# Forest Restoration in the Northern Sierra Nevada:
# Thinning Effects on Forest Structure, Microclimate, Fuels and Shrubs.

Study Plan for Vegetation Module of Plumas-Lassen Administrative Study
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*Current conditions in most low-to-middle elevation forest of the Sierra Nevada are unacceptable in terms of wildfire hazard, diversity, and sustainability…most people would agree that these forests should be less dense, have less fuels, and have more large trees (Weatherspoon 1996: Sierra Nevada Ecosystems Project)*

A century of fire suppression, forest management practices, and a warmer and moister climate have left Sierran forests with many dense stands of small diameter, shade-tolerant, fire-sensitive trees (McKelvey et al. 1996). This change in forest and fuel conditions has shifted the fire regime from frequent low-intensity, small-scale ground fires (Stephens and Collins 2004) to large-scale, intense, crown fires. These fires poise a substantial threat to rural communities and can convert forested landscapes to shrub fields that persist for decades (McDonald and Fiddler 1995). One management approach to restoring forest conditions and reducing fire intensity is to use thinning and gap-creation to increase the proportion of large fire-resistant trees and encourage more shade-intolerant regeneration (e.g., Herger-Feinstein Quincy Library Group Forest Recovery Act ). The vegetation module of the Plumas Lassen Administrative Study (PLAS) will focus on the effects of fuel treatments on forest structure and composition, understory microclimate and forest succession because changes in these conditions will define how fire and the developing forest will respond to restoration efforts.

Thinning alters stand structure, modifying the forest microclimate and affecting whether trees, shrubs or grass regenerate treated areas. There is, however, little information on the effects of thinning on microclimate in Sierran forest. A summary of Sierra fire-silviculture relationships (Weatherspoon 1996) cites only one reference, a 1955 conference abstract, which conjectures that “the greater the stand opening, the more pronounced the change in microclimate is likely to be”. Microclimate conditions (e.g., light, temperature, humidity, and heat flux) directly affect fuel moisture and fire behavior, and as such are important inputs to fire models (Agee 1978, Finney 2001). Changes in microclimate will also have a significant influence on forest vegetation affecting whether treated areas regenerate with shrubs, shade-tolerant trees or fire-resistant pines. Understanding how thinning and other forest restoration actions affect forest succession across resource gradients in the PLAS landscape is essential for determining the long-term effects of fuel treatments.

To address these questions, we will conduct studies at the stand and landscape levels. First we will focus on a stand-level manipulation experiment to understand how different levels of canopy reduction affect microclimate, fuels and forest succession. Concurrent with this experiment we will develop a network of vegetation plots across the PLAS landscape to investigate how resource gradients affect the model of stand structure, microclimate and forest succession developed in the manipulation experiment. Specifically we will examine the following ideas and test specific hypotheses for each:

1) The relationship between canopy cover and microclimate is linear (Weatherspoon 1996): alternatively, there may be a canopy cover threshold where rapid changes in microclimate occur, or an asymptotic approach to maximum levels

2) Changes in understory plant communities, and rates of recovery, are proportional to changes in canopy cover and stem density from thinning and restoration treatments. Alternatively, there may be disturbance thresholds which when exceeded result in new, enduring plant communities (Figure 1).

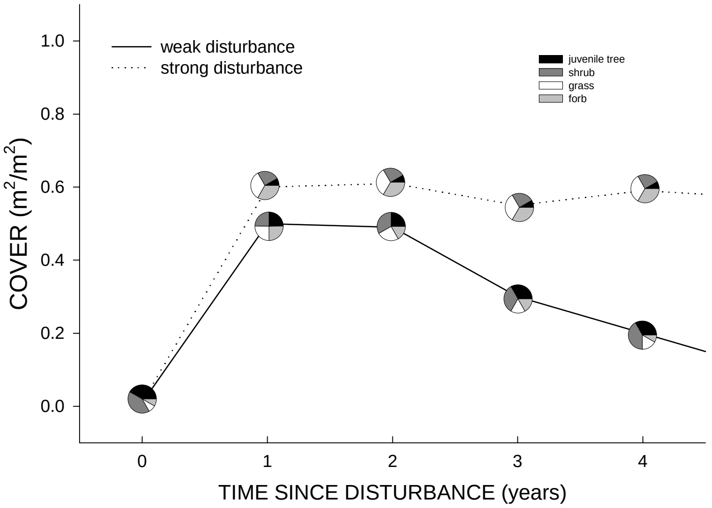


Figure 1. Hypothetical change in understory plant cover and life-form spectrum (tree, shrub, grass, forb) with respect to disturbance intensity. The higher intensity disturbance results in a permanent change to the ecosystem, but the lower intensity disturbance results in a steady change back to original cover level and proportional representation of plant life forms.

