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FINAL PROJECT REPORT

EFFECTS OF FOREST BIOMASS FUEL REDUCTION TREATMENTS ON BIRDS AND SMALL MAMMAL COMMUNITIES IN THE SIERRA NEVADA:

RESEARCH TO INFORM FOREST BIOMASS ENERGY PRACTICES

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PREPARED BY:

Primary Author(s):
Patricia N. Manley
Traynor G. Biasiolli
Angela M. White

USDA Forest Service
Pacific Southwest Research Station
1731 Research Park Dr.
Davis, CA 95618
Phone: 530-750-1700 | Fax: 530-747-0241
http://www.fs.fed.us/psw/

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Prepared for:

California Energy Commission

Lillian Mirviss
Joe O'Hagan
Contract Manager

Aleecia Gutierrez
Office Manager
Energy Generation Research Office

Laurie ten Hope
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Robert P. Oglesby
Executive Director

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PREFACE

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ABSTRACT

In 2009, staff members of the Forest Service's Pacific Southwest Research Station modeled the ecological and economic impacts of a biomass energy industry in the Sierra Nevada. These biomass energy facilities would be supplied by fuels reduction and forest thinning operations, one of the primary means of reducing high-intensity fire risk in this region. However, this research identified several knowledge gaps, including a lack of detailed knowledge regarding wildlife response to fuels management. In this project, the researchers examined changes in abundance and community composition for both birds and small mammals following fuels treatments at two different study areas in the Sierra Nevada. The work was conducted on the Sierra National Forest and the Lake Tahoe Basin Management Unit and spanned a range of treatment intensities and pre-treatment conditions. There was clear variation across species in their responses to treatments, and site managers will need to account for the responses of management-relevant species at their locations. In spite of some variability at the species level, the researchers observed primarily positive responses of both birds and small mammals to the range of fuels management intensities found across this region. At the two study areas examined, birds appeared to respond most positively to the fuels treatments found on the Sierra National Forest, and mammals fared better following the treatments implemented on the Lake Tahoe Basin Management Unit. These patterns may be driven by several factors, including differences in species composition, treatment intensities, or pre-treatment forest conditions. However, the work indicates that both bird and small mammal communities are likely to benefit modestly from more widespread fuels treatments and that forest managers can meet fuels objectives without significantly diminishing diversity or abundance of these wildlife communities.

Keywords: Fuels treatment, wildlife, Sierra Nevada, small mammal, bird, wildfire, biomass energy

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EXECUTIVE SUMMARY

Introduction

Before fire suppression began in the early 20th century, low- to moderate-intensity fires occurred regularly in the mixed-conifer forests of the Sierra Nevada. Due primarily to wildfire suppression, forests throughout this region now have high levels of flammable materials and face increased risk of high-intensity, large-scale wildfires. Forest managers are attempting to reduce fuel loads throughout large portions of the region, primarily through mechanical or hand removal of woody fuels to moderate fire behavior and protect human infrastructure and other resource values. These projects typically target small diameter trees and other vegetation, which have little commercial value. Establishing biomass energy facilities in or near the Sierra Nevada has been proposed as a means of providing a market for these small woody fuels, which would help fund these fuels treatments and allow forest managers to apply these treatments over a larger area of fire-suppressed forests. However, the impacts of more widespread fuels management on other components of the forest, such as native wildlife, have not been adequately explored within the Sierra Nevada.

Project Purpose

This research examined impacts of fuels treatments, as currently applied within the Sierra Nevada, on bird and small mammal communities. The researchers studied wildlife response to fuels treatments at two locations that spanned a diversity of forest types and featured fuels treatments of markedly different intensities. This information can help forest managers better decide on the timing, location, and intensity of fuels treatments, and understand how these decisions may influence populations of a range of management-relevant species.

Project Results

The researchers examined responses to fuels treatments for birds and small mammals at both the community and species levels. Of note, they found that:

- Overall bird abundance increased following fuels treatment, significantly so at one study area.
- Abundance of small mammals increased significantly following treatment at one study area and remained neutral at the other
- Out of 45 species examined, the researchers observed significant increases in abundance for 11 bird species following treatment and significant declines in five species. One additional species showed a mixed response, increasing significantly at one study area while declining significantly at the other, suggesting that its response varies substantially based on treatment intensity.
- The researchers investigated treatment response of 13 species of small mammals and found significant responses in two species. The yellow-pine chipmunk increased

significantly following treatment, and the northern flying squirrel declined significantly. Small mammal population showed tremendous fluctuations but were largely not associated with fuels treatments, indicating that other resources have greater influence over population trends of many species.

- Many of the species reported in this study had not been previously examined for response to fuels treatments. Additionally, the results for several species differed from the treatment responses reported elsewhere in the scientific literature, highlighting the importance of regionally-specific research in informing management decisions.

Project Benefits

The risk of high-intensity wildfire is one of the more pressing concerns for land managers throughout the Sierra Nevada, and this risk is projected to grow under future climate conditions. Impacts from these large-scale wildfires extend beyond the forest immediately impacted by fire, and include negative effects to regional air quality, infrastructure such as municipal drinking water sources, electricity transmission and distribution lines, and tourism-dependent economies. More effective fuels management would minimize many of these negative effects associated with high-intensity wildfires.

Forest managers have previously been constrained by a poor understanding of wildlife responses to the fuels management approaches implemented in the Sierra Nevada. This work helps close this knowledge gap and presents information on the impacts of forest fuels management on a wide diversity of birds and small mammals found throughout the Sierra Nevada. Results presented here will allow managers to better plan timing, location, and intensity of fuels treatments to meet fire risk and wildlife objectives, reducing unwanted impacts on infrastructure, air quality, and local economies. Reliable planning of fuels management activities will provide for more predictable availability of small-diameter fuels for potential biomass energy facilities. Presence of biomass energy facilities located within the Sierra Nevada could help offset management costs by providing a viable market for these small-diameter fuels. In doing so, a biomass energy market could help mitigate high-intensity fire risk, provide a reliable source of local energy, and maintain or enhance bird and small mammal communities throughout the region.

CHAPTER 1: Introduction

1.1 Project Background

Prior to Euro-American settlement, low- to moderate-intensity fires occurred regularly in the mixed-conifer forests of the Sierra Nevada. These frequent fires strongly influenced both the species composition and vegetation structure of these forests (Stephens and Collins 2004). However, intensive fire management beginning in the early 20th century, in concert with logging and grazing, has resulted in forests that differ substantially from pre-settlement forests (Agee and Skinner 2005, McKelvey et al. 1996). Fire-intolerant species are more common, tree stem densities have increased, and ground and ladder fuels are found at greater densities. Fire behavior has changed accordingly, as fires have grown in both scale and intensity, a change highlighted by the appearance of recent mega-fires such as the Rim and King fires (Lydersen et al. 2014, McKelvey et al. 1996). The risk of large-scale, high-intensity wildfire is now one of the most vexing concerns facing forest managers in the Sierra Nevada.

While the absence of fire has resulted in marked changes to Sierran forests, managers are highly constrained in their ability to reintroduce fire to the landscape. In addition to the heightened risk of high-intensity fires in contemporary forests, the expansion of the wildland-urban interface (WUI) and air quality concerns further limit opportunities to implement prescribed fires or allow for natural fires. Given these limitations, removal of fuels through mechanical or hand-thin treatments is the sole option available for managing high-intensity fire risk in many portions of the Sierra Nevada.

Despite these challenges, fuels management has been a top priority in the Sierra Nevada in recent years. Recent large-scale fires, such as the Rim Fire in 2013 and King Fire in 2014, have focused national attention on the risks posed by fire-suppressed forests, particularly within the WUI. The National Fire Plan, the Healthy Forests Restoration Act, and the Sierra Nevada Public Lands Management Act (SNPLMA) have made more funds available for management of fuel loads in fire-prone forests. Yet in spite of increased funding opportunities for fuels management, the availability of funds is still inadequate relative to the present need for fuels treatments. Given that fuels treatments are focused primarily on removal of ground fuels and smaller diameter trees which serve as ladder fuels, the cost of these projects typically exceed any revenue generated through sale of wood products.

One potential revenue source for these fuels projects lies in development of a regional biomass energy market. Given the volume of excess fuels throughout much of the Sierra Nevada, there is potential for establishment of biomass energy facilities within the region, which would both help offset costs of needed forest management activities and provide Californians with a reliable source of local, renewable energy. A wide array of researchers from the Pacific Southwest Research Station contributed to the Biomass to Energy report, which was funded by the California Energy Commission, and examined many economic and ecological impacts of biomass energy production in the Sierra (USDA Forest Service, Pacific Southwest Research

Station 2009). However, one of the limitations highlighted by that research was the lack of reliable information on wildlife response to fuel management and forest thinning in this region, which precluded researchers from accurately modeling impacts to habitat suitability.

Given the potential development of biomass energy facilities fueled through fuels treatments across wide portions of the Sierra, forest managers need information to better understand the likely impacts associated with these projects. In this project, the researchers aim to fill existing information gaps regarding the response of wildlife to fuels treatments, with a particular emphasis on the songbird and small mammal communities.

1.2 Current State of Knowledge

An extensive body of scientific literature addresses many issues associated with wildland fire and fuels treatments applied in frequent-fire forests. Applying these treatments is aimed primarily at modifying fire behavior and reducing risk of high-intensity fires, and corresponding research has focused on understanding how treatments influence behaviors of future fires. With respect to wildlife habitat, treatments that are primarily designed to reduce fire risk may simplify and homogenize the landscape (North et al. 2009). Removal of overstory and understory trees, more uniform spacing of residual trees, and mastication or removal of ground fuels and vegetation will likely result in significant changes in wildlife populations, particularly species that are closely associated with specific habitat features (e.g., canopy cover, snag density, coarse woody debris; Manley 2009).

Much of the prior research examining wildlife response to fuels management has been limited by the challenge of implementing prescribed burns or fuels treatments across a sufficiently large number of treatment locations. Due to sample size limitations, it was often difficult to draw conclusions except in the most abundant of species. To overcome the limits imposed by small sample sizes, Fontaine and Kennedy (2012) used a meta-analysis to examine wildlife (primarily bird and small mammal) response to fuels management from locations throughout North America. This research presented results for many species found within the Sierra Nevada, although the data used were primarily from different forest types located outside of the study region. Furthermore, the majority of data for these species came from monitoring following prescribed fires, as opposed to fuels treatments in the absence of fire. The researchers expect to build upon the work presented by Fontaine and Kennedy by presenting information for species not considered previously and determining whether fuels treatment responses within the Sierra Nevada are consistent with those found in different regions and forest types.

In prior work within the Lake Tahoe Basin, the researchers examined response of both the bird and small mammal communities to fuels treatments (Manley et al. 2012). At the community level, the researchers observed no significant change in diversity or evenness of either birds or mammals, although the researchers did observe consistent, but non-significant changes in abundance following treatment. When considering individual species, the researchers found significant treatment responses in a handful of species. However, most observed responses were non-significant, perhaps a result of sample size limitations. This project provides an

opportunity to build upon this knowledge base and draw conclusions from a more robust sample size.

1.3 Project Objectives

With this study, the researchers aimed to understand the changes to plant and animal communities in response to conventional fuels treatments in the Sierra Nevada. Specifically, the objectives were to:

- Describe changes in forest structure following fuels treatments; and
- Understand how fuels treatments may change community composition and abundance of birds and small mammals.

