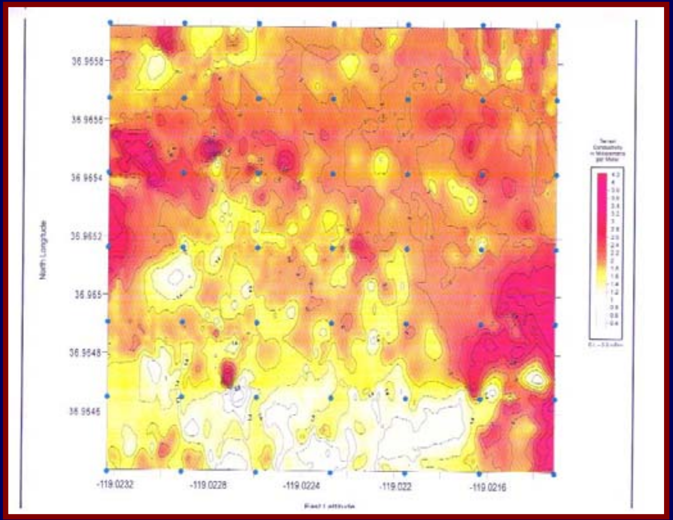




Some Key Results for Management:
Soil Depth & Bedrock Water



Kriged distribution of tree basal area in a 4 ha area

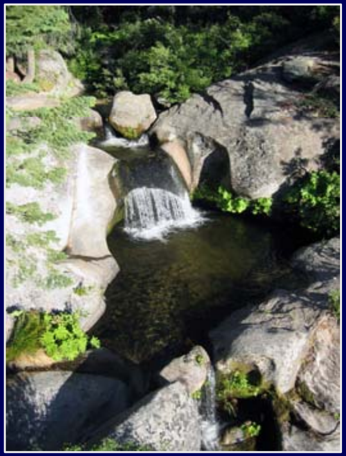


Depth to bedrock for the same 4 ha area, where deeper soils are in red. (Note: correlation between the amount of tree basal area supported and the depth to bedrock)

Within the Teakettle experimental area, in the southern Sierra Nevada:

- The underlying geomorphic template has a strong effect on above ground forest distribution and productivity.
- Gaps are often in areas where the granitic bedrock is close to the surface (< 3 ft.).
- Deep soils support trees clusters and the highest basal area.
- Regardless of fire or thinning, stem density and diameter distributions will not be uniform in these conditions.
- In these forests, gaps should be maintained rather than planted as they are an important feature providing light for shade-intolerant pine.

Some Key Results for Management:



Small Mammal Habitat

Riparian areas have more truffles and edible lichen and have most of the flying squirrels. Low intensity burning seemed to have little effect on these areas, but the effects of yarding and additional fuel, if riparian areas were thinned, might be detrimental.

Change in Mortality Pattern

Present mortality patterns are out of synch with historical conditions: Drought and pest/pathogens select for high-density groups and kill all trees (large and small), where as historically fire mortality was widespread and primarily selected small, thin barked trees.

The current mortality pattern is creating a stronger gap pattern and reducing the number of large trees.

Gap created from beetle damage mortality

Conclusions:
Focal Questions Revisited

Below are answers to the five focal questions presented earlier. These questions helped guide and influence the component studies, data collection, and final study integration:

1) What are the primarily influences on ecosystem function in mixed-conifer forests?

Water: largely determined by snowpack depth, soil depth and % organic matter. Temperature is also a strong, but secondary influence. Soil nitrogen has little effect. After thinning, slash and litter can retard diversity and some ecosystem processes.

2) In the absence of fire what drives tree regeneration and mortality?

Canopy cover, climate and pests. Regeneration is influenced by overstory canopy cover (> 50% for firs and cedar, and pines on edge of gaps) and El Niño (pine and red fir). Mortality is driven by drought and pests. Water stress is produced by high stem densities from fire suppression and periodic La Niña events. This drought stress predisposes trees, and pest/pathogens (particularly beetles) are the final agent. At Teakettle, wind was not significant.

Conclusions:
Focal Questions Revisited (cont)

3) What are some of the key functions of large trees and pieces of coarse woody debris?

Large logs do not act at moisture reservoirs, nutrient sources, or seedling nurseries and are fairly ephemeral (< 60 years). Large snags are used by flying squirrels and cavity-nesting birds. Fire consumes most logs, although some large snags are not completely consumed or are able to entirely escape burning.

4) How does thinning affect fire intensity and extent?

Off-season *(outside July-Sept)* prescribed fire may have reduced intensity and extent without thinning slash. In unthinned plots, the prescribed fire did not carry, and where it did burn there was little consumption. Thinning increased fire intensity, but the extent was patchy in places of concentrated skid trails.

Conclusions:
Focal Questions Revisited (cont)

5) How does thinning differ from fire in its effect on ecosystem function and succession?