3) Across the PLAS landscape, fuel treatments will produce a greater change and slower recovery in forest composition and structure in ecotones between forest types. Alternatively, the greatest changes may occur in areas where abiotic stress is high – for example, areas of serpentine soils or steep, southwest aspect sites.

In the short-term, fuel treatment effectiveness will depend on how thinning changes stand-level microclimate and fuel conditions because these are key drivers of fire behavior. Fuel treatments, however, will also have a long-term impact on forest succession and a cumulative effect on wildlife habitat and connectivity within the PLAS landscape. To bridge these temporal and spatial scales, the vegetation module will focus on investigating mechanistic (i.e., microclimate) effects of fuel treatments at the stand level and forest successional response at both stand and landscape levels.

## Background

Sierra Nevada forests are maintained by complex feedbacks between fire, microclimate, species traits, site conditions and forest management. The Plumas Lassen Administrative Study will impact these feedbacks from stand to landscape levels and with both immediate and long-term effects. We cannot study the effects of fuel treatments on vegetation and fire across all these spatial and temporal scales. Rather we've used current ecological theory and an extensive review of Sierra Nevada literature to focus our study on microclimate and forest succession because these will directly affect fuels, wildlife habitat and future forest conditions. In particular we've focused our studies to build upon extensive silvicultural research on forest and shrub response to thinning and spacing trials conducted at Challenge and Blodgett Experimental Forests (McDonald 1966, Isik 1978, Kosco and Bartolome 1983, McDonald and Abbott 1994, Helms and Tappeiner 1996, McDonald and Reynolds 1999, Battles et al. 2001, York et al. 2003). This work gives us a good basis for predicting forest response to fuels treatments under conditions where species composition and site productivity are more controlled. The challenge of the PLAS project is to examine multi-species forest response to thinning across the landscape's variable site and soil conditions. We also want to examine the cumulative effects of fuel treatments on landscape habitat and connectivity over different time steps into the future. To do this we need to extrapolate silvicultural models of stand dynamics to a broader array of conditions. The focus on microclimate at the stand level is intended to investigate a key mechanism behind these models by quantifying the relation between canopy structure and abiotic conditions that directly affect forest stand development. With a better understanding of this mechanism, we will develop a model of how the PLAS landscape responds to fuel treatments using ecological concepts of resilience and resistance in plant succession.

### *Canopy cover effects on microclimate, fire, forest succession and wildlife habitat*

Tree canopy cover is an important influence on plant succession and ecosystem function, and is a stand condition directly manipulated by management practices. Canopy cover can strongly influence successional trajectory because it determines the partitioning of radiant energy between understory and overstory, affects the vertical distribution of soil moisture, and controls the regeneration environment. Microclimate experiments in areas with contrasting canopy cover in southern boreal and temperate evergreen forest have consistently showed lower air and soil temperatures, higher humidity, and lower diurnal fluctuation in forest than in large openings (Chen et al. 1993, Carlson and Groot 1997). Small gaps (e.g., 40 $m^2$ or 436 $ft^2$) have microclimate conditions approximating those of unbroken forest, and they change in proportion to increasing gap size (Gray et al. 2002). Soil temperatures were driven mainly by direct solar radiation, but air temperatures differed little among gap sizes.

Canopy cover also affects a stand's fire behavior. The higher temperatures and understory wind-speeds that occur at lower canopy cover levels are believed to lead to increased fuel drying and faster propagation of fire through the understory (Agee et al. 2000). There is, however, little information on how the scale of canopy reduction affects fire conditions. Group selection openings, which will be widely used in the PLAS area, are heavy thinnings but at a small scale (0.2-1 ha). We don't know if their open overstory will produce hot daytime temperatures (Smith et al. 1997) and very dry fuels or whether the surrounding forest will buffer microclimate conditions and fuel drying?