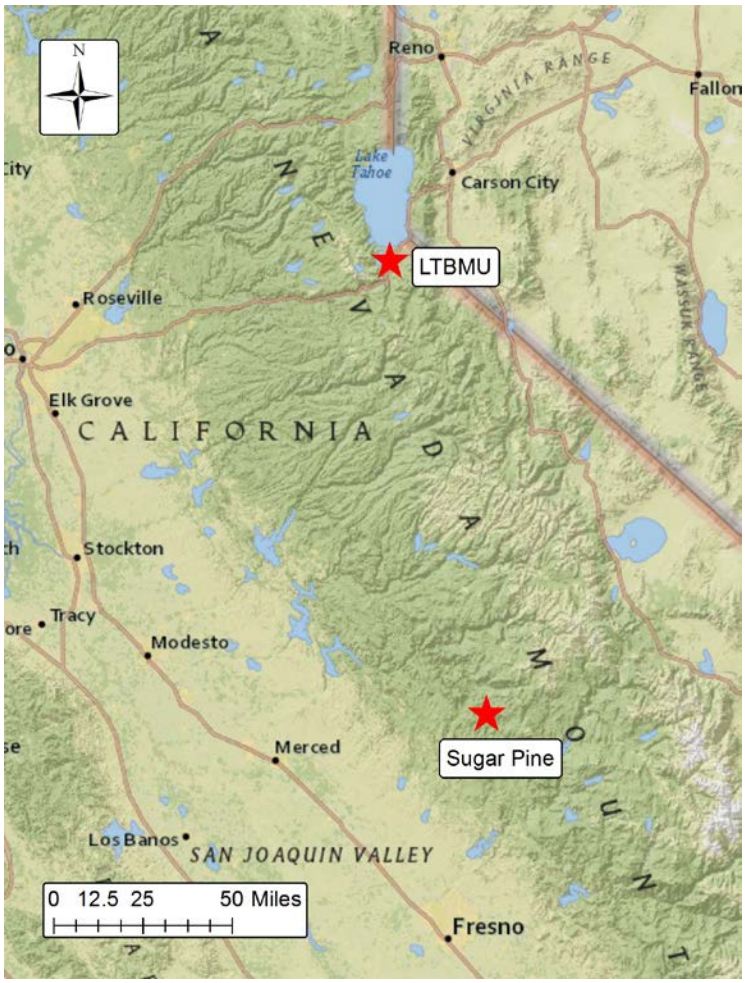
Understanding how these elements respond to fuels treatments is essential for addressing key management questions identified in the Sierra Nevada Forest Plan Amendment (SNFPA). The data for this project has been collected across a range of forest types throughout the Sierra Nevada. The resulting dataset represents a synthesis of eight years of research aimed at understanding wildlife response to fuel management as currently implemented in the Sierra Nevada.

CHAPTER 2: Methods

2.1 Study Areas

The researchers initially collected data for this report at two study areas within the Sierra Nevada, located just north of Lake Tahoe at Sagehen Experimental Forest and just south of Yosemite National Park at the Sugar Pine study area (Figure 1). They collected pre-treatment data at both locations in 2010 and 2011. Unfortunately, treatments at Sagehen have been delayed for several reasons and are only scheduled to begin in summer 2015. Given the lack of post-treatment data at Sagehen, the researchers decided to incorporate treatment response data collected under separate grants within the Lake Tahoe Basin Management Unit (LTBMU). This allows them to better meet the original intent of providing information that may inform management decisions across a range of forest types within the Sierra Nevada.

Figure 1: Sierra Nevada Fuels Treatment Study Areas



Map of the central and southern Sierra Nevada showing the location of our two study areas.

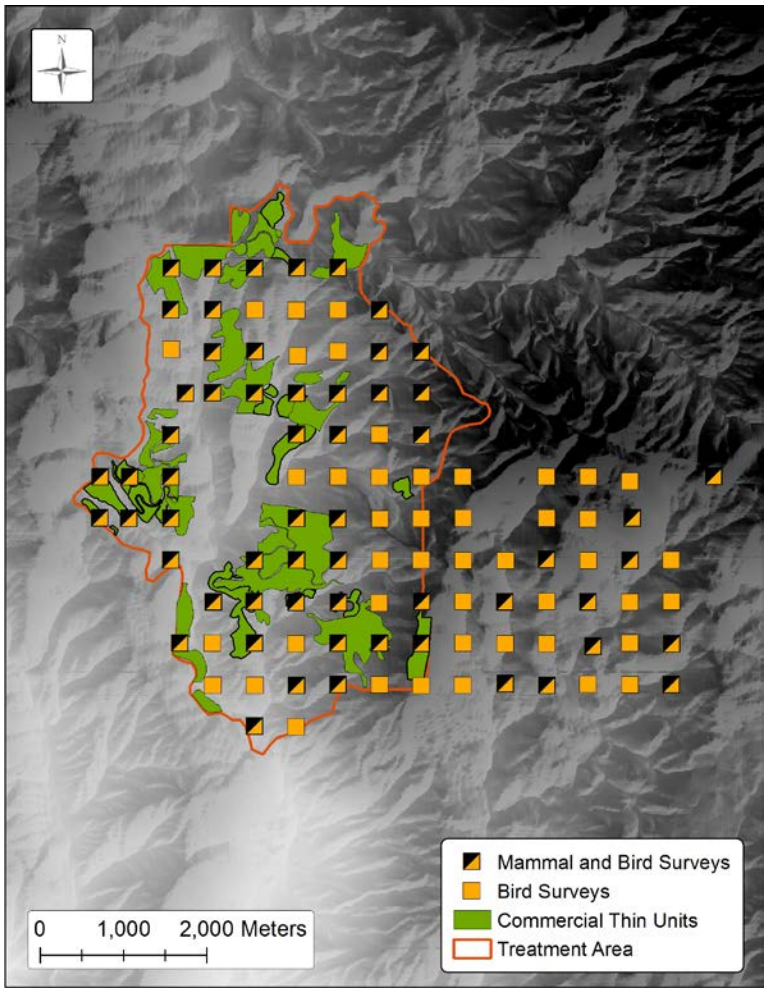
Climate at all of the study areas is Mediterranean with a summer drought period. The majority of precipitation falls as snow in the winter from December to March, with less than 10 percent falling as rain between May and October. The western slope of the Sierra receives greater precipitation and water balance declines east of the crest.

2.1.1 Sugar Pine Study Area

The Sugar Pine study area is located on the western slope of the Sierra Nevada on the Sierra National forest, just south of Yosemite National Park. It was established by the Sierra Nevada Adaptive Management Project (SNAMP), a collaborative effort between US Forest Service personnel and academic researchers that formed to investigate the impact of fuels reduction treatments on wildlife, water, fire resistance and forest health. The Sugar Pine study area ranges in elevation from 1200 to 2100 meters. The forest is mainly Sierran mixed conifer, consisting primarily of white fir (*Abies concolor*), sugar pine (*Pinus lambertiana*), incense cedar (*Calocedrus decurrens*), ponderosa pine (*Pinus ponderosa*), giant sequoia (*Sequoia giganteum*), and interspersed with black oak (*Quercus kelloggii*).

A sampling grid of 103 points, with 500 meters spacing between points, was established by SNAMP researchers and served as the basis of survey efforts (Figure 2). The researchers collected four years of wildlife survey data at this study area, including two years prior to fuels treatments (2010-2011) and two years post-treatment (2013-2014), with treatment implementation occurring in 2012. Fuels treatments at this location were considered as part of the Sugar Pine Adaptive Management Project, located on the Bass Lake Ranger District. This fuels treatment project was undertaken to reduce intensity and spread of wildfires, and to enhance forest vigor and resiliency to stressors such as insects and drought. Treatment prescriptions were modified based on management considerations relative to site occupancy by California spotted owl (*Strix occidentalis occidentalis*), northern goshawk (*Accipiter gentilis*) and Pacific fisher (*Martes pennanti pacifica*). These species are all associated with relatively mature forests containing high levels of tree stem densities and canopy cover. Particularly in project locations close to nest or den sites, treatments were of lower intensity to minimize disturbance to these sensitive species. Given these modifications over large portions of the project area, the treatments found within the Sugar Pine project are likely of lower intensity than those found in most portions of the Sierra Nevada.

Figure 2: Sugar Pine Survey Locations

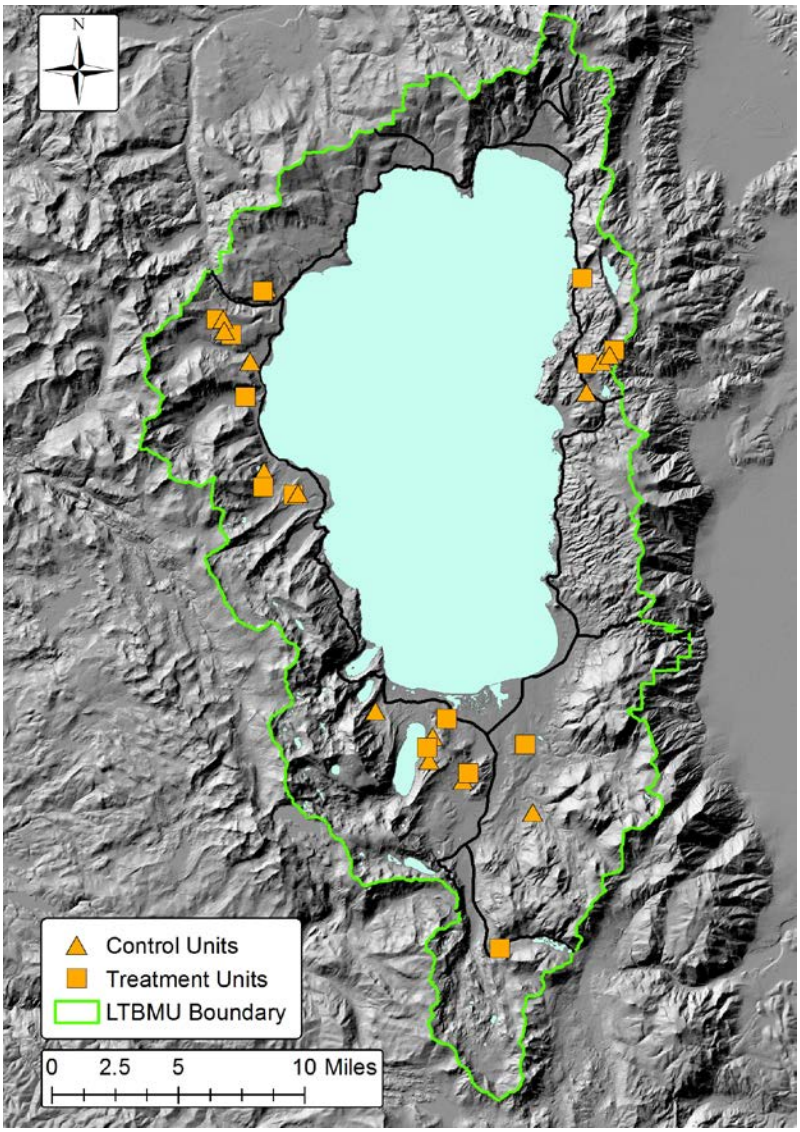


Location of 103 bird survey points and 59 mammal trapping grids within the Sugar Pine study area. Survey locations were located on a grid with 500 m spacing between points.