- Thinning alone, even when designed to mimic fire (i.e., CASPO with no burn), appears to stall some processes such as nutrient cycling, plant succession, and decomposition and respiration, possibly because of the increase in slash and litter.

- Overstory thinning, like a crown fire, has the potential to significantly change microclimate and forest structure, further reducing the number of large trees already thinned by pest mortality.

- Moderate thinning may beneficially increase off-season fire intensity.

- Fire was the most important process for restoring ecosystem 'health'. Our research suggests thinning prescriptions should be designed to serve fire by 1) separating crown from surface fuels; 2) distributing slash to increase the extent of the surface burn; and 3) removing large fuels such as logs from leave tree boles.

Further Information: Publications

Forest Science 51(3) issue devoted to Teakettle Research:

- North, M., and J. Chen. Introduction to the Special Issue on Sierran Mixed-Conifer Research. pp. 185-186.
- North, M., M. Hurteau, R. Fiegener, and M. Barbour. Influence of Fire and El Niño on Tree Recruitment Varies by Species in Sierran Mixed Conifer. pp. 187-197.
- Gray, A., H. Zald, R. Kern, and M. North. Stand Conditions Associated with Tree Regeneration in Sierran Mixed-Conifer Forests. pp. 198-210.
- Erickson, H., P. Soto, D. Johnson, B. Roath, and C. Hunsaker. Effects of Vegetation Patches on Soil Nutrient Pools and Fluxes within a Mixed-Conifer Forest. pp. 211-220.
- Ma, S., J. Chen, J. Butnor, M. North, E. Euskirchen, and B. Oakley. Biophysical Controls on Soil Respiration in the Dominant Patch Types of an Old-Growth, Mixed-Conifer Forest. pp. 221-232.
- Schowalter, T. and Y. Zhang. Canopy Arthropod Assemblages in Four Overstory and Three Understory Plant Species in a Mixed-Conifer Old-Growth Forest in California. pp. 233-242.
- Izzo, A., M. Meyer, J. Trappe, M. North, and T. Bruns. Hypogeous Ectomycorrhizal Fungal Species on Roots and in Small Mammal Diet in a Mixed-Conifer Forest. pp. 243-254.
- Marra, J. and R. Edmonds. Soil Arthropod Responses to Different Patch Types in a Mixed-Conifer Forest of the Sierra Nevada. pp. 255-265.
- Smith, T., D. Rizzo, and M. North. Patterns of Mortality in an Old-Growth Mixed-Conifer Forest of the Southern Sierra Nevada, California. pp. 266-275.

Further Information:

Other Teakettle Publications

• Concilio, A., S. Ma, Q. Li, J. LeMoine, J. Chen, M. North, D. Moorhead, and R. Jensen . In press. Soil respiration response to prescribed burning and thinning in mixed conifer and hardwood forests. Can. J. Forest Research.

• Izzo, A., J. Agbowo and T. Bruns. 2005. Detection of plot-level changes in ectomycorrhizal communities across years in an old-growth mixed-conifer forest. New Phytologist 166: 619-630.

• Meyer, M. D., and M. North. 2005. Truffle abundance in riparian and upland forests of California's southern Sierra Nevada. Canadian Journal of Botany 83: 1015-1020.

• Meyer, M., D. Kelt, and M. North. 2005. Nest trees of the northern flying squirrels in the Sierra Nevada. J. of Mammalogy 86: 285-290.

• Meyer, M., M. North, and D. Kelt. 2005. Short-term effects of fire and forest thinning on truffle abundance and consumption by Neotamias speciosus in the Sierra Nevada of California. Can J. For. Res. 35: 1061-1070.

• North, M., B. Oakley , R. Fiegener, A. Gray and M. Barbour. 2005. Influence of light and soil moisture on Sierran mixed-conifer understory communities. Plant Ecology 177: 13-24.

• Ma, S., J. Chen, M. North, H. Erickson, M. Bresee, and J. Le Moine. 2004. Short-term effects of experimental treatments on soil respiration in an old-growth, mixed-conifer forest. Environmental Management 33(1): 148-159.

• North, M., J. Chen, B. Oakley , B. Song, M. Rudnicki, and A. Gray. 2004. Forest stand structure and pattern of old-growth western hemlock/Douglas-fir and mixed-conifer forest. Forest Science 50 (3): 299-311.

• Oakley, B., M. North, J. Franklin, B. Hedlund, and J. Staley. 2004. Diversity and distribution of Frankia strains symbiotic with Ceanothus in California . Applied and Environmental Microbiology 70: 6444-6452.

• Oakley B, M. North, and J. Franklin. 2003 The effects of fire on soil nitrogen associated with patches of the actinorhizal shrub Ceanothus cordulatus. Plant and Soil 254: 35-46.

• Maloney, P. and D. Rizzo. 2002. Dwarf mistletoe-host interactions in mixed-conifer forests in the Sierra Nevada. Phytopathology 92: 597-602.

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