Canopy cover can have a strong effect on understory vegetation because it controls the amount of solar radiation and precipitation that reaches the forest floor. Most studies have focused on gaps and suggested an effect of gap size. Small gaps may favor saplings over shrubs (McDonald 1976, McDonald and Abbott 1994), and large gaps can favor establishment and growth of graminoids and shrubs over saplings (McDonald 1999). Growth of conifer saplings in gaps has been shown to increase with increases in gap size up to 2 ha (York et al. 2003). Gap size has also been shown to influence regeneration composition with an increase in shade-intolerant trees with gap size (Oliver and Dolph 1992).

As a direct control on microclimate, several studies suggest canopy cover influences habitat quality for forest wildlife. Spotted owl nesting, reproduction and preferred foraging habitat has been associated with stand-level canopy structure and its potential at moderating climate conditions (Forsman et al. 1984, Forsman et al. 1996; North et al. 2000). Several small mammals, including the principal prey of the owl, the northern flying squirrel, are influenced by canopy cover and shrub distribution (Carey et al. 1992). Changes in songbird diversity and abundance have been documented in response to canopy thinning and shrub cover increases (Siegel and DeSante 2003). Changes in microclimate conditions from fuel treatments are likely to have a significant impact on wildlife habitat, yet we have little current information to estimate what those effects may be.

### *Fuel treatments effects on succession*

Resilience is the ability of an ecosystem to rebound from external perturbations without significantly changing structure, composition and function (Peterson 2002). Some ecosystems are characterized by stable states which periodically undergo transitions from one state to another. Strong positive feedbacks maintain stability of ecosystem function and species composition for long periods (Chapin et al. 1996).

Sierran forest response to fuel treatments will vary with thinning intensity and site conditions. In some cases the forest may return to a state of shade-tolerant regeneration, while in other cases treatments may flip the ecosystem to a different state, e.g., one dominated by shade-intolerant tree regeneration, or even by shrubs. Historically, Sierran forests were fairly resilient to frequent fire disturbance at least in part because they contained more drought tolerant (Lopushinsky 1969, Jackson and Spomer 1979), shade intolerant and fire resistant (van Mantgem and Schwartz 2002) pines (*Pinus ponderosa, P. Jeffreyi* and *P. lambertiana*). Frequent, extensive fires (Beaty and Taylor 2001, Stephens and Collins 2004) helped to maintain the open conditions and bare mineral soil surfaces that selected for regeneration of these species. The loosely packed, long needles of pine are believed to burn more readily than the tightly packed, short needles of white fir (Miller and Urban 1999). Currently, however, forests have shifted to a composition more dominated by white fir and incense cedar, and this state has proved to be fairly resilient under modern conditions. Both species are shade-tolerant, and in the absence of fire can readily regenerate under existing dense canopies (Oliver and Dolph 1992). White fir and incense cedar also can change the nature of the disturbance regime so that when fire does occur it favors their re-establishment. Ladder fuels and high mortality from drought events can increase fuel loads and favor crown fire. Extensive brush-fields often form following crown fires and under these conditions white fir is often the only species that can regenerate, albeit slowly (McDonald and Fiddler 1995).

The challenge of the vegetation module is to identify how forest conditions can best be redirected from their current, stable state toward a historic condition resilient to frequent fire perturbation. We anticipate that forest resilience and response to fuels treatment will vary with different growing conditions across the PLAS landscape. Dense-canopied forests dominated by shade-tolerant regeneration may prove quite resilient to moderate thinning, while open, droughty forests may easily shift to shrub communities. Resilience is also a measure of long-term sustainability. Current projections are that shaded fuelbreaks will require additional management after 10 years to maintain their effectiveness (Peña 2004). Long-term restoration, however, will hinge on restoring forests to a state of reliance that, with frequent underburning, can be maintained.