2.1.2 Lake Tahoe Basin

The research sites within the Lake Tahoe Basin include multiple sampling locations throughout the south and east shores of the Basin. Surveys were conducted under two separate grants from the U.S. Bureau of Land Management (via funding from SNPLMA) and are incorporated here to present data from a range of treatment conditions representative of the diversity of fuels treatment prescriptions found across the Sierra. These survey locations spanned an elevational range from 1900 to 2250 meters, and covered both Sierran mixed conifer and drier Jeffrey pine-dominated forests within the LTBMU (Figure 3). We conducted pre-treatment surveys from 2006 to 2011 and post-treatment surveys in 2008 to 2014. Treatments were implemented between 2007 and 2013, depending on the unit. Given differences in sampling protocols between the LTBMU work and California Energy Commission-funded study areas (see Field Surveys below), the researchers were required to conduct separate analyses for each study area.

Figure 3: Lake Tahoe Basin Management Unit Survey Locations



Location of research units within the Lake Tahoe Basin Management Unit. All 28 units were surveyed for both birds and small mammals.

2.2 Field Surveys

2.2.1 Vegetation Surveys

Vegetation surveys at Sugar Pine were conducted by crews led by John Battles, research scientist at the University of California, Berkeley as part of a multi-disciplinary study. Pre-treatment vegetation data was collected at each of 103 grid points from 2007 to 2008. Here the researchers focused on structural variables most commonly used to characterize habitat characteristics and model responses of birds and small mammals: forest cover, shrub cover, tree size and density and coarse woody debris (i.e. logs). Post-treatment sampling occurred at Sugar Pine in 2013 following fuel reduction treatments in 2012. Forest structural variables were

measured within a .05 hectare (500 m^2) circular plot (12.6 m radius) centered on each grid point. For trees and snags, DBH was measured through the entire circular plot. Coarse woody debris (CWD) and shrub cover were measured along three transects (12.6 meters in length) originating from the center point with the first transect azimuth determined randomly and the other two transects separated by 120°. CWD that intersected these three transect lines was measured to determine length, diameter, and decay class. Minimum diameter of CWD was 7.62 centimeters (3 inches) at the largest end. Woody shrubs were also sampled on these transects, and species, length of shrub on transect intersection, and average height were recorded. Canopy cover was determined via use of a sight-tube densitometer across a 25-point grid (5 x 5 grid) with 5 meter spacing between points.

Within the Lake Tahoe Basin, treatment sites were located within the boundaries of planed fuels treatments. Within each of the 28 plots, vegetation was measured at 6 to 8 points located randomly within the mammal trapping grid (Figure 4; see Mammal Surveys below). At each vegetation survey point, the researchers measured several structural variables within 17.8 meter radius (0.1 hectare) plots centered on each sampling point. Within each plot, tree diameter at base height (DBH) was measured to determine basal area. Canopy cover was measured using a densitometer in a 5 x 5 grid as described above. Coarse woody debris was measured along four 17.8-meter transects, one in each cardinal direction originating at the grid point. Shrub cover was determined via visual estimate within the entire 0.1 hectare circular plot. Vegetation surveys were conducted once during the pre-treatment period, between 2006 and 2011, and once between 2008 and 2014 to assess post-treatment conditions.

2.2.2 Avian Surveys

To evaluate treatment effects on avian diversity and abundance, the researchers conducted point count surveys at 103 points in the Sugar Pine study area (Figure 2). Pre-treatment surveys were conducted at each point in both 2010 and 2011, and post-treatment point counts were conducted at Sugar Pine in both 2013 and 2014. At each grid point, a 10-minute point count survey was conducted where all individuals seen and heard were recorded in 20-meter distance intervals out to 100 meters (Ralph et al. 1993). The researchers surveyed each point three times during the breeding season, and rotated observers between surveys to minimize bias at each point. The researchers conducted point counts between 15 minutes after sunrise and 09:30 am. Counts were not conducted when precipitation or wind would impede our ability to detect birds.

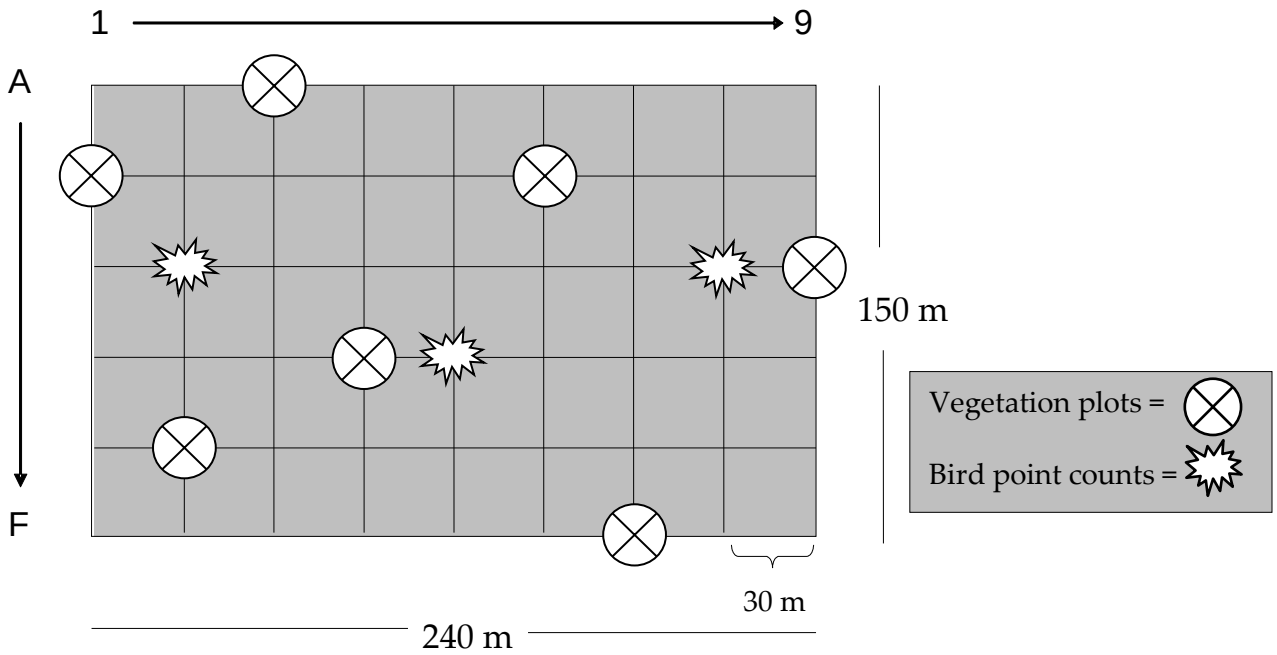
Within the LTBMU, the researchers used a survey framework based on the mammal trapping grid framework at 28 research units (14 controls and 14 treatments). Bird point count stations were located at three points along the center line of the sample plot (Figure 4). The researchers conducted three point count visits to each sample plot between late May and early July. The researchers used a 10-minute survey period and recorded the distance to all birds using 20-meter increments, out to 60 meters maximum to avoid repeated counting of individuals at separate points. The researchers followed the same protocols listed above regarding rotation of observers, timing of counts, and weather conditions during counts. Pre-treatment counts were

conducted from 2006 to 2011 (two consecutive years per site), and post-treatment counts in 2008 to 2014 (one or two years per site, depending on timing of treatment).

2.2.3 Small Mammal Surveys

At both study areas, the researchers sampled small mammals using rectangular trap grids with a 30-meter distance between traps. The researchers established trapping grids at all 28 research units at LTBMU, and 59 of the 103 survey points at Sugar Pine. At Sugar Pine, these grids were 6 x 8 (150 x 210 meters; 3.1 hectares), and at LTBMU were 6 x 9 (150 x 240 meters; 3.6 hectares; Figure 4). This spacing represents a balance between encountering a sufficient number of squirrel home ranges and obtaining a high enough recapture rate for chipmunks and mice to obtain reliable estimates of density (Converse et al. 2006a). The authors mounted one Tomahawk trap (12 x 12 x 40 centimeters) in a tree and placed one extra-large (10 x 11 x 38 centimeters) Sherman trap at each trap station (n = 96 traps total at Sugar Pine, 108 at LTBMU sites). Tomahawk traps were attached to trees 1.5 to 2.0 meters above ground on the trunks of a trees > 20 in DBH that were not marked for removal. Sherman traps were placed at the base of trees or along larger logs or under shrubs and covered with natural materials to insulate traps and polystyrene was placed in the back of the trap for warmth. The researchers baited all traps with a mixture of oats, peanut butter, raisins, and molasses, following the formula used by Carey et al. (1991). The researchers pre-baited traps for 3 to 4 days and subsequently opened traps for 5 days and nights, checking traps twice per day. Due to bear damage to traps in the beginning of the season, the researchers waited to add the peanut butter and molasses until after the second trap day. With the exception of shrews, all individuals were marked with one uniquely numbered ear tag (model 1005-1) in each ear. All shrews (*Sorex* sp.) were marked by cutting a small patch of fur on the hind. We recorded the species, age, sex, breeding status, and weight of all captured animals.

Figure 4: Survey Grid Structure at LTBMU Research Sites



Surveys on LTBMU units were conducted on 6 x 9 grids, with 30-meter spacing between points. Mammals were surveyed at each point, birds were surveyed at 3 points located along the center of the grid, and vegetation structure was measured at 6 to 8 randomly located points within the grid. Mammal surveys at Sugar Pine used a similar but slightly smaller structure of 6 x 8 grids. We surveyed birds and vegetation from a single point at the center of the Sugar Pine mammal grids.

Mammal surveys were conducted over the same time periods as mentioned above for bird surveys. At Sugar Pine, the researchers conducted trapping on 59 trapping grids during both the pre- and post-treatment periods. All sites were surveyed at least once during both the pre-treatment and post-treatment periods, and ten of these sites were surveyed in all four years of sampling to allow us to better assess the influence of annual variability in species abundance. At LTBMU sites, mammal trapping occurred on each of 28 units in the same years as for bird surveys described above.

2.3 Data Analysis

2.3.1 Vegetation Analysis

The researchers analyzed changes in tree size classes, basal area, canopy cover, shrub cover, and CWD using PROC MIXED in SAS 9.4 (SAS Institute 2012). As they were not interested in main effects (treatment or timing) in isolation, but rather the interaction of main effects, the researchers included the interaction of treatment and timing as the only fixed effect. Treatment unit was included as a random effect. The researchers included an ESTIMATE statement to provide estimated differences in response variables between specified treatment types and time periods. On the LTBMU, treatment and control units were clearly delineated. At Sugar Pine, the researchers considered survey points to be "treatment" points for the purposes of assessing vegetation change if the center point was located within the boundary of a fuels treatment unit.

2.3.2 Bird Survey Analysis

At Sugar Pine, survey locations were placed on a regularly-spaced grid and sampling radius (100-meter detection radius) overlapped imperfectly with treatment boundaries (Figure 2). As a result, classifying sampling locations as either treatment or control units proved challenging. The researchers ultimately decided to approach this problem through two related but separate analyses, both of which relied on the proportion of the 100-meter radius located within fuels treatment units. First, the researchers classified sites as treatment sites if greater than ten percent of the 100-meter radius was within treatment unit boundaries. They felt that sites with less than ten percent of the sampling radius with treatment units were unlikely to be appropriately representative of conditions found in treated forests and wildlife populations were likely to be influenced by treatments impacted such a small portion of the landscape. Classified via this approach, the researchers surveyed birds on 30 treatment sites and 73 control sites.

Given the somewhat arbitrary cutoff point used to determine treatment or control status, the researchers also considered response to the proportion of the sampling radius found in treatment units, ranging from 0 (no treatment) to 1 (fully treated). This allowed for more thorough exploration of the influence of the proportion of the landscape treated in influencing changes in species abundance.

As the LTBMU data involved more clearly defined treatment and control units, analysis for these sites exclusively considered differences between treatment and controls and did not examine proportion treated. For both LTBMU data and Sugar Pine treatment/control data, the researchers used PROC MIXED as above with vegetation variables. They used species abundance as the response variable, and the interaction of treatment (treatment or control) and timing (pre- or post-treatment) as the fixed predictor variable. Year and unit were included as random factors. Given the previously mentioned differences between survey protocols at these two study areas, the researchers conducted separate analyses for each project.

With the Sugar Pine data regarding proportion of site treated, the researchers repeated the above analysis but with treatment proportion as the sole fixed variable. Year and unit were again included as random factors.

Additionally, the researchers examined changes in avian community diversity and evenness in response to treatment. They used Shannon's diversity index (Shannon 1949) to examine changes in species richness at the treatment sites before and after treatment. They also separately examined community evenness before and after treatment using Shannon's evenness index (Pielou 1966). These metrics were calculated for each site and each year sampled. The researchers then assessed changes to Shannon's diversity and evenness indices using PROC MIXED, as outlined above, with the relevant community index as the response variable. Finally, they combined abundance of all species to examine community-wide changes in abundance following treatment, using the mixed model analyses outlined above. These analyses were done with respect to treatment/control sites and, for Sugar Pine only, treatment proportion.

2.3.3 Mammal Survey Analysis

To examine small mammal response to fuels treatment, the researchers examined changes in abundance of individual species abundance following treatment implementation. Abundance was expressed as a function of trapping effort, using the number of unique individuals captured per 100 trap nights. We analyzed species-specific responses to treatment, and proportion of site treated (Sugar Pine), using PROC MIXED as outlined above for birds. Surveys were conducted on 29 sites classified at treatment units and 30 control units.

The researchers also examined changes in diversity, evenness, and abundance for mammals at the community level. These analyses were conducted using the same procedures outlined above for the avian community.

CHAPTER 3: Results

3.1 Vegetation

Pre-treatment forests at both Sugar Pine and LTBMU study areas were composed of primarily small (15 to 30-centimeter DBH) and medium (30 to 61 centimeter) trees, though the forests at Sugar Pine had both higher proportions of small trees and higher overall tree densities (Figure 5). While treatment prescription and intensity varied by site, treatments generally targeted smaller-diameter trees, given their fire susceptibility and ability to serve as ladder fuels. At both study areas, density of both small and medium trees was significantly reduced following treatments ($p < 0.01$ at both study areas; Table 1), while large tree densities were not significantly different ($p > 0.1$ at both study areas; Table 1). Though these structural changes were similar in type across study areas, they differed substantially in the intensity of treatments. Following treatments, Sugar Pine sites were still composed predominantly of small-diameter trees, while LTBMU forests saw a marked reduction in small trees and were generally dominated by 30 to 61-centimeter trees (Figure 6). While the quantity of large (greater than 61 cm) trees was unchanged at both study areas, they became a more prominent component of post-treatment forests, given the removal of trees in smaller size classes.

Figure 5: Tree Size Class Distribution at Sugar Pine

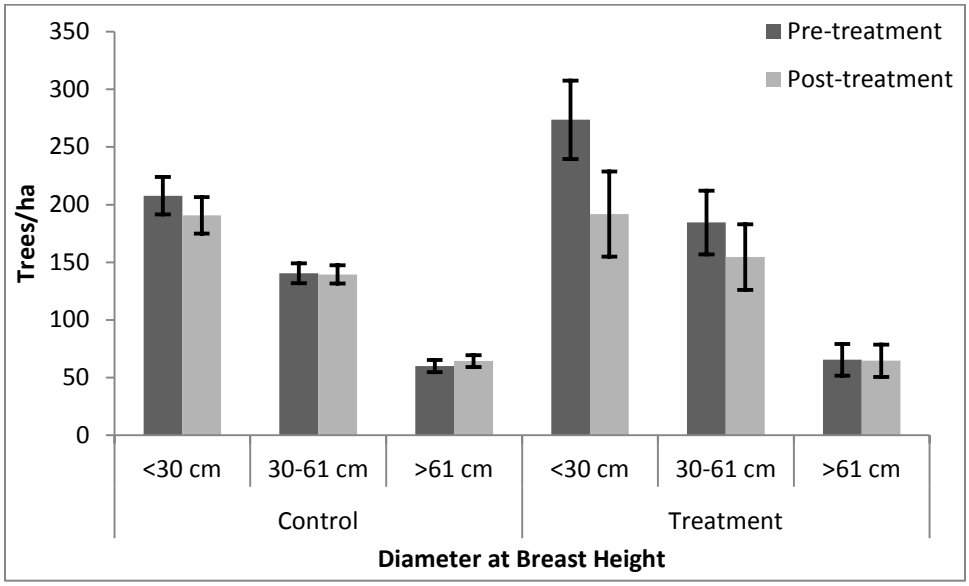
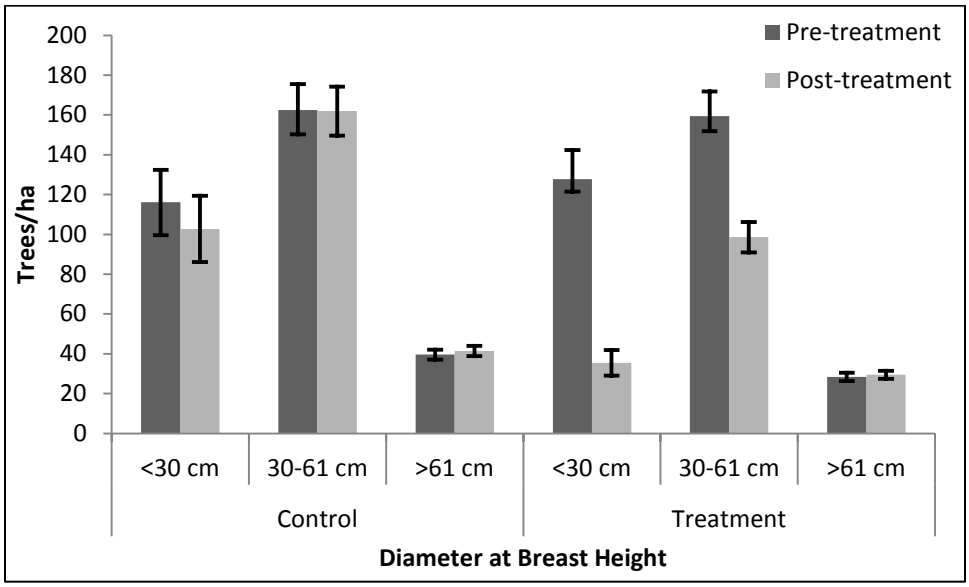
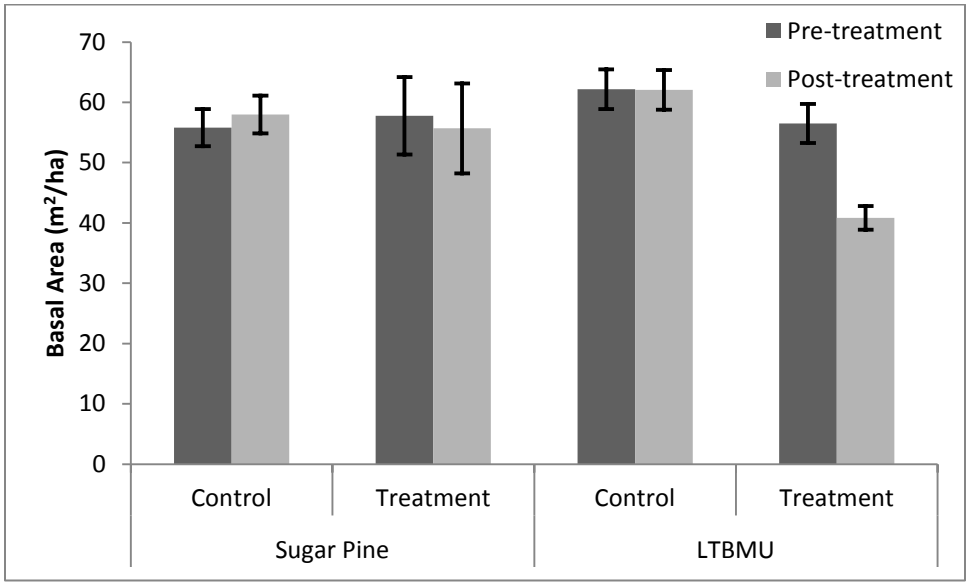


Figure 6: Tree Size Class Distribution at LTBMU



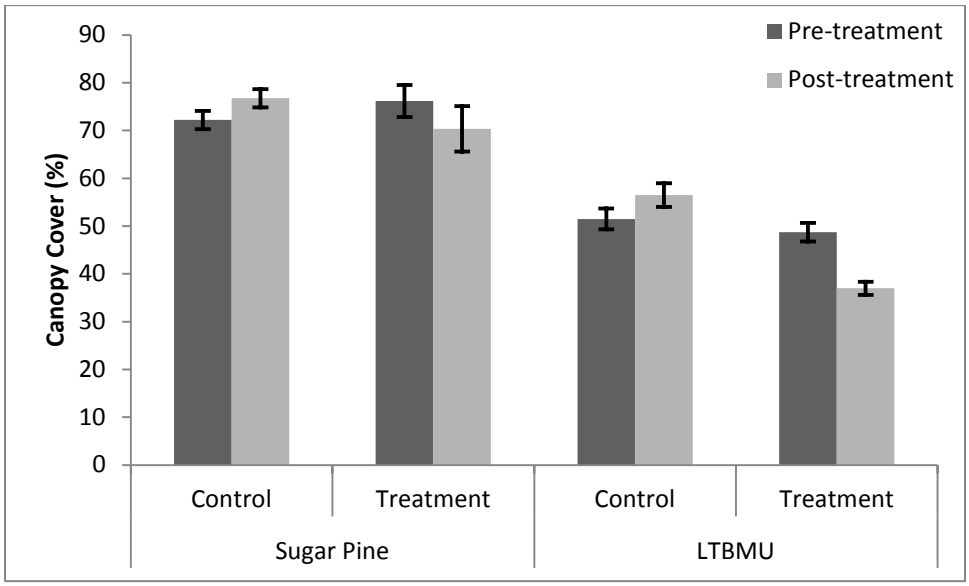
Fuels treatments led to significant reductions in basal area at both study areas, but at notably different intensities between study areas. Basal area on Sugar Pine treatment sites was reduced by 4.2 (± 2.1) m^2/ha ($p = 0.05$; Table 1), while LTBMU treatment sites were reduced by 15.5 (± 3.7) m^2/ha ($p < 0.001$; Figure 7). There was wide variation in retained basal area both across and within study areas. At Sugar Pine, post-treatment basal area on treatment units averaged 55.7 (± 7.5) m^2/ha but values at individual sites differed by more than an order of magnitude, ranging from 12.7 to 150.7 m^2/ha. Basal area on post-treatment LTBMU sites averaged 40.8 (± 2.0) m^2/ha, and covered a much narrower range, from 22.4 to 60.3 m^2/ha.