Sierran forests are characterized by strong gradients of moisture availability, temperature, and solar radiation, and these gradients affect plant species distribution (Whittaker 1960, Stephenson 1998, Urban et al. 2000). In many environments as the harshness of the abiotic environment increases, so does the importance of facilitation, or positive beneficial interactions among plants (Bertness and Shumway 1993, Brooker and Callaghan 1998, Callaway 1998, Callaway et al. 2002). The relative importance of competition and facilitation across gradients has not been well researched in the Sierra Nevada, although some evidence suggests that tree-shrub competition becomes more intense on harsh sites (Oliver and Powers 1978, Conard and Sparks 1993). We hypothesize that the ecosystem response to perturbation (i.e., resilience) changes across abiotic gradients in the northern Sierra Nevada, possibly as a result of a changing balance of competition and facilitation among plants. We predict that resilience to changes in canopy cover will be lower on harsh sites, and that the threshold for changes in ecosystem state will be decreased on such sites. Plant canopy modification of the microclimate should be strongest on harsh sites where water availability is low or temperature stress is high, and non-linear effects may occur with comparatively minor changes in canopy cover.

# Methods

## STAND-LEVEL STUDY: EFFECT OF OPENING THE CANOPY ON UNDERSTORY RESILIENCE AND MICROCLIMATIC DRIVERS

### *Experimental design*

We have designed a manipulative experiment to evaluate the effects of changes in canopy cover on understory microclimate and growth of shrubs and young trees. The experiment is in cooperation with small mammal researchers of the Plumas-Lassen Administrative Study and the Ecosystem Management team of the Mt. Hough Ranger District of Plumas National Forest. Treatments will consist of an unmanipulated control (60-70% canopy cover), two levels of partial canopy removal (thinning to 50% and 30% cover), and complete canopy removal in group selection openings. Plots are located in mixed-conifer forest. There will be three replicated blocks of the four treatments.

Several operational constraints dictated the location of experimental blocks and how plots were selected. Plots scheduled for thinning are located within areas already planned for fuels-reduction treatments (also known as Defensible Fuels Profile Zones or DFPZs), and control plots were located in adjacent but untreated areas. At each block three stands with similar structure and canopy conditions have been selected. Criteria for establishing plots were they should 1) be 300 × 300 m (~22 acres) to provide a 100 m buffer zone around the core grid where measurements are done, 2) be without roads or surface water, 3) have a significant component of ponderosa or Jeffrey pine in addition to the more common white fir component, and 4) be at least ½ mile from other plots to prevent overlap of small mammal home ranges. No single plot met all these criteria, and some compromises on buffer size and the presence of old skid trails were made in selecting some of the plots. Complete canopy removal plots were selected from among ones that had already been slated for harvest by the Ranger District. These were selected by choosing the nearest, large (1.5 – 2 acres) group select plot with similar forest and site conditions.

After two summer field seasons of measurements, two stands in each block will be mechanically thinned (the experimental treatment, thinning to 30% or 50% canopy cover, has been randomly assigned to the two plots in each block) and the group selection harvest will take place. In both cases, a combination of *low thinning* and *crown thinning* (Smith et al. 1997) methods would be applied to achieve the desired canopy cover as uniformly as possible across each plot. Harvesting would be done in all size classes >3’ in height and ≤30 inches DBH. Trees harvested would be those with ladder fuels, interlocking crowns, disease, and/or damage. Ground based mechanical harvesting equipment would be used to accomplish the thinning. Stand marking will be done cooperatively by PSW and ranger district personnel. Some marking will be done in test areas in the winter and spring of 2004/2005 to ensure that prescriptions will achieve the desired canopy cover. Merchantable material will be hauled to landings outside of the 22 acre stands. Non-merchantable material will be scattered. All plots, including three control plots that will receive no thinning treatment, will be underburned within one year after thinning treatment is completed on thinned plots and group selection areas.

*Measurements: microclimate*

Nine permanent sample points in each plot are on a 3 by 3 grid, and spaced 50 m apart. A series of measurements will be taken biweekly from mid-May to the end of June, then monthly until the end of October. At each of the nine sample points per plot we will measure 1) midday soil temperature, 2 cm and 5 cm depth (thermistor thermometer, Oakton Acorn Temp 5 Digital Temperature Meter), 2) volume soil wetness in organic horizon (gravimetry) and 0-10 cm mineral soil (step-pulse time-domain reflectometry, Campbell Scientific Australia 620), and 3) fuel moisture in 10- and 100-hour fuels (to 5/16" depth) using a portable moisture meter (J-2000, Delmhorst Instrument Co., Towaco NJ). Fuels will be labeled so that repeat measurements are made on the same items.