Figure 7: Basal Area Change Following Fuels Treatment



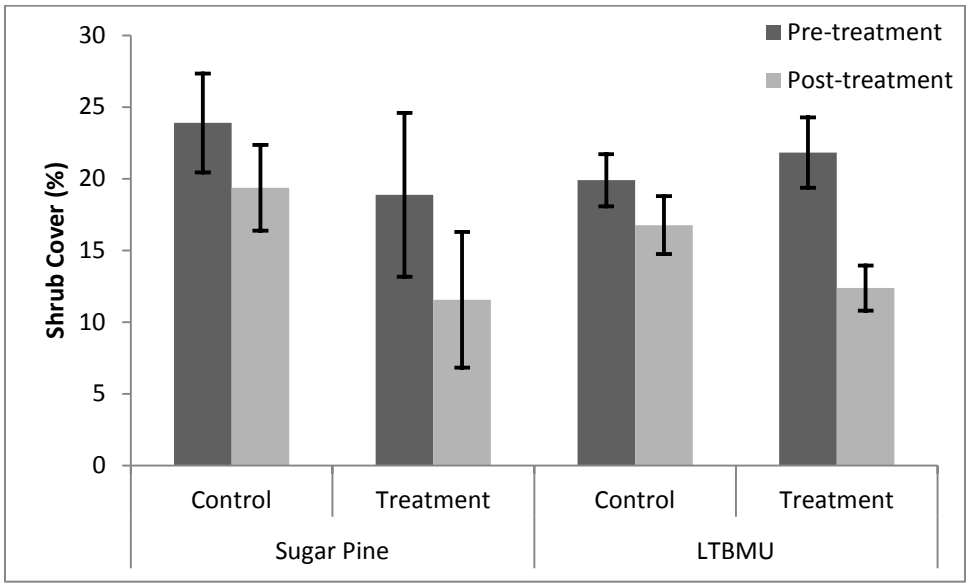
Given the removal of small and medium-diameter trees at both locations, there was a predictable decrease in canopy cover on Sugar Pine and LTBMU treatment units. At Sugar Pine, treatment units averaged 10.3 percent (± 3.7) lower canopy cover ($p = 0.005$; Table 1). LTBMU treatment units, which started from a lower average canopy cover, experienced a 16.7 percent (± 3.6) reduction in canopy cover ($p < 0.001$; Figure 8). As with basal area, there was considerable variability in this measure. Sugar Pine sites averaged 70.4 percent (± 4.7) canopy cover following treatment, and spanned a range from 20 to 96 percent. LTBMU sites were considerably more open following treatment, averaging 37.0 percent (± 1.4) canopy cover, and ranged from 27.3 to 52 percent.

Figure 8: Canopy Cover Change Following Fuels Treatment



Understory vegetation showed greater variation following treatment. Shrub cover was significantly reduced on treatment plots only on LTBMU treatment units, with average shrub cover declining by 6.3 percent (± 2.6) at this study area ($p = 0.02$; Figure 9). On average, shrub cover was reduced at Sugar Pine following treatments (average decline of 2.8 percent ± 3.8), but this trend was non-significant ($p > 0.1$; Table 1) and there was substantial variance between units. Post-treatment shrub cover on LTBMU treatment units averaged 12.4 percent (± 1.6), and ranged from 1.5 to 29.2 percent. Shrub cover at Sugar Pine treatment units averaged 11.5 percent (± 4.7), and spanned a much greater range, from 0 to 84.8 percent.

Figure 9: Shrub Cover Change Following Fuels Treatment



Another important component of forest understory structure, coarse woody debris, showed inconsistent and non-significant ($p > 0.1$; Figure 10; Table 1) changes following treatment at both study areas, perhaps a result of variation in management of residual fuels across study areas and units. Within LTBMU, mean change in CWD was -44.4 (± 35.7) m^3/ha, and post-treatment average CWD was 57.7 (± 4.9) m^3/ha , ranging from 7.8 to 106.2 m^3/ha. At Sugar Pine, treatment units showed a non-significant positive trend in CWD, on average increasing 25.9 (± 18.3) m^3/ha following treatment. Post-treatment CWD ranged from 0 to 268.2 m^3/ha.

Figure 10: Coarse Woody Debris Change Following Fuels Treatment

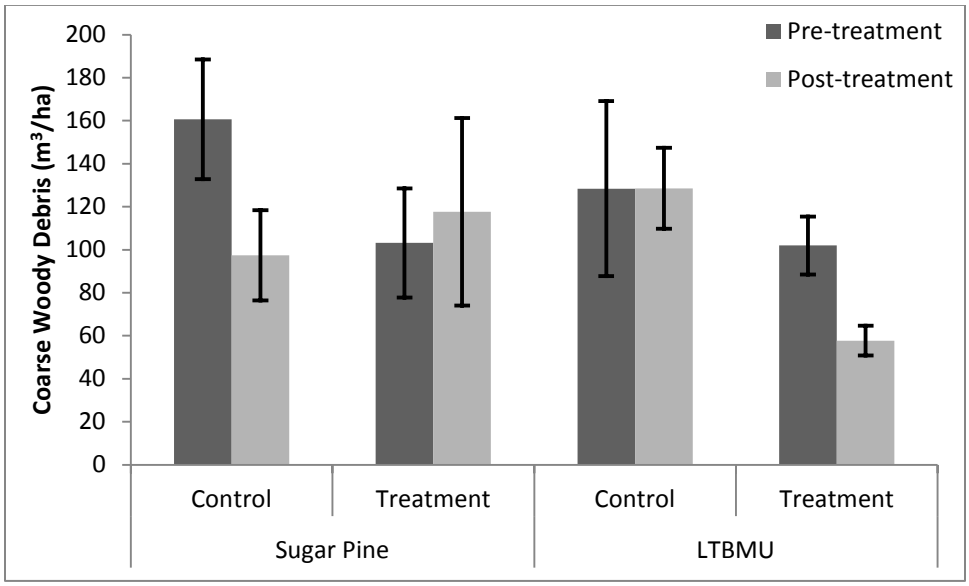


Table 1: Vegetation Change Following Treatment

	Sugar Pine			LTBMU		
Variable	**Treatment Change**	***t***	***p***	**Treatment Change**	***t***	***p***
Small (< 30 cm) trees/ha	**-64.90**	**-2.82**	**0.006**	**-78.89**	**-4.09**	**<0.001**
Medium (30-61 cm) trees/ha	**-28.97**	**-3.08**	**0.003**	**-60.31**	**-4.33**	**<0.001**
Large (> 61 cm) trees/ha	-5.27	-1.25	0.21	-0.74	-0.38	0.71
Canopy Cover (%)	**-10.38**	**-2.82**	**0.006**	**-16.74**	**-4.59**	**<0.001**
Basal Area (m^2/ha)	**-4.27**	**-1.99**	**0.05**	**-15.53**	**-4.22**	**<0.001**
Shrub Cover (%)	-2.81	-0.73	0.46	**-6.31**	**-2.47**	**0.02**
Coarse Woody Debris (m^3/ha)	25.88	1.41	0.16	-44.39	-1.24	0.23

Bold = $p < 0.05$, statistically significant change following treatment. Treatment change is per each variable's measurement unit, listed alongside the variable name.

3.2 Birds

Across the eight years of research at our two study areas, the researchers detected 32,735 individuals from 93 species of birds (Appendix A). They observed greater species diversity at our LTBMU sites (83 species) compared with Sugar Pine (67 species), though the work in LTBMU covered a larger geographic area and greater diversity of forest types. At the LTBMU sites, species composition showed minimal change following treatment. The researchers detected 63 species on treatment units prior to treatment, and 65 species following treatment; 54 of these species were found both before and after treatment. Sugar Pine showed a more noticeable difference in diversity following treatment, with 52 species detected prior to treatment, and 44 species following treatment; 40 of these species were found during both time periods. However, the species that were only detected during pre-treatment surveys were observed very rarely (on less than 1 percent of point counts), so their absence during post-treatment counts may not reflect treatment impacts per se.

In examining the metrics of community composition, there were only small and non-significant changes in Shannon's diversity index at both study areas (3.19 pre-treatment, 3.09 post-treatment at LTBMU; 2.52 pre-treatment, 2.55 post-treatment at Sugar Pine; both $p > 0.1$). Regarding community evenness, there was minimal, non-significant change in Shannon's evenness index at LTBMU sites (0.90 before treatment, 0.89 following treatment; $p = 0.74$), indicating that there were only minimal changes in community diversity and relative abundance following treatment within the Tahoe Basin. At Sugar Pine, the change in Shannon's evenness index was also minor, but significant (0.93 prior to treatment, 0.92 following treatment; $p = 0.04$), suggesting that community evenness declined slightly and observed increases in community abundance (see below) were driven disproportionately by increases in abundant species. When all species were grouped for analysis, abundance of the entire bird community increased at both locations, though this trend was only significant in Sugar Pine forests. At LTBMU, avian density increased non-significantly by 7.4 (± 5.6) individuals per 10

hectares ($p = 0.2$), while at Sugar Pine avian density increased 5.4 (± 1.6) individuals per 10 hectares ($p = 0.001$).

The researchers analyzed changes in abundance of all species for which we had greater than 30 observations (Table 2), amounting to 35 species at each study area (though composition of those 35 species differed slightly between our two study areas, representing 45 species in total). With respect to changes in response to treatment, they observed significant ($p < 0.05$) changes in abundance for 16 species across the two study areas (nine in each location). On LTBMU units, the researchers found positive responses to treatment in the hairy woodpecker (*Picoides villosus*), olive-sided flycatcher (*Contopus cooperi*), pygmy nuthatch (*Sitta pygmaea*), warbling vireo (*Vireo gilvus*), and western wood-peewee (*Contopus sordidulus*). Negative responses were observed in the golden-crowned kinglet (*Regulus satrapa*), hermit thrush (*Catharus guttatus*), Nashville warbler (*Oreothlypis ruficapilla*), and red-breasted nuthatch (*Sitta canadensis*). At Sugar Pine, they observed positive responses to treatment in the dark-eyed junco (*Junco hyemalis*), hairy woodpecker, red-breasted nuthatch, spotted towhee (*Pipilo maculatus*), Townsend's solitaire (*Myadestes townsendi*), western tanager (*Piranga ludoviciana*), and yellow-rumped warbler (*Setophaga coronata*). The researchers observed significant negative responses in only two species, the black-headed grosbeak (*Pheucticus melanocephalus*) and pileated woodpecker (*Dryocopus pileatus*). When considering changes relative to proportion of the survey area treated, they detected significant responses in six species, all of which responded positively. They were Cassin's vireo (*Vireo cassinii*), dark-eyed junco, hairy woodpecker, spotted towhee, western tanager, and yellow-rumped warbler.

Table 2: Bird Species Response to Fuels Treatment

	Sugar Pine					LTBMU		
	Treatment			Treatment Proportion		Treatment		
Species	**Density Change (#/10 ha)**	***t***	***p***	***t***	***p***	**Density Change (#/10 ha)**	***t***	***p***
American Robin	0.28	1.36	0.17	0.33	0.74	1.36	1.80	0.07
Band-tailed Pigeon	0.04	0.50	0.62	-0.90	0.37	-0.06	-0.34	0.73
Black-backed Woodpecker	-	-	-	-	-	-0.05	-0.29	0.77
Black-headed Grosbeak	**-0.65**	**-1.96**	**0.05**	-1.80	0.07	-	-	-
Brown Creeper	0.39	1.53	0.13	1.21	0.23	0.09	0.14	0.89
Brown-headed Cowbird	-0.08	-0.73	0.46	0.66	0.51	0.28	0.49	0.63
Cassin's Finch	-	-	-	-	-	0.03	0.08	0.94
Cassin's Vireo	0.14	0.64	0.52	**2.80**	**0.01**	0.14	0.50	0.62
Chipping Sparrow	0.02	0.26	0.80	1.68	0.09	0.25	1.37	0.17
Clark's Nutcracker	-	-	-	-	-	-0.01	-0.07	0.95
Common Raven	0.01	0.10	0.92	1.06	0.29	-	-	-
Dark-eyed Junco	**0.92**	**2.04**	**0.04**	**4.68**	**<0.001**	1.73	1.53	0.13
Dusky Flycatcher	0.06	0.31	0.76	-0.41	0.68	0.36	0.56	0.58
Evening Grosbeak	-	-	-	-	-	1.56	1.72	0.09
Fox Sparrow	0.03	0.28	0.78	-0.93	0.36	-0.61	-0.92	0.36
Golden-crowned Kinglet	-0.09	-0.31	0.76	-0.65	0.51	**-2.8**	**-3.02**	**0.003**
Green-tailed Towhee	-	-	-	-	-	-1.16	-1.42	0.1
Hairy Woodpecker	**0.19**	**2.05**	**0.04**	**1.91**	**0.05**	**1.21**	**2.74**	**0.007**
Hammond's Flycatcher	0.27	1.51	0.13	0.52	0.60	-	-	-
Hermit Thrush	-	-	-	-	-	**-0.87**	**-2.80**	**0.005**
Hermit Warbler	-0.38	-0.98	0.33	0.71	0.48	0.4	1.31	0.19
MacGillivray's Warbler	0.19	0.91	0.36	0.61	0.54	-0.25	-0.92	0.36
Mountain Chickadee	0.02	0.14	0.89	-0.49	0.62	2.47	1.59	0.11
Mountain Quail	-0.13	-0.92	0.36	-0.46	0.64	-	-	-

Nashville Warbler	-0.41	-1.02	0.31	0.00	1.00	**-1.61**	**-2.88**	**0.004**
Northern Flicker	0.06	0.43	0.67	0.73	0.47	-0.21	-1.01	0.31
Olive-sided Flycatcher	0.08	1.01	0.31	-0.40	0.69	**0.57**	**2.03**	**0.04**
Pacific Wren	0.14	0.70	0.49	0.61	0.54	-	-	-
Pacific-slope Flycatcher	-0.13	-0.77	0.44	-0.57	0.57	-	-	-
Pileated Woodpecker	**-0.27**	**-2.33**	**0.02**	-0.72	0.47	-	-	-
Pine Siskin	-	-	-	-	-	0.08	0.11	0.91
Purple Finch	0.09	1.00	0.32	1.24	0.22	-	-	-
Pygmy Nuthatch	-	-	-	-	-	**2.94**	**2.66**	**0.003**
Red Crossbill	-	-	-	-	-	0.58	1.26	0.21
Red-breasted Nuthatch	**0.71**	**1.92**	**0.05**	1.74	0.08	**-2.25**	**-2.03**	**0.04**
Red-breasted Sapsucker	-0.13	-1.10	0.27	-1.35	0.18	-	-	-
Spotted Towhee	**1.30**	**4.06**	**<0.001**	**4.62**	**<0.001**	-	-	-
Steller's Jay	0.54	1.41	0.16	0.84	0.40	-0.89	-0.99	0.32
Townsend's Solitaire	**0.25**	**2.16**	**0.03**	-0.66	0.51	0.35	0.91	0.36
Warbling Vireo	0.05	0.22	0.82	-0.47	0.64	**1.04**	**2.88**	**0.004**
Western Tanager	**0.76**	**2.12**	**0.03**	**1.94**	**0.05**	1.29	1.61	0.11
Western Wood-Pewee	0.33	1.18	0.24	0.02	0.99	**2.34**	3.93	**<0.001**
White-breasted Nuthatch	-	-	-	-	-	0.13	0.27	0.79
White-headed Woodpecker	0.23	1.34	0.18	-0.09	0.93	0.4	0.90	0.37
Yellow-rumped Warbler	**0.74**	**2.22**	**0.03**	**2.22**	**0.03**	0.11	0.11	0.91

Bold = $p < 0.05$, statistically significant response to treatment. A dash indicates insufficient detections to test treatment response. Change following treatment is expressed as number of individuals per 10 ha. For Sugar Pine, we examined response to both treatment and the proportion of the survey area (100 m radius) treated.

3.3 Small Mammals

The researchers captured 14,272 small mammals from 18 species during the course of the project (Appendix B). As with birds, there was greater species diversity at the LTBMU sites (17 species) than at Sugar Pine (11 species). At the community level, there was minimal change in either community diversity or relative abundance following treatment at either study area. Treatment units at LTBMU had 16 species detected during both pre- and post-treatment surveys, and nine species were detected during both pre- and post-treatment surveys at Sugar Pine. Shannon's diversity index remained virtually unchanged in the post-treatment time period, with no significant difference between treatment and control units ($p > 0.1$ at both locations). Likewise, there was minor, non-significant change in community evenness following treatment, as indicated by Shannon's evenness Index ($p > 0.1$), suggesting that the proportion of the community represented by different species remained similar.

With respect to community abundance, the researchers observed a significant increase in small mammals following treatments at our LTBMU sites. Abundance increased 26 percent (9.7 (± 4.6) ind/100 trap-nights, $p = 0.04$) on treatment units relative to controls, and appeared to be driven primarily by increases in chipmunks (*Tamias* spp.) following treatment. However, the small mammal community at Sugar Pine demonstrated no significant change following treatment ($p = 0.95$).

At the species level, there was sufficient data from 13 species to analyze their response to treatment at one or both study areas (Table 3). Although several species exhibited substantial changes in abundance following treatment, these changes were statistically significant for only two species. Northern flying squirrels (*Glaucomys sabrinus*) declined on treatment units at both study areas (-0.56 individuals/100 trap-nights at LTBMU, -0.82 individuals/100 trap-nights at Sugar Pine; $p = 0.05$ at both locations), and yellow-pine chipmunks (*Tamias amoenus*) increased following treatments at LTBMU (+5.92 individuals/100 trap-nights; $p = 0.004$). With respect to treatment proportion at Sugar Pine sites, the researchers did not observe any significant changes in abundance, though northern flying squirrels showed a marginally non-significant decline (-0.80 individuals/100 trap-nights; $p = 0.08$).

Table 3: Small Mammal Species Response to Fuels Treatment

	Sugar Pine					LTBMU		
	Treatment			Treatment Proportion		Treatment		
Species	**Treatment Change (#Ind/100 TN)**	***t***	***p***	***t***	***p***	**Treatment Change (#Ind/100 TN)**	***t***	***p***
Allen's chipmunk	-	-	-	-	-	1.79	1.11	0.27
Brush mouse	-1.33	-0.96	0.34	0.41	0.68	-	-	-
California ground squirrel	0.29	1.28	0.21	0.59	0.56	-0.08	-0.37	0.71
Deer mouse	0.63	0.60	0.55	-0.03	0.98	-0.52	-0.59	0.56
Douglas' squirrel	0.00	0.04	0.97	0.38	0.71	-0.32	-0.70	0.49
Golden-mantled ground squirrel	-	-	-	-	-	0.19	0.37	0.71
Least chipmunk	-	-	-	-	-	0.09	0.31	0.76
Lodgepole chipmunk	-	-	-	-	-	0.80	0.63	0.53
Long-eared chipmunk	-0.09	-0.11	0.91	-0.57	0.57	0.77	0.49	0.62
Long-tailed vole	-	-	-	-	-	0.02	0.32	0.75
Northern flying squirrel	**-0.82**	**-2.03**	**0.05**	-1.77	0.08	**-0.56**	**-1.99**	**0.05**
Trowbridge's shrew	-0.02	-0.30	0.77	-1.22	0.23	0.04	0.64	0.53
Yellow-pine chipmunk	-	-	-	-	-	**5.92**	**3.02**	**0.004**

Bold = $p < 0.05$, significant response to fuels treatment. A dash indicates insufficient detections to examine treatment response. Treatment change is expressed as change in the number of individuals captured per 100 trap-nights, a measure of trapping effort.

CHAPTER 4: Discussion

4.1 Vegetation

Fuel reduction treatments in both study areas resulted in a more open forest with fewer smaller diameter trees indicative of a management approach to mitigating fire behavior. Specifically, these treatments targeted removal of the smaller diameter trees that are more prone to serve as ladder fuels and increase potential for crown fires. We observed significant reductions in small (15 to 30 centimeters) and medium (30 to 61 centimeter) trees, canopy cover, and basal area at both study areas following treatments, while density of large trees (greater than 61 cm) did not significantly change at either location. Management of understory fuels, as reflected by shrub cover and CWD, was much more varied, both within and across study areas. While CWD did not change significantly following treatments at either study area, treatments resulted in significantly less shrub cover on LTBMU units only. This difference in management of understory vegetation and fuels arose at least in part from operational limitations imposed by steep slopes at many treatment units. On sites where slopes allowed for adequate mechanical access, understory fuels were frequently treated via mastication (chipping and spreading). However, in sites where opportunities for mastication was limited, treatments focused primarily on thinning of ladder fuels, after which many of these smaller trees and snags were deposited in burn piles on site. Thus, ground fuels were not substantially reduced at many of these sites, though the removal of ladder fuels likely limited the probability of crown fires on treated units.

Although the patterns of structural change were similar across study areas, the intensity of treatment implementation varied markedly and in a manner that likely had important consequences for wildlife response. Forests in the LTBMU, being on the east side of the Sierra, are naturally drier and more open than the west slope forests at Sugar Pine. Nonetheless, in spite of lower initial canopy cover and tree densities, treatments at LTBMU sites resulted in greater reductions in canopy cover and in densities of small and medium trees. Canopy cover reduction was 50 percent greater, small tree reduction was 20 percent greater, and reduction of medium trees was double at the LTBMU sites. These patterns of treatment intensity led to reductions in basal area that was nearly four times greater in LTBMU treatment stands.

The differences in post-treatment structure are important to note, particularly regarding changes in canopy cover and small tree densities. Following fuels treatments, forests in the LTBMU averaged 37 percent canopy cover, relative to 70 percent post-treatment at Sugar Pine. With respect to small tree densities following treatment, the difference was even more pronounced, with 35 small trees/ha remaining on LTBMU sites, compared with 192 small trees/ha at Sugar Pine. This variation in structure of post-treatment forests is important to consider when assessing differences in wildlife response across the treatment regimes at these two study areas.

4.2 Birds and Small Mammals

This synthesis of research across two diverse study areas in the Sierra Nevada makes a significant contribution to the literature regarding wildlife response to fuels management. The researchers conducted wildlife surveys across multiple forest types and treatment intensities, thus providing robust sample sizes and allowing for adequate assessment of treatment response for a wide range of species. In the final report for the researchers' BLM-funded Upland Fuels project (Manley et al. 2012), they emphasized that the results were likely influenced by our moderate sample sizes, and noted that they were only able to find significant responses for the most abundant species. Here, the researchers observed significant treatment responses in both abundant and less common species, thus providing a greater range of management-relevant information.

With respect to the bird community, the researchers observed minor changes in community diversity and evenness following treatment. The only significant change in these variables was a minor reduction in evenness at Sugar Pine following treatment, indicating that treatment had a disproportionate effect on some species. Regarding changes in abundance, the researchers observed increases in overall avian abundance following treatment at both locations, though this pattern was significant only at Sugar Pine. This indicates that the intensities of treatment found at both study areas is, at a minimum, consistent with maintenance of avian abundance in forests of the Sierra Nevada, and may ultimately increase songbird densities across a range of forest and treatment types.