To measure understory microclimate, temperature and humidity sensors (Hobo H8 Pro Series Temp/RH, Onset Computer Corporation, Pocasset MA) have been installed in radiation shields at 2 m height at three of the 9 sample points, selected to cover the range of canopy openness encountered. An additional set of sensors will be added at these same sites at 0.1 m above the ground surface in May 2005. On the sensors 2 m above ground, data loggers take readings at 16 minute intervals throughout the year. On the sensors 0.1 m above the ground, data will be collected only during the summer season. An anemometer has been installed at 2 m above ground in each plot, and continuously recording soil temperature, moisture (0-20 cm), and PPFD sensors have been added to four plots in order to provide increased temporal resolution to aid in interpreting the periodic environmental measurements.

To assess spatial variability in microclimate, an array of 25 temperature/humidity sensors will be installed on a 25 by 25 m grid for a two week period. Two plots will be sampled during each 2 week period and comparisons between plots will be for relative differences between sensors during a recording period.

Hemispherical photographs will be analyzed with GLA software. For each photograph we used four metrics calculated by the program: canopy closure and direct, diffuse, and total photosynthetically active photon flux density (PPFD) (μmol $s^{-1}$ $m^{-2}$). PPFD is calculated from the latitude, longitude, and elevation of the study area and the tracking angle of the sun over the course of a year. We will use PPFD values as an approximation of the relative difference in understory light conditions between sample points.

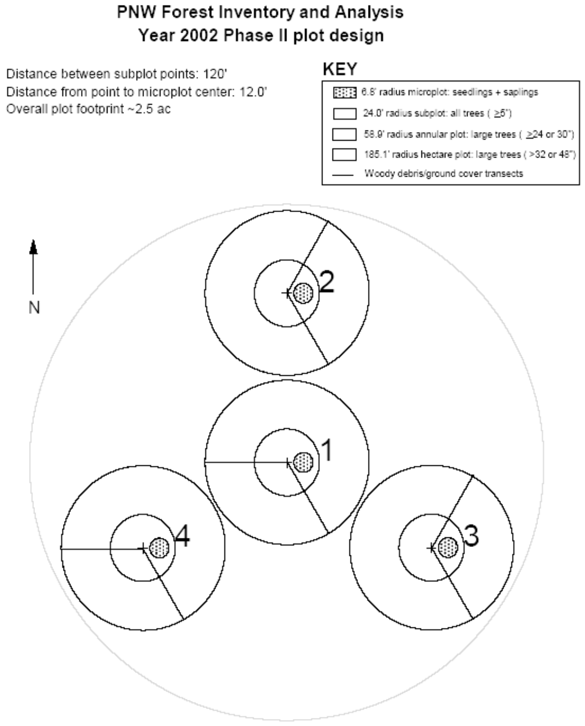
*Measurements: understory plant community and canopy openness*

The understory plant community will be measured at two scales in each plot. In a 20 $m^2$ circular plot displaced to the side of each of the nine sample points, we will visually estimate cover of all herbs and shrubs by species. Within each treated stand there is an additional rectangular grid of 120 points at 10 m intervals where trapping is done by small mammal researchers. Canopy openness has been measured at each point using a hemispherical-lens photograph. Within a 2 m radius of each trapping-grid point, shrubs are identified to species and measured for height, width, and cover. Understory surveys will continue annually at these sample points but will be modified to include plant lifeforms other than shrubs.

Cover of six plant life-forms will be visually estimated within a 2 m radius of each trapping-grid point, using the Daubenmire cover-class scale (McCune and Grace 2002). An additional network of sampling stations will be established in group-selection openings. Cover from five plant life-forms (needle-leaved trees, broad-leaved trees, shrubs, forbs, and grasses) and two functional groups (shade-tolerant and shade-intolerant conifers) will be monitored. We will identify the species contributing the most cover to each life-form group at each sampling point. Transmittance of light through the shrub layer at each trapping grid point will be measured by placing a linear PPFD sensor (LiCor 191, Lincoln NE) at breast height then at the ground surface, integrating PPFD over 10 seconds at each height, and dividing PPFD at the ground surface by PPFD at breast height.