At the species level, the researchers observed significant responses to treatment in 16 bird species. This list of species differed substantially between the two study areas, with only two species showing significant responses at both locations. These species were hairy woodpecker, which responded positively to treatment at both locations (and responded positively to thinning in Fontaine and Kennedy's (2012) meta-analysis), and intriguingly, red-breasted nuthatch, which responded positively to Sugar Pine treatments but negatively in LTBMU treated stands. There has been little prior research on the response of red-breasted nuthatches to fuels treatments and Fontaine and Kennedy (2012) were unable to assess their response to this type of fuels management. Given the substantial sample sizes of red-breasted nuthatches in this project, it is unlikely that this pattern is a statistical artifact, and may indicate that the optimum conditions for this species lies somewhere between the two treatment intensities found at the study areas.

Outside of the red-breasted nuthatch, patterns of species response were generally consistent between the two study areas and treatment intensities. There were ten additional species that responded positively to treatment at a single study area (olive-sided flycatcher, pygmy nuthatch, warbling vireo, and western wood-peewee at LTBMU; Cassin's vireo, dark-eyed junco, spotted towhee, Townsend's solitaire, western tanager, and yellow-rumped warbler at Sugar Pine). When there were sufficient sample sizes to consider their response at the additional study area, each of these species also showed a positive, though non-significant, response to treatment. This pattern suggests that these species may benefit from fuels treatments across a range of intensities, although benefits to populations may be more pronounced at certain

treatment intensities. Importantly, the species that increased significantly in LTBMU treatments are associated with rather open forests throughout their ranges, suggesting that treatments at Sugar Pine may have been too limited to noticeably improve habitat for these species. Likewise, the species that significantly increased only at Sugar Pine are generally species found in forests of moderate densities. This may indicate that the pre-treatment forests found on the LTBMU were already close to optimum and further opening of these forests produced little additional benefit for these species. In examining prior research regarding these species, only data for dark-eyed juncos and yellow-rumped warblers were available for Fontaine and Kennedy's (2012) meta-analysis. Their analysis indicated a neutral response to thinning-based fuels treatments for the dark-eyed junco and a significant negative response for yellow-rumped warbler. This highlights both the lack of information available for many species in the Sierra Nevada and the importance of site specific conditions and treatment intensities in predicting responses to management.

In addition to the observed negative response of the red-breasted nuthatch in LTBMU forests, the researchers detected negative responses to fuels treatments in five additional species (golden-crowned kinglet, hermit thrush, and Nashville warbler on the LTBMU, and black-headed grosbeak and pileated woodpecker at Sugar Pine). Among these species, the hermit thrush, black-headed grosbeak, and pileated woodpecker were only detected at sufficient densities at one study area, and thus the researchers could not examine their responses to treatment at the additional location. With the remaining two species, golden-crowned kinglet and Nashville warbler, their responses were also negative at Sugar Pine, but non-significant, indicating that the relatively light treatment intensity at that location was not sufficient to substantially diminish their populations. There was little prior research on fuels treatment impacts to the black-headed grosbeak, golden-crowned kinglet, or Nashville warbler, and Fontaine and Kennedy (2012) were unable to consider treatment responses of these species in their meta-analysis. For the hermit thrush, they found a significant negative response to treatments, and a non-significant positive response for pileated woodpeckers.

In examining the small mammal community, the researchers observed minimal, non-significant change in species composition and relative abundance at both locations, as determined by the Shannon's diversity and evenness indices. The researchers did not observe any significant change in community abundance at Sugar Pine, though small mammal abundance increased significantly following treatment implementation on LTBMU units. This increase was driven primarily by an increase in chipmunks, which are not found in the same diversity or abundance in Sugar Pine forests. Several other projects in the mountain West have found increases in community abundance following treatments (Bagne and Finch 2010, Converse et al. 2006b). However, these results indicate that changes in abundance at the community level are ultimately influenced by the composition of individual species present at a site and cannot be applied generically across different regions or forest types.

When considering treatment response of individual species, the researchers observed a significant positive response for only one species, the yellow-pine chipmunk, which was found only on LTBMU forests and was the most abundant species at that study area. Prior research elsewhere in this species' range has demonstrated positive response to higher intensity thinning

(Sullivan and Klenner 2000), and Fontaine and Kennedy (2012) found a positive, though non-significant, response to treatment. The researchers also found negative responses to thinning for northern flying squirrels at both study areas. While the change in density following treatment was greater at Sugar Pine, initial densities were also greater there relative to LTBMU. There was insufficient data from fuels reduction projects for Fontaine and Kennedy (2012) to model treatment response of this species. While several other projects have found negative impacts to northern flying squirrels following forest thinning (Manning et al. 2012, Meyer et al. 2007), here the researchers demonstrate negative response to a wide range of thinning intensities. These results suggest that even low-intensity fuels treatments that retain high levels of canopy cover, such as those implemented at Sugar Pine, are likely to reduce northern flying squirrel populations.

4.3 Project Limitations and Future Directions

While the researchers were able to assess treatment response in a wide diversity of birds and small mammals across a wide range of treatment intensities, there are still several relevant questions that they were unable to address with our current dataset. Of particular relevance to the current project are the importance of understory structure and the diversity of approaches for ground fuel management in determining wildlife response. As noted above, changes in both shrub cover and CWD showed substantial variability and inconsistent trends across study areas. In part, this was driven by differences in management of understory fuels, differences that varied both across and within study areas. While changes in tree cover understandably receives greater attention in understanding forest management activities, populations of many birds and small mammals may be influenced substantially by activities that impact the forest floor. To a greater degree than birds, most small mammals make regular use of ground-level resources for cover, denning, and foraging. Likewise, although some birds are capable of using canopy-level resources exclusively, many species depend on ground-level resources for nesting or foraging sites. Species that depend on these resources are undoubtedly influenced by differences in ground fuel management, perhaps more so than management of tree density and cover. Unfortunately, there lacked data to appropriately describe understory management strategies on many treatment units and the researchers were thus unable to examine this question, though it warrants further investigation.

Additionally, the fuels treatments applied at the study areas were relatively conventional with respect to approaches to managing for high-intensity fire risk. However, there has been increasing interest in implementing fuels treatments in a manner that mimics the structure of historic forests with active fire regimes (North et al. 2009). This approach is being pursued at several locations in the Sierra Nevada, most notably at the Stanislaus-Tuolumne Experimental Forest and Sagehen Experimental Forest. The researchers hoped to include data from Sagehen as a means of comparing wildlife response to these differing approaches to designing fuels treatments. As noted above, the researchers have been unable to collect post-treatment data at this site as a result of delays to the treatment schedule. They hope to shed light on this important question with data from both of these locations in the coming years.

Finally, the post-treatment data reflects a relatively brief period following treatment implementation. Vegetation recovery following treatment, particularly for understory vegetation, is likely to be limited in the post-treatment window of our research. Thus, a more complete understanding of wildlife response to these fuels treatments would involve re-visiting these sites five to ten years following treatment. Re-survey of these sites over longer time scales would allow for examination of the consistency of the results presented here and illustrate the role of understory recovery in determining wildlife abundance in treated forests.

CHAPTER 5: Conclusion

In this project, the researchers examined bird and small mammal responses to fuels treatments as currently applied throughout the Sierra Nevada. Their work covered a variety of forest types with differing structural attributes, which were inhabited by diverse wildlife communities. The study areas differed dramatically with respect to treatment design, which allowed for comparison of wildlife responses across different treatment intensities.

Species responses to fuels treatments have been examined in many areas of the mountain West and were summarized recently by Fontaine and Kennedy (2012). However, few studies have reported on the impacts of fuels management in the Sierra Nevada. Thus, our project provided an opportunity to determine management responses of many species that had not previously been investigated and to examine regional variability in treatment response for more widespread species.

At the community level, there were generally positive treatment responses for both birds and small mammals. For the bird community, the magnitude of increase following treatment was similar at both study areas, although this increase was only significant at Sugar Pine, which had lower treatment intensity. Thus, bird abundance may increase across a broad range of fuels treatment intensities in the Sierra Nevada, though this pattern may be more pronounced following lower-intensity treatments. Small mammals increased significantly following treatments on LTBMU sites, a trend that was driven primarily by species not found at Sugar Pine. There is more widespread variation in composition and diversity of the small mammal community across the Sierra Nevada, and changes to overall community abundance will likely be driven by site-specific species composition.

With respect to treatment responses of individual species, there were significant treatment responses in a number of species, the large majority of which had not been thoroughly examined in previous fuels treatment research. In the bird community, the researchers detected significant increases following treatment in 11 species, and significant decreases in abundance for 5 species. Only one species showed a consistent significant response at both study areas, though the other 15 species, when detected at both research sites, showed consistent but non-significant trends at the additional study area. This suggests that while many species will respond consistently to a range of treatments, treatment intensity is likely important in determining the magnitude of a species' response. The researchers observed only one significant inconsistent response, in the red-breasted nuthatch, indicating that optimum conditions for this species lie between the post-treatment conditions found at the study areas.

In the mammal community, significant responses to fuels treatments were observed in only two species. The northern flying squirrel declined significantly at both sites, indicating that even modest forest thinning is detrimental to this species in the Sierra Nevada. As this species is an important prey item for California spotted owls, management for this species may take precedence at some locations. The yellow-pine chipmunk increased significantly on LTBMU

treatment units and was not detected at Sugar Pine. The researchers observed substantial changes in abundance across our study period for many additional species, though these changes were not significantly associated with fuels treatments. Instead, populations of many species of small mammals appeared to vary irrespective of fuels management activities, and may be associated more closely with annually variable factors such as food availability or snowpack.

Implementation of fuels reduction projects has been prioritized in most national forests in the Sierra Nevada, and the importance of these projects will only increase under future climate conditions. Beyond impacts to the forest landscape immediately impacted by wildfires, large-scale fires pose risks to a range of human interests including air quality, infrastructure, and tourism-based economies, indicating that more widespread fuels management would likely have wide societal benefits. However, implementation of fuels treatments has been limited both by funding availability and a poor understanding of wildlife response to fuels management. The research presented here provides managers with thorough information on the impact of a range of fuels treatments and enhances their ability to select the location, extent, and intensity of fuels treatments appropriate to local conditions. This will allow for more reliable planning of fuels management activities, and provide for more predictable availability of small-diameter fuels for potential biomass energy facilities. Presence of biomass energy facilities located within the Sierra Nevada could help offset management costs by providing a viable market for these small-diameter fuels. In doing so, a biomass energy market could help mitigate high-intensity fire risk, provide a reliable source of local energy, and maintain or enhance bird and small mammal communities throughout the region.

GLOSSARY

Term	Definition
Basal area	A measure of the density of trees in a given forest stand, which measures the cross-sectional area of tree trunks in a given area. Expressed in our work as m^2/ha.
Biomass energy	The use of renewable organic materials to generate energy, typically electricity. The woody material removed during fuels treatments is one potential source of biomass energy.
Crown fire	Wildfire that spreads throughout the forest canopy; these fires are of higher intensity and can spread more rapidly than ground fires. Crown fires result in high levels of tree mortality.
CWD	Coarse Woody Debris; large (> 7.6 cm or 3 in) pieces of wood, generally fallen trees or limbs, on the forest floor. CWD is important both as a structural element of wildlife habitat and as an important component of the total ground fuel (see below) load. CWD loading is expressed as volume per unit area (m^3/ha) for purposes of our research.
DBH	Diameter at breast height ; this is a standard method for expressing the diameter is a standard method of expressing the diameter of the trunk or bole of a standing tree.
Fuels	Flammable materials that contribute to fire spread and intensity, located both on the ground and throughout vertical strata of the forest.
Fuels reduction	Used synonymously with "fuels treatment" (see below).
Fuels treatment	Management activities aimed at reducing accumulated fuels within fire-prone forested stands. Typically applied for purposes of moderating fire behavior and minimizing risk of high-intensity wildfires. For purposes of this work, fuels treatments rely exclusively on mechanical or hand removal of fuels; fuels treatments that incorporate prescribed fire are not considered.
Ground fuels	Accumulated fuels on the forest floor. Consists of both live and dead fuels, such as dead leaves/grasses, twigs, bark, CWD, and live shrubs and grasses.
Ladder fuels	Fuels that can carry fire from the forest floor to the canopy. These can consist of smaller trees, snags or large shrubs. Ladder fuels are frequently reduced during fuels treatments given their role in promoting high-intensity crown fires.