*Measurements: canopy cover and forest structure.*

To document initial forest structure and changes subsequent to thinning, we will set up inventory subplots following Forest Inventory and Analysis (FIA) protocol (see Figure 3 and description below). To assess changes in fuels, we will establish fuel transects within each subplot. These fuels transects will be consistent with those established by the Fire and Fuels module of the Plumas-Lassen Administrative Study. Downed fuels will be measured each year using standard protocol (Brown 1978).



| From | To | Horizontal Distance | Azimuth |
|---|---|---|---|
| Subplot 1 | Subplot 2 | 120.0 ft. | 360 |
| Subplot 1 | Subplot 3 | 120.0 ft. | 120 |
| Subplot 1 | Subplot 4 | 120.0 ft. | 240 |
| Subplot 2 | Subplot 3 | 207.8 ft. | 150 |
| Subplot 2 | Subplot 4 | 207.8 ft. | 210 |
| Subplot 3 | Subplot 4 | 207.8 ft. | 270 |

Figure 3. Layout of forest inventory and analysis plot.

We will measure canopy cover in the 100 m X 100 m (1 ha) microclimate sampling area of each each plot using a sighting tube or vertical densitometer (Geographic Resource Solutions, Arcata CA). We will record presence or absence of overhead canopy cover at 5 m intervals throughout the 1 ha plot (400 observations) and express canopy cover as number of points with canopy cover overhead divided by 400 (i.e, the number of observations). Canopy cover will also be estimated from FIA plot data using allometric equations developed by Gill et al. (2000). (FIA plots are located in the same place as the 1 ha microclimate sampling area but have a different spatial configuration.) To assess canopy closure over the nine microclimate sampling points we will use three methods: spherical densiometer, moosehorn, and analysis of hemispherical photograph. All measurements will be taken at each sample point (n = 9) before and after thinning treatments.

*Data analysis*

1) Among-plot analyses of microclimate. We will use several methods for analyzing microclimate data, depending in part on the response variable. One key variable, soil moisture, is expected to be fundamentally non-linear in its response to canopy cover reduction. There are physically imposed lower and upper limits on soil moisture, and these limits are likely to be approached asymptotically. Therefore, a sigmoid curve is the best model for the expected response pattern (**Figure 2**).

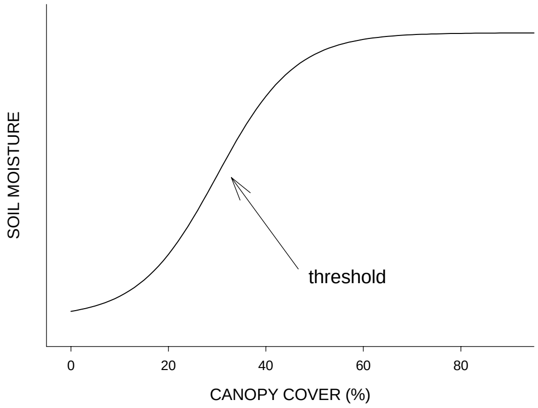


**Figure 2. Hypothetical relationship between soil wetness and canopy cover.**

We will fit the surface soil moisture and canopy cover data to a general equation for a sigmoid curve,

$$\theta = \theta_{min} + \frac{\theta_{max}}{1 + e^{-\left(\frac{C - C_t}{b}\right)}} ,$$

using maximum likelihood estimation in the non-linear mixed procedure of SAS (SAS 1999). Soil wetness ($\theta$) and canopy cover ($C$) are variables, and there are four fitted parameters: $\theta_{\text{min}}$ and $\theta_{\text{max}}$ for minimum and maximum soil wetness, $C_t$ for threshold canopy cover, and $b$ to control the steepness of the sigmoid curve. Sequential, monthly measurements on the same plots will be treated as repeated measures. Although the number of data points will be few, we will be guided in model fitting by specifying realistic upper and lower bounds for parameters gleaned from the literature. We will test whether canopy-cover threshold and steepness parameters differ among the three blocks. We will test this model against a simpler, unconstrained linear formulation of the cover-surface soil moisture relationship using Akaike's Information Criterion to select the most parsimonious model.