LTBMU	Lake Tahoe Basin Management Unit; the Forest Service administrative unit for federal lands within the Lake Tahoe Basin. Location of one of our two study areas.
Point count	A common method for surveying birds. Surveyors are located at the point center and record birds detected by sight or sound within a specified radius and time frame.
Snag	A standing dead tree. Snags can serve as important habitat features for wildlife and as a significant source of fuel in wildfires.
SNAMP	Sierra Nevada Adaptive Management Project. A collaborative effort between University of California researchers and state and federal agencies, including the Forest Service, to examine a range of impacts from fuels treatments. Sugar Pine (see below) was initially established as a SNAMP study area.
Sugar Pine	Our southernmost study area, located on the Sierra National Forest. Established by SNAMP partners.
SNPLMA	Sierra Nevada Public Lands Management Act. A source of funding for our research conducted on the LTBMU. These grant funds were administered by the US Bureau of Land Management.
Trap-night	A measure of mammal trapping effort, measured as one night for which a trap is set and effective. For example, 3 traps set and effective for 3 nights would equal 9 trap-nights. This is a measure of trapping effort, as it accounts for traps rendered ineffective due to mechanical failures or disturbance (by bears, ravens, etc.). These corrections allow for enhanced comparison of small mammal abundance between sites with different levels of trap disturbance.
WUI	Wildland-urban interface. The zone of transition between forest lands and human infrastructure; the homes and other infrastructure in the WUI are at higher risk of impacts from wildfires and are frequently the focus of fire protection activities, such as fuels treatments.

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APPENDIX A:
Bird Species Abundance and Site Frequency at Fuels Treatment Research Locations

Bird species observed during point counts at Sugar Pine and Lake Tahoe Basin Management Unit study areas. We surveyed at 103 sites at Sugar Pine, and 28 sites at LTBMU.

Common Name	Scientific Name	Sugar Pine		LTBMU	
		Total Detections	# Sites	Total Detections	# Sites
Acorn Woodpecker	*Melanerpes formicivorus*	3	2	0	0
American Kestrel	*Falco sparverius*	0	0	2	1
American Robin	*Turdus migratorius*	235	85	680	28
Anna's Hummingbird	*Calypte anna*	5	5	0	0
Bald Eagle	*Haliaeetus leucocephalus*	0	0	1	1
Band-tailed Pigeon	*Columba fasciata*	34	21	32	11
Bewick's Wren	*Thryomanes bewickii*	0	0	1	1
Black-backed Woodpecker	*Picoides arcticus*	0	0	33	14
Black-headed Grosbeak	*Pheucticus melanocephalus*	746	102	32	14
Black-throated Gray Warbler	*Setophaga nigrescens*	20	14	3	2
Brewer's Blackbird	*Euphagus cyanocephalus*	0	0	26	9
Brown Creeper	*Certhia americana*	503	95	494	28
Brown-headed Cowbird	*Molothrus ater*	76	33	375	24
Bushtit	*Psaltriparus minimus*	2	1	0	0
California Quail	*Callipepla californica*	1	1	0	0
Calliope Hummingbird	*Stellula calliope*	0	0	6	3
Cassin's Finch	*Carpodacus cassinii*	1	1	205	25
Cassin's Vireo	*Vireo cassinii*	313	93	130	17
Chipping Sparrow	*Spizella passerina*	37	26	43	12

Common Name	Scientific Name	Sugar Pine		LTBMU	
		Total Detections	# Sites	Total Detections	# Sites
Clark's Nutcracker	*Nucifraga columbiana*	0	0	51	9
Common Nighthawk	*Chordeiles minor*	1	1	0	0
Common Raven	*Corvus corax*	92	45	38	12
Cooper's Hawk	*Accipiter cooperii*	3	2	4	2
Dark-eyed Junco	*Junco hyemalis*	1426	103	1180	28
Downy Woodpecker	*Picoides pubescens*	8	6	8	4
Dusky Flycatcher	*Empidonax oberholseri*	212	65	689	28
European Starling	*Sturnus vulgaris*	0	0	4	3
Evening Grosbeak	*Coccothraustes vespertinus*	0	0	638	27
Fox Sparrow	*Passerella iliaca*	148	27	784	27
Golden-crowned Kinglet	*Regulus satrapa*	966	96	836	27
Golden-crowned Sparrow	*Zonotrichia atricapilla*	0	0	3	2
Great Horned Owl	*Bubo virginianus*	0	0	1	1
Green-tailed Towhee	*Pipilo chlorurus*	2	1	68	7
Hairy Woodpecker	*Picoides villosus*	69	45	222	27
Hammond's Flycatcher	*Empidonax hammondii*	185	64	6	4
Hermit Thrush	*Catharus guttatus*	11	10	245	23
Hermit Warbler	*Setophaga occidentalis*	1542	103	120	14
House Wren	*Troglodytes aedon*	17	7	32	7
Hutton's Vireo	*Vireo huttoni*	10	9	0	0
Lazuli Bunting	*Passerina amoena*	1	1	0	0
Lesser Goldfinch	*Carduelis psaltria*	4	3	4	2
Lewis's Woodpecker	*Melanerpes lewis*	0	0	2	1
Lincoln's Sparrow	*Melospiza lincolnii*	3	3	2	2
MacGillivray's Warbler	*Geothlypis tolmiei*	312	84	114	21
Mountain Bluebird	*Sialia currucoides*	0	0	3	1

Common Name	Scientific Name	Sugar Pine		LTBMU	
		Total Detections	# Sites	Total Detections	# Sites
Mountain Chickadee	*Poecile gambeli*	156	60	2393	28
Mountain Quail	*Oreortyx pictus*	110	57	12	11
Mourning Dove	*Zenaida macroura*	8	6	27	9
Nashville Warbler	*Oreothlypis ruficapilla*	1068	101	338	22
Northern Flicker	*Colaptes auratus*	125	73	127	24
Northern Goshawk	*Accipiter gentilis*	4	4	4	2
Northern Pygmy-Owl	*Glaucidium gnoma*	6	6	6	2
Olive-sided Flycatcher	*Contopus cooperi*	31	20	93	17
Orange-crowned Warbler	*Oreothlypis celata*	10	7	5	4
Osprey	*Pandion haliaetus*	0	0	10	5
Pacific Wren	*Troglodytes pacificus*	254	58	2	1
Pacific-slope Flycatcher	*Empidonax difficilis*	198	57	1	1
Peregrine Falcon	*Falco peregrinus*	1	1	0	0
Pileated Woodpecker	*Dryocopus pileatus*	95	57	27	10
Pine Grosbeak	*Pinicola enucleator*	0	0	5	4
Pine Siskin	*Carduelis pinus*	14	10	248	27
Purple Finch	*Carpodacus purpureus*	43	30	14	2
Pygmy Nuthatch	*Sitta pygmaea*	1	1	96	16
Red Crossbill	*Loxia curvirostra*	1	1	73	10
Red-breasted Nuthatch	*Sitta canadensis*	1028	102	1455	28
Red-breasted Sapsucker	*Sphyrapicus ruber*	112	53	47	21
Red-shouldered Hawk	*Buteo lineatus*	0	0	4	3
Red-tailed Hawk	*Buteo jamaicensis*	2	2	16	3
Red-winged Blackbird	*Agelaius phoeniceus*	0	0	28	3
Ruby-crowned Kinglet	*Regulus calendula*	0	0	21	2
Rufous Hummingbird	*Selasphorus rufus*	0	0	4	4

Common Name	Scientific Name	Sugar Pine		LTBMU	
		Total Detections	# Sites	Total Detections	# Sites
Sharp-shinned Hawk	*Accipiter striatus*	0	0	2	2
Song Sparrow	*Melospiza melodia*	6	4	9	3
Sooty Grouse	*Dendragapus fuliginosus*	0	0	7	4
Sora	*Porzana carolina*	0	0	1	1
Spotted Sandpiper	*Actitis macularia*	0	0	4	2
Spotted Towhee	*Pipilo maculatus*	852	90	3	1
Steller's Jay	*Cyanocitta stelleri*	914	103	1078	28
Townsend's Solitaire	*Myadestes townsendi*	104	59	213	27
Townsend's Warbler	*Setophaga townsendi*	20	15	1	1
Tree Swallow	*Tachycineta bicolor*	0	0	1	1
Warbling Vireo	*Vireo gilvus*	354	78	268	22
Western Bluebird	*Sialia mexicana*	0	0	3	2
Western Tanager	*Piranga ludoviciana*	1345	103	1030	28
Western Wood-Pewee	*Contopus sordidulus*	384	86	555	28
White-breasted Nuthatch	*Sitta carolinensis*	9	6	222	25
White-crowned Sparrow	*Zonotrichia leucophrys*	1	1	0	0
White-headed Woodpecker	*Picoides albolarvatus*	197	74	288	27
Williamson's Sapsucker	*Sphyrapicus thyroideus*	0	0	48	15
Wilson's Warbler	*Cardellina pusilla*	10	9	49	13
Wrentit	*Chamaea fasciata*	5	5	0	0
Yellow Warbler	*Setophaga petechia*	16	13	1	1
Yellow-rumped Warbler	*Setophaga coronata*	804	99	1331	28

APPENDIX B:
Small Mammals Species Abundance and Site Frequency at Fuels Treatment Research Locations

Small mammal species observed during surveys at Sugar Pine and Lake Tahoe Basin Management Unit study areas. We surveyed at 59 sites at Sugar Pine, and 28 sites at LTBMU.

Common Name	Scientific Name	Sugar Pine		LTBMU	
		Total Detections	# Sites	Total Detections	# Sites
Allen's chipmunk	*Tamias senex*	2	1	958	27
Brush mouse	*Peromyscus boylii*	1967	57	4	3
Bushy-tailed woodrat	*Neotoma cinerea*	0	0	3	3
California ground squirrel	*Spermophilus beecheyi*	243	28	260	19
Deer mouse	*Peromyscus maniculatus*	2196	59	1365	28
Douglas' squirrel	*Tamiasciurus douglasii*	46	29	200	24
Golden-mantled ground squirrel	*Spermophilus lateralis*	0	0	578	17
Least chipmunk	*Tamias minimus*	0	0	27	11
Lodgepole chipmunk	*Tamias speciosus*	0	0	814	19
Long-eared chipmunk	*Tamias quadrimaculatus*	853	44	1660	27
Long-tailed vole	*Microtus longicaudus*	0	0	40	13
Northern flying squirrel	*Glaucomys sabrinus*	795	58	245	27
Pinyon mouse	*Peromyscus truei*	0	0	13	7
Trowbridge's shrew	*Sorex trowbridgii*	54	24	37	15
Vagrant shrew	*Sorex vagrans*	2	2	11	5
Western gray squirrel	*Sciurus griseus*	0	0	1	1
Western jumping mouse	*Zapus princeps*	4	4	0	0
Yellow-pine chipmunk	*Tamias amoenus*	1	1	1810	24