For the remaining microclimate variables, we will use repeated-measures analysis of variance followed by a multiple comparison procedure to test for differences among the experimental treatments after thinning or canopy removal. Variables will be absolute air humidity (mass of water vapor per volume of air), and air temperature at 0.1 and 2 m height above the soil surface). Because we believe that extreme temperatures are of particular biological significance, temperature data will be analyzed as the average maximum daily temperature of the 10 hottest days per month. Analyses will be done in SAS using the Mixed procedure, with time as a repeated measure.

We will use non-parametric multiple regression (LOESS; Neter et al. 1996) models to assess the linear and nonlinear relationships between the three measures of canopy closure and the environmental variables. We will also assess whether a combined measure of microclimate can be built using all or a set of the environmental measurements. We will assess combinations by the proportion of variance explained by the 1st eigenvector in a principal components analysis. We will use eigenvector scores from the best model of the combined microclimate variables to evaluate canopy closure measurements against this synthesized measure of microclimate. The analysis will be repeated with 1-, 10- and 100-hour fuel moisture as the dependent variable.

2) Within-plot analysis of microclimate variables. We will focus on the range and spatial pattern of microclimate variability. Using the 25 sensor array, we will compare the maximum/minimum and standard deviation for surface temperature and relative humidity. We will also examine the strength and range of spatial autocorrelation in these microclimate measures using variogram analysis.

*Resistance, resilience, and trajectory of the understory community.*

The understory is expected to increase in plant life-form diversity and cover after canopy opening treatments, and the change is expected to be proportionate to the intensity of disturbance (e.g., Halpern 1988). We predict that at the highest levels of canopy removal, the zone of resilience will be surpassed and that quantitatively new communities will emerge, and that at lower levels of canopy removal, the zone of resilience will not be surpassed and in time the former community composition will be reestablished (Figure 1). At the level of plant functional group, we predict that the ratio of shade-intolerant to shade-tolerant conifers in the understory will increase in proportion to degree of canopy opening.

Change in understory plant life-form composition over time with respect to canopy opening treatment will be analyzed by reducing life-form spectrum (i.e., composition) to a single variable then applying mixed-model analysis of variance (Von Ende 2001). Initial surveys of life-form spectrum will yield data from ~1500 sampling points. These will be reduced using an appropriate eigenvector ordination technique (e.g., nonmetric multidimensional scaling; McCune and Grace 2002) to yield a scale that summarizes the life-form spectrum. To obtain the value of this variable for a plot, we will use the average value from each of the >100 sampling points with the plot. The mixed-model analysis of variance will have canopy-opening treatment as a fixed, ordinal effect. The part of the landscape where a given group of plots is located will be a blocked, random effect, time (year in which sampling was done) will be a repeated measure. Selection of an covariance structure is a necessary step in mixed-model analysis, and we will select one which accounts for the influence of initial, pre-treatment life-form spectrum on subsequent values in a given plot.

The first analysis of changes in understory plant communities will be carried out primarily with respect to canopy cover, but a variety of ancillary data will be available to explore alternative hypotheses and to suggest the proximate causes of understory plant community change. Important alternative hypotheses include the following: 1) degree of shrub vs. tree dominance is a priority effect (Harper 1961), such that lack of masting by surrounding overstory trees within a few years of canopy-opening treatment will result in shrub dominance (Helms and Tappeiner 1996); 2) proportion of tree, shrub, and grass cover in semi-arid environments is determined by vertical and horizontal distribution of soil water (Breshears and Barnes 1999); and 3) establishment of trees is determined by small-mammal activity (e.g. Schnurr et al. 2004). Ancillary datasets for our site pertain to 1) microclimate and soil wetness, 2) stand structure and overstory species composition, 3) annual cone production in conifers, and 4) small mammal community.

Measurements of forest structure will not be analyzed with inferential statistics but will be used as descriptive measures of the stands. Stands will be summarized in terms of tree species richness, and basal area by species, and the changes due to management.

We will assess canopy cover by pooling all data at the stand level. Each measure of canopy cover will then be analyzed with LOESS models against mean microclimate values ($N = 9$). In this stand-level analysis we will include basal area as a potential predictor of canopy cover. We will also examine whether different measures of canopy cover are correlated with understory herb and shrub cover, a multi-layered canopy (measured as the stand's coefficient of variation of the height to the base of the live crowns), and foliage volume.

### *Implications for management*

This study will investigate how measures of canopy cover and canopy closure obtained with a variety of instruments relate to one another. It will document how reductions in canopy cover will affect microclimate, which will help managers anticipate the probability of successfully regenerating desired species under the various treatments. Finally, it will provide better understanding of how current thinning prescriptions affect fire risk, and influence successional processes.

## STUDY: ECOSYSTEM RESILIENCE AND FACILITATION ACROSS LANDSCAPE GRADIENTS

Species composition and growth of Sierran forests is governed by variation in the abiotic environment (e.g. slope, aspect, and soil depth) across many spatial scales (Stephenson 1998, Urban et al. 2000), so it is probably that resilience to disturbance is governed by these factors as well. We have designed a study to test this idea in east-side pine forest, taking advantage of a series of recent group-selection harvest openings in the canopy. We will extend this study to other parts of the landscape as additional group-selection openings are created. Our study design is based on a number of concepts that have been proposed regarding the function of communities along environmental gradients in semi-arid environments. First, facilitation, or the amelioration of environmental conditions by organisms is thought to increase in importance in proportion to environmental harshness (Bertness and Callaway 1994), and provision of shade is a key element of facilitation in these systems (Breshears et al. 1998, Maestre et al. 2003). Second, consistent asymmetry of plants and resources around focal organisms has been proposed as being evidence for facilitation of the abiotic environment (Haase 2001, Phillips and Barnes 2003). Third, the vertical distribution of soil moisture is hypothesized to be a key factor regulating the balance between trees, shrubs, and grasses in semi-arid environments (Breshears and Barnes 1999).

East-side pine in the Sierra Nevada is poised between mixed-conifer and Ponderosa pine forest to the west, and arid shrub steppes to the east. In 2001-2002 a series of ~160 group-selection openings (1-2 acres in size) were created in east-side pine on the Beckwourth District of the Plumas National Forest as part of a new forest management initiative (the Herger-Feinstein Quincy Library Group Forest Restoration Act). Group selection openings were randomly selected using a GIS and cover a range of slopes (up to 25%) and aspects. We propose to choose a subset of these openings stratified by slope and aspect and carry out a suite of measurements to assess for evidence of resilience and facilitation.

Measurements for the first study will be done in late summer 2004. Thirty group-selection openings will be chosen. Each group-selection opening will be paired with a nearby, un-harvested forest site by going to the center point of the group-selection opening, randomly selecting a compass azimuth, proceeding 150 m, and choosing the nearest tree of breast-height diameter > 20”: the paired plot will be centered on this tree. In each group-selection opening or paired forested site we will establish a circular sampling plot 5 m in radius, with eight sampling points evenly spaced around the circle. At each point we will measure surface soil wetness (0-10 cm depth) and will classify the plant life-form spectrum within a circle of 2 m radius using methods presented in the stand-level study. Two additional measurements will be taken at the south-west and north-eastern sampling points; soil wetness will be measured across the soil depth profile (to 2 m depth), and a hemispherical photograph of the forest canopy will be taken for estimation of irradiance. Additional soil measurements will be done at each plot: organic horizon depth, bulk density of mineral soil in 0-10 cm, pH, and nitrogen mineralization rate.

We have a series of hypotheses and predictions. We expect that surface-soil wetness will be higher in forest than in opening, and that the difference will increase on paired sites with increasing southwesterly aspect. We also predict that local anisotropy of soil wetness (the difference in soil wetness between the sampling points in the north-east and south-west halves of each sampling circle) will be greater in forest than in opening, and will increase with increasing southwesterly aspect. We will accept positive findings in these regards as providing evidence for facilitation. We predict that vertical soil depth profiles will show a shift to dryer surface soils and wetter subsoils in openings compared to forested sites. Finally, we expect that openings of southwesterly aspect will show slower recovery of the vegetative community, and more of a shift to grasses and shrubs, than openings of northeasterly aspect.

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